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Port supply chains: how to ensure sufficient capacity?

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Title

TransportNet Policy paper: Port supply chains: how to ensure sufficient capacity?[1]

TransportNet

TransportNet is a network of leading university groups involved in transport research and high-level education, from several European countries, created in March 2003. These groups are located in schools of economics and of engineering, and their activities cover all modes and geographical ranges of transport. Its purpose is to reinforce and stimulate the quality and efficiency of the research activities carried out by its members, and then to integrate some of those activities in research programs of higher complexity carried out at the network level.
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INVOLVED UNIVERSITIES

The **University of Antwerp** has a long-standing tradition in transportation research, as part of the wider field of Applied Economics. Academic teaching is closely linked to original scientific research by the University's academic staff of top-quality international research. The international accreditations that the faculty Business and Economics has received from AACSB and EFMD testify to the high quality of its education and research, and this type of recognition ensures our students have a wide range of international opportunities on all continents. The department '**Transport and regional economics**' (TPR) offers both business economics and general economics. The Department's lines of research are located on the interface of general and business economics. The research activities unfold within the framework of programmes instigated by the university and the authorities (regional, federal and European) as well as specific assignments from the public and private sectors. More info: https://www.uantwerpen.be/tpr

The **University of Genoa** (UniGe) is a public research university located in the city of Genoa, on the Italian Riviera in the Liguria region of northwestern Italy. It is one of the oldest and largest universities in Italy, with a history dating back to 1481. The university has five schools, 22 departments, five libraries, 11 research centres and two centres of excellence, covering a wide range of disciplines from humanities and social sciences to engineering and medicine. The university also has regional campuses in Savona, Imperia, Ventimiglia and La Spezia, as well as a botanical garden and a protected area in the Mediterranean Alps. The university is known for its academic excellence, research, and innovation, and has a strong international orientation, with partnerships and exchange programs with many universities around the world.

The **Aegean University** is a public research university in Greece, with campuses on six islands of the Aegean Sea: Lesvos, Chios, Samos, Rhodes, Syros, and Lemnos. It was founded in 1984 and has five schools: Humanities, Social Sciences, Sciences, Engineering, and Environment. It offers 18 undergraduate and 38 postgraduate programs, as well as doctoral studies, summer schools, and lifelong learning courses. The university has a strong focus on interdisciplinary and innovative fields, such as Mediterranean studies, marine sciences, digital governance, and cultural informatics. It also has a high international profile, with collaborations and exchange programs with many universities around the world.

[1] The research was presented at WCTRS –Special Session 'Governing Capacity in Port Supply Chains: Decision-Making, Resilience and Policy Challenges' July 8th, 2026 -Toulouse.

The **Karlsruhe Institute of Technology** (KIT) was established by the merger of the Forschungszentrum Karlsruhe and the Universität Karlsruhe (TH) in 2009. KIT combines the tasks of a university of the state of Baden-Württemberg with those of a federal research center of the Helmholtz Association in the areas of research, teaching, and innovation. Research at KIT is organized along eight "KIT Centers", which focus on challenges of fundamental importance to our society or on key issues resulting from the striving for knowledge. The KIT Center Mobility Systems embraces a wide range of multidisciplinary competencies to develop solutions for tomorrow's mobility. The Center brings together about 800 engineers, natural scientists, economists and social scientists from more than 35 institutes. As part of the Center, the division **Network Economics** of the **Institute of Economics (ECON)** covers a wide range of mobility related research topics, such as transport economics, regulation, the assessment of transport policies and innovative mobility concepts, economic aspects of transport infrastructure planning, as well as transport demand modelling.

The TU Delft has as its motto "impact for a better society" and strives to have both societal impact as well as academic excellence. This is pursued through an interconnected science, technology and design focussed research and education. As top-quality research institute, it has been in the top 10 of international quality overviews on technical or engineering education. The department 'Maritime and Transport Technology' offers both mechanical and maritime related research, ranging from hydromechanics and structures to the technological and design impacts of AI and the energy transition on the transport and shipping operations, including inland shipping. The departments research is primarily executed together with industry partners at National, EU and global level.

The **University of Lisbon** (ULisboa) is the largest and most prestigious public university in Portugal. It was founded in 1911, but its current structure dates from 2013, when it merged with the Technical University of Lisbon. ULisboa has 18 schools and research institutes, covering various fields of knowledge, from humanities and social sciences to engineering and medicine. ULisboa offers a wide range of programs at different levels of education, including bachelor's, master's, doctoral, and diploma programs. Some of these programs are taught entirely in English, such as Data Science, Design for Sustainability, and Law and Management. ULisboa also has a strong international orientation, with partnerships and exchange programs with many universities around the world. The Instituto Superior Técnico, is the school of Engineering where Transport courses and research is based

Since its creation in 1973, the **Université Lumière Lyon 2** has been committed to a strong and demanding vision of Higher Education and Research, driven by a spirit and values that are also its trademark: human and humanistic, committed and supportive, democratic and civic-minded. The Université Lumière Lyon 2 welcomes nearly 30,000 students on two campuses to its bachelor's, master's, and doctoral degrees. Attached to the Université Lumière Lyon 2, to the CNRS (National Centre for Scientific Research), and the to ENTPE engineering school, LAET is an academic research unit specialized in transport, mobility and land use issues. Its two main academic disciplines are economics and urban planning. LAET researcher's topic are mainly to : understand and model the spatial mobility of persons and goods, as well as residential and activity location ; evaluate transport and land use policy ; and provide decision-support to stakeholders seeking solutions to current critical issues facing society.

AUTHORS

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Aim

The aim of the TransportNet policy paper is to provide Regulators, port authorities and non-specialized audience insights and recommendations of research. The present policy paper addresses the issue of capacity in the port supply chain.

Picture cover

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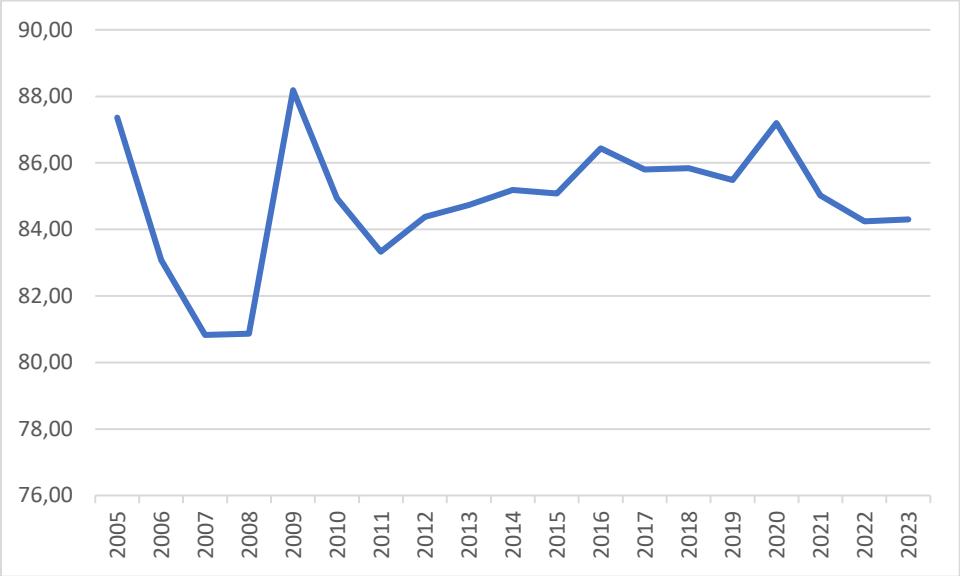
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1 Introduction

The core business of a port is to attract (and retain) cargo flows. If the trade forecasts of the International Monetary Fund (IMF), the World Trade Organisation (WTO) and the World Bank come true, world total trade is expected to grow; and consequently, world seaborne trade too. Figure 1 shows the evolution of world seaborne trade as a percentage of world total trade. In 2022, world seaborne trade accounts for 83.4% of world total trade (2022: 14,46 billion tonnes – all transport modes).

Figure 1: World Seaborne Trade as % of World Total Trade?



Source: own presentation based on database Clarkson NV, 2022

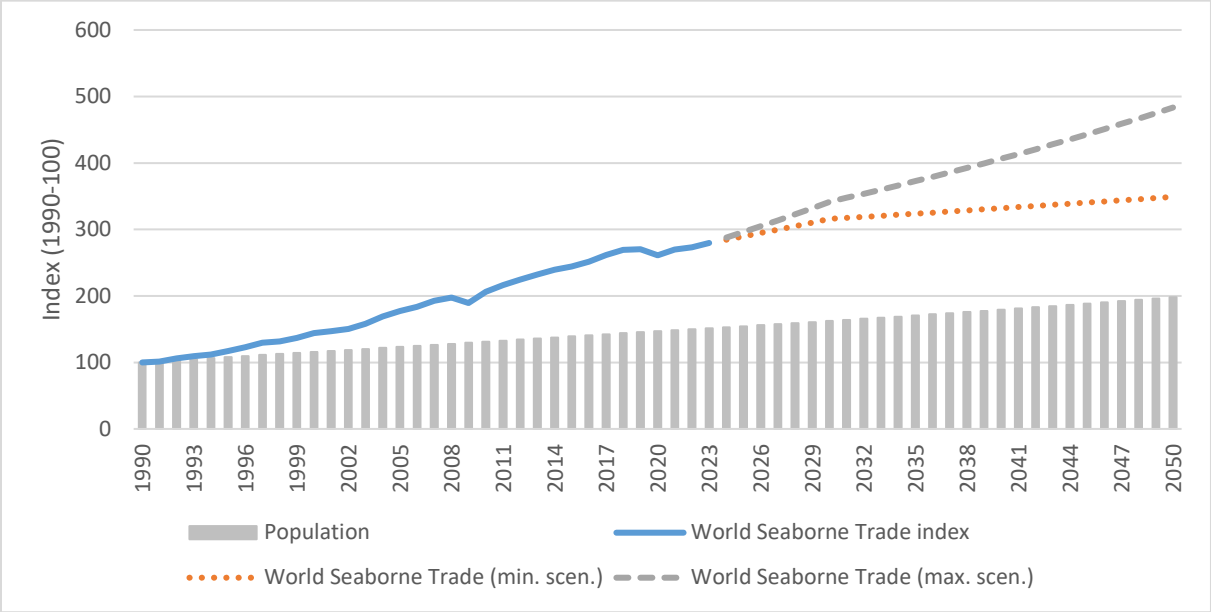
The key drivers of growing worldwide demand are population and economic growth. The world population is projected to reach nearly 10 billion by 2050 (7.9 billion in 2022). Population growth is expected to increase by 1% per annum over the 2023-2050 period (United Nations, 2019). Growth in world population brings an increase in the development of the world economy; and subsequently in seaborne trade. In the report 'Maritime Forecast to 2050' of DNV, two scenarios for seaborne trade demand are explored: 25% for the low growth scenario and 180% for the high growth scenario covering the 2020-2050 period. (DNV, 2022, p. 79)

Figure 2 shows the evolution of the world population (United Nations, 2019) and world seaborne trade over the 1990-2022 period and gives, based on the outlooks as mentioned above, a minimum/maximum estimate through 2050 by index score (Clarkson Research, 2022).

By 2030, the 'world seaborne trade' index will reach a score of 315 no units? (minimum scenario – an average growth of 1.75% per annum over 2023-2030 period) and 341 (maximum scenario – an average growth of 2.9% per annum) compared with 100 in 1990. For 2050, the index rises to 348 (minimum scenario – an average growth of 0.5 % per annum over period 2031-2050) and 483 (maximum scenario - average growth of 1.75.5% (?) per annum). While the population index almost doubled compared to 1990, from figure 2, it can be observed that the world seaborne trade will increase almost by a factor 3.5 in the minimum trajectory and by a factor 5 in the maximum scenario compared to 1990. Between 1990 and 2022, the transported volume per capita increased from 0.8 tonnes per person to 1.54 tonnes. Estimated seaborne trade divided by population is expected to increase, varying between

1.496 tonnes per capita (minimum scenario) and 2.68 tonnes per capita (maximum scenario). The question arises whether the current port capacity is sufficient.

Figure 2: Evolution of population and world seaborne growth



Source: own compilation based on statistics of United Nations, 2019 and Clarkson Research NV, 2022

Based on the above, the authors involved do not expect that the economy will never grow again, but that there will be sustainable growth. Sustainable growth is understood an economic growth without exhausting resources and causing environmental problems for the next generation. Consumers spending might alter; this explains the slight kink after 2030.

The question arises whether the current port capacity is sufficient. Decisions related to (future) infrastructure by (port) policymakers rely on world seaborne forecasts. Given the volatility and uncertainty of the global economy, Brooks et al. (2014) state that inadequate (container) port infrastructure can cause logistics bottlenecks and a constraint on growth. Rashed (2016) concludes that wrong (timed) investment decisions may lead to inefficient operations further down the chain as well as generate congestion as a result from under-capacity or extra unjustified cost of overcapacity. From a port competitiveness perspective, it is important to belong to a highly integrated maritime ecosystem.(Vanelslander & Sys, 2020a)

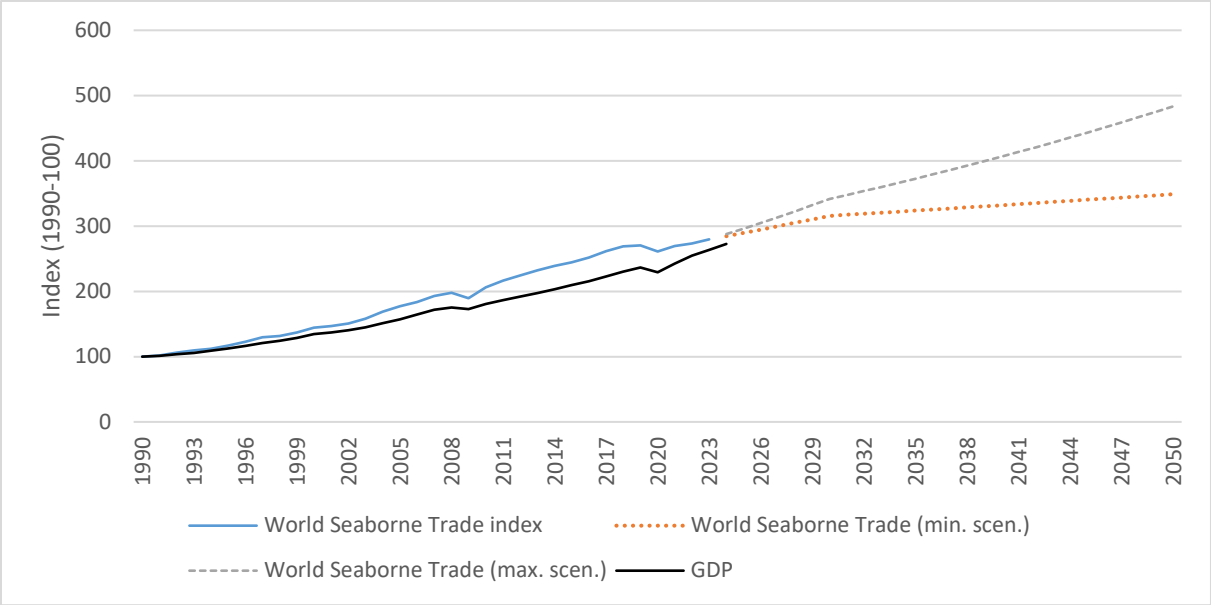
Although other than production processes, changed consumption patterns, etc. are widening the gap between seaborne trade and economic growth proxied by GDP over the 1990-2020 period, it remains interesting to see the evolution of world gross domestic product (GDP) and seaborne trade; expressed in index (1990=100) (Figure 3). With respect to GDP, data over the 2020-2026 period reflects the potential impact of the COVID-19 crisis, the shift from services to durable goods due to lockdown measures, mobility restrictions, the international context and fiscal support. This evolution was accompanied by port congestion and brought the debate on expanding port capacity high on the agenda to alleviate the recent bottlenecks in the maritime supply chain.

Neither International Monetary Fund (IMF), the World Trade Organisation (WTO) and the World Bank are venturing to long-term prospects. The outlook for GDP has been adjusted to a growth rate of 3.2% in both 2024 and 2025, matching the pace observed in 2023. Based on the assumption that consumer behavior will rotate back towards services, although the share of durable goods remains high due to savings and therefore no prospect of a short-term reduction in port congestion, it remains nevertheless

important to formulate long-term recommendations on port capacity (including amount of cost and time) even if it is a very difficult exercise.

Munim and Schramm (2018) studied the significance of port infrastructure quality, logistics performance and seaborne trade, they found a positive relation between the variables in the case of developing countries while this finding weakens when evolving towards a developed country.

Figure 3: Evolution GDP and seaborne trade



Source: own compilation based on World Bank national accounts data, and OECD National Accounts data files (2023)

Next, the European Commission (2020) encourages with the 'European Green Deal' a path to full decarbonisation by 2050 with a modal shift to the alternative modes: rail and inland navigation. Suppose that this modal shift finally manifests, is the capacity of the respective transport modes sufficient? Transporting goods is not an isolated process; goods are also stored in all kinds of depots, warehouses, bulk locations, etc. A much more intensive use of railways and inland waterways may also have an impact on the location and additional capacity of warehouses and logistics, assuming the energy taxation directive in the Fit for 55 package does not result in a reverse modal shift in favor of road transport. The CCNR study on a financial instrument for greening the Inland waterway transport sector[2] examines 'polluter pays' schemes and suggests that the expected market impact of fuel costs might alter the perception that IWT remains the most cost-effective transportation option. UNCTAD (2019) put forward that '*ports should adopt sustainable growth strategies to protect ports from climate change as well as strengthening greener and more sustainable ports*'. The associated transition towards a more sustainable port requires large-scale investment resources. The Draghi report on the future of European competitiveness (2024) highlights clear priorities for sustainable infrastructure development; indirectly also including ports given the term 'port capacity' is not mentioned. It projects an increase in demand due to global trade growth, necessitating capacity expansion and emphasizes technological advancements and environmental considerations. Building on these priorities, the European Union has more recently advanced a dedicated port and maritime industrial strategy, further

[2] https://ccr-zkr.org/files/documents/EtudesTransEner/Deliverable_RQ_G_and_H.pdf

underlining the strategic importance of ports in ensuring resilient, sustainable and competitive supply chains.

Moreover, innovative digital solutions (Cârlan, 2019; Cârlan et al., 2018) contribute to the development of a maritime supply ecosystem. According to Sys and Vanelslander (2020), under the term 'maritime supply ecosystem' is understood: '*to match supply and demand globally, efficient and effective cargo, information and financial flows are interconnected in a variety of multi-layered networks linking all actors (B2B, B2G) (living components) and infrastructure (e.g. port, hardware,…) (non-living components) whilst reducing costs, improving (operational) efficiency, ensuring sustainability, complying with regulation and simultaneously improving customer satisfaction (e.g. reliability) to retain or increase market share'*. The same authors state that one cannot expect ecosystems to develop if basic conditions like (digital) capacity are not in place. (Sys & Vanelslander, 2020). Reforming/transforming the port sector and by extension the warehouse/warehouse environment and logistics players (e.g. shippers) can provide a sustainable competitive advantage for the actors active in the maritime ecosystem being part of a complete logistics ecosystem based on promoting interconnectivity.

Sys and Vanelslander (2020) emphasize the importance of optimizing capacity for transport infrastructure, based on the principle of optimal generalized costs, when policymakers are responsible for it. They also claim that "a supply chain, also a maritime one, is as weak as its weakest link. Especially in times when public funds turn scarce, and the needs (climate change) are high, well-thought-over choices need to be made. If fundamental infrastructure (non-living components) is not present, which can typically only come into place with public support, one risks having market players invest a lot of money and effort into sub-optimizing on other parts of the chain, thereby seeing funds go lost that could be spent in development of maritime supply ecosystems." (Sys & Vanelslander, 2020) (Sys & Vanelslander, 2020)

Given the problem setting outlined above, in this policy paper, different points of view are brought together of how to ensure sufficient capacity in the maritime supply ecosystem, with ports in focus.

Five points of view are analysed: three 'physical' ones, a 'digital' one and a 'regulatory' one as a fifth. The three physical ones correspond to the three sections in port supply chains: the port itself, with its infrastructure (docks, locks, etc.) and superstructure (terminal), the warehouses (including in the hinterland) and the port hinterland connections (road/rail capacity/challenges inland navigation/pipelines). Not the holy grail, but digital capacity can help optimize the port supply chain, especially regarding communication, data transparency, automation and reduction of carbon footprint. The fifth one focuses on the tight competition that exists between ports covering the same (or adjacent) hinterlands.

For each of those, a first step is to define the respective capacity. Second, indicators of how to measure the capacity concerned are mentioned. Third, for the Western-European context, it is reflected in who typically takes the decision to invest, and how that decision is typically taken (incl. economic analysis methods applied). Fourth, it is considered what current and future challenges are in that decision-making (e.g. lack of public funds, influence from China through belt road initiative, attention for environmental sustainability (climate, use of environmental concrete for locks, canals,…), etc.). Fifth and finally, recommendations are given on how to make European ports future-proof in terms of the capacity type concerned.

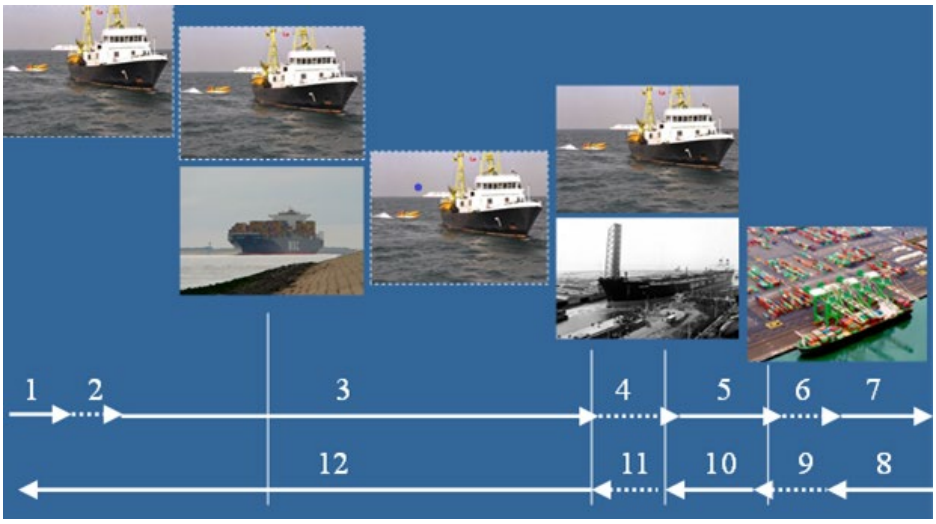
2 Port capacity

An unambiguous/one-size-fits-all definition of 'port capacity' is not known; to this end, the port process is first explained to establish a clear basis for a universally accepted definition of 'port capacity'.

2.1 Definition

The route of a vessel calling at a seaport can be divided into several stretches; each influenced by factors such as navigational constraints, water depth, and the vessel's draught, which determines the minimum depth of water it can safely traverse. Figure 4 shows a general overview of such seaport setting. A vessel that is on its way to a port can sail on several stretches, depending on the port setting as well as on its own characteristics or on environmental factors: starting with maritime transport at sea, a part of a river or canal can be used, further on also a lock, and finally docks will be reached. Once the ship is berthed, other activities can start: terminal activities such as unloading/loading, storage and unloading/loading of hinterland modes. After this, the goods transformed will be moved to hinterland connections.

Figure 4. Theoretical sea-port setting



(1): full sea stretch; (2): buoy waiting stretch; (3): buoy-to-lock stretch; (4 and 11): locking stretch; (5): lock-to-berth stretch; (6 and 9): berth waiting stretch; (7 and 8): berth (un-)loading stretch; (10): berth-to-lock stretch; (12): lock to full sea stretch

Source: Vanelslander (2014)

It is of course also possible to focus on movements in the opposite direction. The seaport setting is a general typology and can be applied to freight vessels and passenger vessels. It is of course not necessary that every link is used in a specific port typology. Not all ports have locks or breakwaters for instance. Breakwaters are structures designed to protect harbors[3], ports and shorelines from the impact of water (e.g. rubble mound breakwater, Santa Monica, California, USA; innovative sloped

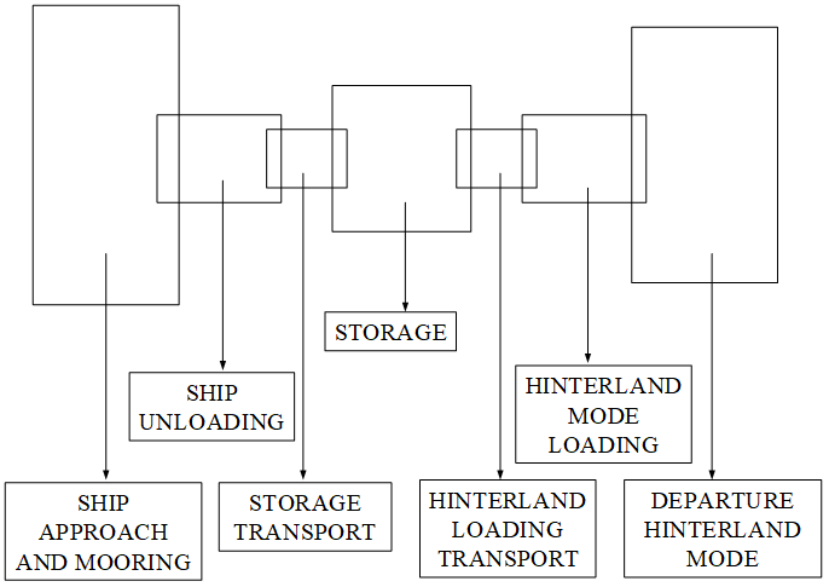
[3] A harbour is a sheltered area of water where ships, boats, and other vessels can anchor or dock safely, protected from rough waters or adverse weather conditions. Harbours can occur naturally (e.g., a bay or inlet) or be artificially constructed with breakwaters, piers, or seawalls. (Cambridge dictionary)

design, Port of Antwerp-Bruges, platform Zeebrugge breakwater, Belgium; designed to protect from tsunamis and typhoons, Port of Kobe, Japan).

In view of capacity, the specific situation that forms a port in comparison to other types of companies needs to be considered. That situation is unique for several reasons. A container port is part of a logistics chain (Van de Voorde & Vanelslander, 2014a). Where a normal company has the goal of producing one type of good or service (or a certain category of goods or services), a port can have various goals, in line with the functions it can perform. Ports can have functions in trading, handling, industry and distribution (Verhoeven et al., 2015. Given the fact that all these functions over time seem to get blurred more, and that more actors take up various roles, an evolution towards supply networks rather than chains seems inevitable (Vanelslander & Sys, 2020b).

Focusing on handling, a classic in production functions and capacity analysis is Jansson and Shneerson (1982), which shows how the capacities of the various sub-units diverge (Figure 5). This structure, even though it is about 40 years old, is essentially fully valid still, be it that individual capacity balances have changed, and that new sub-elements have been added over time. Containers were in 1982 not a main commodity type but became so during the past decades. That involves specific handling, like for instance stripping and stuffing, that at first featured in ports, but over time got pushed out of ports, since too labor-intensive and expensive.

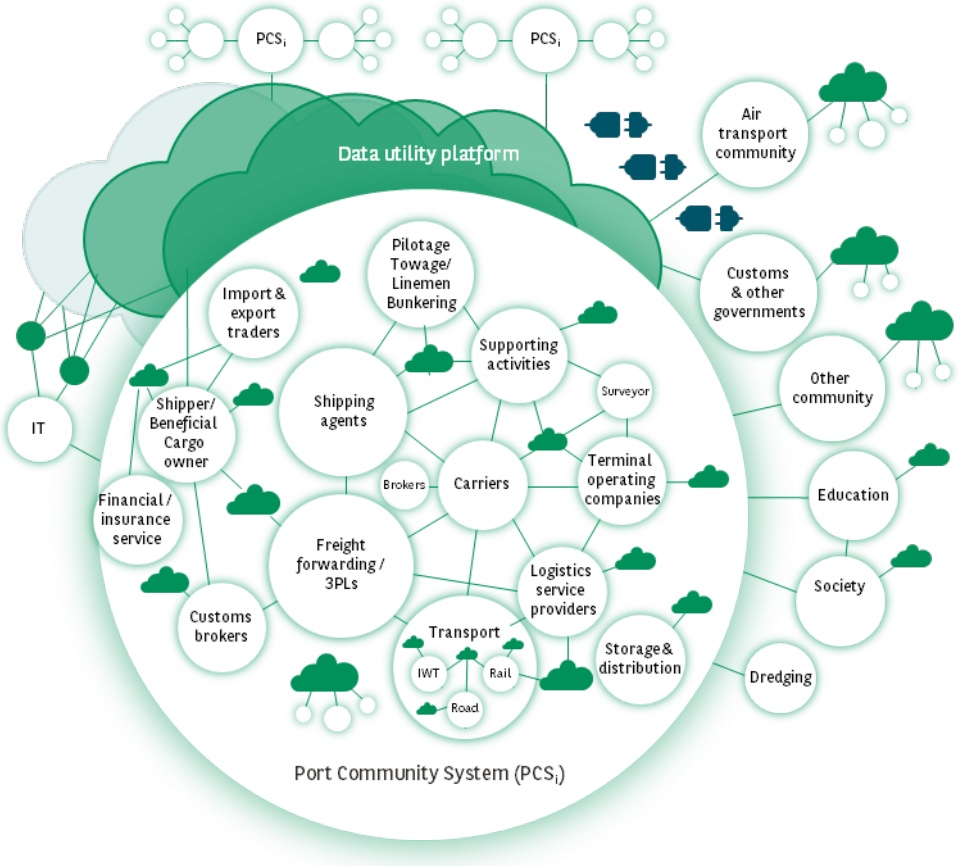
Figure 5. Capacity in different port call segments



Source: own processing based on Jansson and Shneerson (1982)

The fact that ports feature multiple stakeholders at the same level is another reason that makes them unique in dealing with capacity. Normal companies are one entity, having suppliers, customers, competitors and co-operators in their ecosystem (Figure 6). Ports must also address complex health issues, comply with diverse customs regulations, and adhere to stringent phytosanitary rules to ensure smooth operations and safeguard global trade.

Figure 6. Visualisation of maritime ecosystem



Source: Sys and Vanelslander (2020)

Due to the magnitude of activities in ports, multiple operators together must provide the 'port product', often not in a co-ordinated way: company independence but especially unbalanced power relationships make that co-ordination is not easy. Take the balance between the large terminal operators, the smaller forwarders and the even smaller customs brokers for instance. Moreover, a typical characteristic of seaports is that staff do not work directly with the operator but is part of a kind of pool system. In the case of vertical integration of course, the owning party can more easily align the capacity of chain sub-elements so that overall profit is maximized. Table 1 shows which actors typically oversee what inputs to capacity in the port supply network.

Table 1: Port capacity elements, responsibilities and measures

localization	*factor*	*subfactor*	*nature of factor*	*influenced by*	*measured in*
gateway	sea-/ fairway (e.g. extent of anchorage possibilities)	depth/ width	physical	Authority	meter
	ship	draft	physical	ship owner	meter
	marine services	presence	physical	Authority	-
		availability	institutional	Authority	working hours, # strike days
	lock	dimensions	physical	Authority	meter
		accessibility	institutional	Authority	working hours, # strike days
	gates	accessibility	physical	Authority	# of entry/exit points
	administration	reliability	institutional	Authority	hours, clearance, # checks per day
	hinterland modes	presence	physical	Authority	-
		reliability	institutional	Authority	working hours, # strike days
terminal	quay	quay length	physical	authority/goods handler	meter
	cranes	amount	physical	goods handler	# cranes
		type	physical	goods handler	HEAT (Highest Economically Achievable Throughput)
		reliability	physical	goods handler	# days out of use
		availability	institutional	authority/goods handler	working hours, # strike days
		occupation	institutional	goods handler	-
	pipelines	amount	physical	goods handler	capacity
	ship	size	physical	ship owner	tonnage, meter
	dock workers	amount	physical	authority/goods handler	# workers (evt. per shift)
		availability	institutional	authority/goods handler	working hours, # strike days
		training	institutional	authority/goods handler	-
		working terms	institutional	authority/goods handler	safety regulations
	terminal-area	size	physical	authority/goods handler	# m²
		shape	physical	authority/goods handler	-
	storage-area	availability	physical	goods handler	specialised storage facilities
		design	physical	goods handler	amount of cargo, number of rows of containers
	vehicles	amount	physical	goods handler	# vehicles
		type	physical	goods handler	HEAT
		reliability	physical	goods handler	# days out of use
	cargo handling	method	institutional	goods handler	lead time
	customs services	availability	institutional	Authority	working hours, # strike days

Source: Vanelslander (1999)

2.2 Indicators of what?

As mentioned previously, port capacity is connected to a variety of factors and stakeholders that do not always have aligned interests. As such, ports have often struggled in finding the optimal size of relevant services and infrastructure (Musso et al., 1999) especially in highly competitive markets in which ports need to meet the growing pressure caused by the increasing ship scale economies(Merk et al., 2015). As such, overcapacity at terminal port level is quite common especially if connected with the potential generated throughput, as also shown in Table 2.

Table 2: Example of Port Utilisation Levels

		North America	Europe	Asia	Middle East /South Asia	Latin America	Africa	Oceania
Average Annual Growth in Port Throughput	2012-2017	4.0%	2.8%	4.0%	5.0%	1.5%	3.8%	3.3%
	2017-2022	3.7%	4.5%	6.1%	6.8%	6.6%	5.5%	4.5%
Utilisation (2017) based on existing capacity		62.9%	59.9%	75.0%	67.1%	55.9%	60.7%	70.2%
Utilisation Forecast (2022) based on confirmed plans only		67.6%	68.3%	95.3%	73.4%	64.5%	57.8%	78.2%
Utilisation Forecast (2022) based on confirmed + unconfirmed plans		63.8%	66.6%	94.5%	69.8%	62.4%	53.8%	77.1%

Source: Own elaboration from Drewry, 2018.

The figures shown in Table 2 relate to the fact the terminal utilisation rates are normally relatively low (i.e., below 80%) and this is often connected to the necessary planning of physical infrastructure over the potential peak of the demand while in normal operational conditions the port is often underutilised. The fact that relevant alternative stakeholders might record misalignments in reaching their own peak (e.g. number of ships entering the ports, utilisation of different gates, marine services, rail slots) normally generates even higher overcapacity overall, especially when a port has differentiated functions and higher probabilities to encounter congestion.

In this respect, the use of traffic-related variables to reflect the port and terminal capacity might be considered tricky: e.g., the throughput often represents the matching between demand and supply of specific port services (i.e., mainly in connection with the terminal activity) and does not reflect the hidden capacity not utilised due to i) unmatched demand and ii) colliding interests (e.g. congestion, prioritisation of certain businesses). Thus, most of the usually capacity related indicators are more connected to the overall port/terminal efficiency (e.g. cargo/sqm) and performance (e.g. annual throughput) rather than reflecting the effective potential capacity.

This latter aspect is of particular importance whenever capacity is not considered as a static element (i.e., looking at the physical characteristics, such as the yard area or the number of cranes) but as dynamic factor (i.e., subject to adapting to fluctuations, e.g. movements per hour): port capacity is therefore subject to bottlenecks that generate cascading effects on different internal and external activities as well as to planning limitations arising from the 'lumpy' nature of capacity investment.

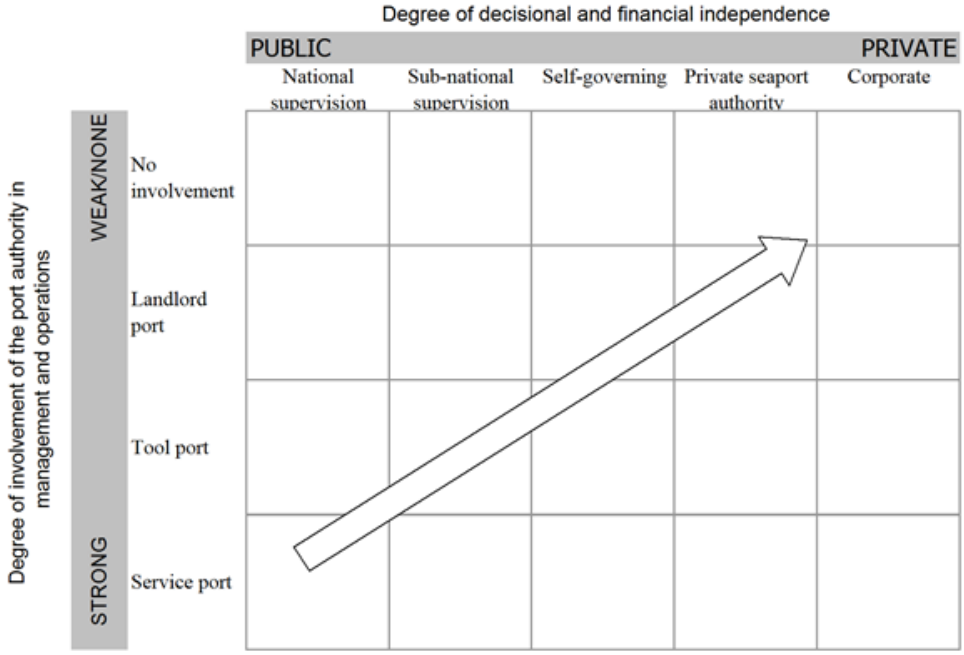
Moreover, most of the key information connected to the potential utilisation rates are often only handled by relevant private stakeholders, decreasing the possibility for exploiting a better planning at port level. The same applies to the possibility of developing effective benchmarking tools: the different port functions and layouts make it difficult to establish specific benchmarking indicators apart from some industry specific indicators, as in the case of the container terminal utilisation rates.

2.3 Who and how?

Choices made by governments, port authorities and container-handling companies, among others, will determine the capacity of ports and terminals. The supply of capacity will be substantially influenced by the government's decision to assign the port a domestic, transit or hub role and plan and design the port accordingly. Altogether, this leads to an overview, as shown in Figure 7. Overall, a shift is observed over time from the outer bottom left to the upper right types of settings.

As a matter of fact, concessions are commonly used in the port sector these days, since they relieve governments of substantial operational risks and financial burdens and simultaneously allow governments to keep ultimate ownership of the port land and the responsibility for licensing port operations and construction activities.

Figure 7: Seaport organization matrix



Source: Van de Voorde et al. (2011)

The main point of port capacity is that it takes time for infrastructure and superstructure investment projects to materialize. Moreover, short run demand can differ considerably from the long run demand projections. As a consequence, one can be confronted with situations of under- or overutilization of the existing capacity. As a result, the short-run marginal cost (SRMC) may either be lower or higher than the long-run marginal cost (LRMC) (see Table 3). SRMC refers to the additional cost of handling an extra unit of traffic given existing infrastructure, whereas LRMC includes the cost of expanding capacity in the longer term. Capacity decisions are then also inextricably linked with pricing of that capacity (Meersman et al., 2010)

Table 3: Relation between short- and long-run marginal cost in a port context

Scenario	Effects on cost	Effect of pricing
High capacity utilization, e.g. demand is higher than forecasted and/or lack of capacity.	The short-run marginal cost will be high (cf. scarcity of port capacity) and above the long-run marginal cost.	With a price close to the long-run marginal cost , congestion would occur; with a price based on short-run marginal cost, congestion would be virtually eliminated. Full cost recovery.
Low capacity utilization e.g. demand is smaller than expected and/or excess capacity.	The short-run marginal cost is below the long-run marginal cost.	With a price based on the long-run marginal cost, the use of the already underutilized port would be discouraged. With a price based on the short-run marginal cost, there will be a higher capacity utilization. No full cost recovery.

Source: Meersman et al. (2010)

2.4 Future challenges

Port capacity investment has several basic characteristics, which constitute challenges of their own. First, infrastructure invariably concerns long-term investments. The technical and economic longevity of locks and docks, for example, is over thirty years and may extend to half a century. In the very short run, overcapacity, mainly due to falling demand as a consequence of for instance an economic and/or financial crisis, leads to the cancellation or slowdown of orderings where contractually possible, and to modified sailing schemes. It appears often hard to match those long and short run perspectives, as shown in section 2.3.

Second, the sums involved are very substantial, as is illustrated in Table 4. In addition, in some cases there are no significant renewal costs in the short run, which may make large-scale investments appear more attractive from a financial perspective**.** Recourse is therefore taken to other forms of financing, like for instance Public-Private Partnerships, whereby inevitably government and port authorities give away part of their autonomy and control. Many North-European ports intend to further expand in the short to medium term, albeit almost entirely in terms of container throughput capacity. Table 3 provides an overview of these expansion plans. It is not always clear whether capacity expansion is motivated to relieve congestion, to cope with increasing demand, and/or to pre-empt expansion by competing ports. The result is quite predictable: any substantial growth in capacity will further aggravate the overcapacity in the global market and at certain European terminals, where operational quays are already lying idle. Linked to financing, it is important not to fall into geopolitical traps also: funding for port capacity may be offered by other nations, creating long-lasting dependencies and debt burdens, if not undesired access to markets.

Third, further increases in vessel sizes may also have a profound impact on the longer-run evolution, mainly in the container segment. Whether there will be a further evolution towards ships of +25k TEU, will depend on the context, but certainly there is no denying that the new generation of giga vessels, with a capacity of over 25k TEU, represent another step in that direction. The question arises how far

one can / should go to achieve economies of scale and scope. For example, in the deployment of 25k-plus TEU vessels, the number of calls is restricted to main ports handling large volumes and serving as 'hubs', ceteris paribus. When the additional handling costs in the hub-and- spoke system become too large (a.o. Jansson & Shneerson, 1982; Sys, 2010), one may reasonably assume that it will then become interesting for non-main-ports to attract smaller ships, for example, in the order of 12à14k TEU, offering direct origin-to-destination services. The economic benefits shipping companies seek through far-reaching scale increases, and the corresponding cost reduction must not be wasted through bottlenecks on the quay, in the terminal or during connecting in-land transport. Strategic and financial considerations by the holdings that control the shipping companies will keep capacity further in check, through strategic alliances, new partnerships, and the rerouting of vessels.

Fourth, besides these plans for additional capacity, there is also the issue of the organization of freight handling at terminals. Here, too, there is a concentration movement, inspired in part by the growing need for investment capital, which the original owners are often no longer able to supply themselves. This concentration movement has also created a buffer against any attempt at vertical integration on the initiative of the shipping companies.

Fifth, the involvement of port authorities in commercial activities within the logistics chain is declining. Consequently, the market power of those port authorities and, as the case may be, the public authorities that control them is also decreasing. In other words, managerial control over the maritime logistics chain now lies only partly with the ports and the undertakings located in those ports. There are, after all, various new reasons why port authorities may continue to play a role, even if it may be a very different one from today. They will certainly continue to play an important facilitating role, including in relation to infrastructure and intermodal integration, and perhaps also in respect of superstructure. Port authorities do, however, hold a strong trump card: they have the power to grant concessions and to determine their duration. Once a long-term concession has been awarded, they lose much of their market power, though. It has, for example, hitherto proven very hard to penalize concession holders who fail to achieve the objectives of their business plan. Consequently, there is an economic incentive for port authorities to award long-term concessions (for example, 30 years), but in conjunction with mandatory interim objectives agreed upon beforehand with the concession holder.

Sixth, a further consideration is often linked to the impact of administrative procedures (border controls, checks) and other time impacting elements (e.g. congestion) that limit the capability of cargo and passenger handling beyond the pure physical infrastructure limitations: such performance-related factors often generate misalignments between the potential deployed capacity and the actual recorded one. This is one of the key aspects that is pushing towards an increasing investment in novel technologies (e.g. Internet of Things, Blockchain) that limit potential capacity losses caused by such elements.

Seventh, there is tendency for further automation in ports, as illustrated in Table 5. Port automation exists on a continuum rather than as a binary distinction, ranging from manual and semi-automated to highly automated terminals. Accordingly, the use of the term "highly/fully automated" does not imply that a port operates without human involvement across all functions/terminals but rather indicates the predominance of automated processes within core terminal operations. If throughput is fully automated, the capital costs increase, while the operational costs become negligible. This will structurally change the cost structure of future port capacity.

While Table 5 illustrates the diversity of port automation initiatives across major European ports, the observed distribution also reflects elements of path dependency, particularly in relation to energy

infrastructure. Fully automated terminals are highly dependent on reliable, high-capacity electrical systems to support automated handling equipment, terminal operating systems, and digital control infrastructures. Ports such as Rotterdam and Hamburg benefit from long-standing investments in electrification, grid capacity, and integrated industrial energy systems, which have facilitated the transition towards full automation. In contrast, ports with more constrained or legacy energy infrastructures may favour semi-automated solutions, reflecting incremental adaptation rather than radical transformation. This suggests that automation trajectories are not solely determined by strategic preference but are shaped by historically embedded technological and energy-related constraints.

Table 4: Port automation initiatives in Europe

Port	Type of automation	Short project description
Algeciras	Semi	Total Terminal Internacional
Antwerp	Semi	Gateway
Barcelona	Semi	Europe South
Dublin	Semi	Ferryport Terminal
Hamburg	Fully	Altenwerder Container Terminal
	Semi	Burchardkai
Liverpool	Semi	Liverpool 2 Container Terminal
London	Semi	Dubai Ports London Gateway
		Thamesport
Rotterdam	Highly automated	Euromax container terminal
		World Gateway
		APM Terminal
Savona-Vado	Semi	Vado Gateway

Source: own composition no French port? *Note: French ports are not included in Table 5 due to the absence of large-scale container terminal automation initiatives comparable to the selected cases at the time of analysis.*

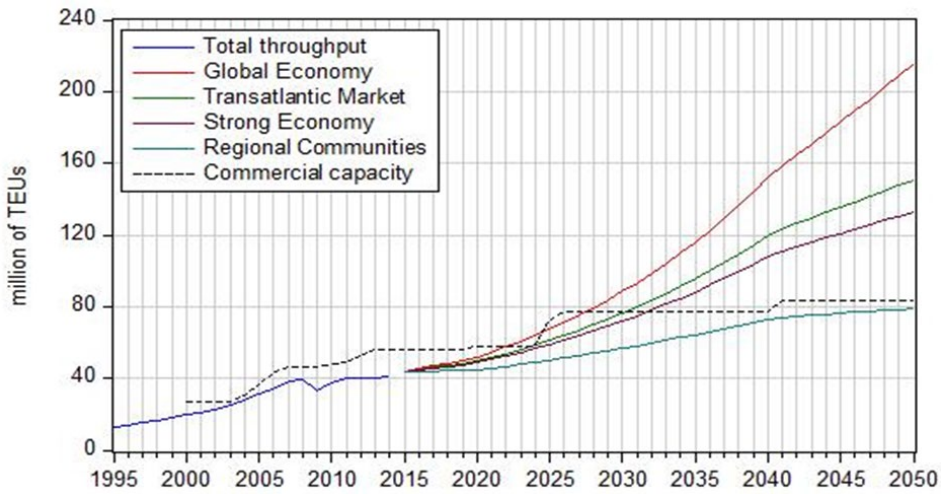
Eight, amongst the adverse effects of global warming, substantial sea-level rise is expected. While estimates vary, the fact remains that by 2100 many ports will face regular inundation if no action is taken for future infrastructure developments. In other words, sea-level rise can challenge the existence of infrastructure related to global trade and logistics chains such as ports and their hinterland connections (Christodoulou et al., 2019). The main concern is the uncertainty about the accelerated increase after 2050 and how soon existing infrastructure will no longer be functionable. At the same time, climate change may also alter global maritime transport patterns, potentially enable new navigable routes or shift trade corridors, thereby reshaping the strategic importance and spatial configuration of ports rather than affecting them uniformly.

Ninth, to mitigate the above-mentioned climate change, ports will play a key role, as they will get to deal with different types of cargo (energy) to be handled, which may require handling capacities of a different nature, and they will need to provide other types of energy provision for ships.

2.5 Recommendations

First of all, it is paramount that any decision regarding the expansion or renovation of port infrastructure should be based on reliable forecasts of throughput demand. The numerous examples worldwide of unused or underused port infrastructure suggest that many past investment decisions were taken on the basis of inaccurate forecasts, if any at all. Accurate forecasts of future port traffic volumes can certainly help in this respect. Nonetheless, forecasting future port throughput and the associated demand for port infrastructure inevitably remains a complex affair. The element of uncertainty may be reduced, but it will never be eliminated entirely. Part of that uncertainty can be channeled into scenarios, as is done in Figure 8 for future port capacity needs in the Hamburg - La Havre range (Rashed et al. (2018).

Figure 8: Future demand scenarios for the Hamburg - Le Havre range ports



Source: Rashed et al. (2018)

Second, a crucially important element in estimating the need for new infrastructure is timing, i.e. pinpointing the appropriate moment to invest. To this end, one can rely on existing techniques and methods, including the real options approach (see for instance Balliauw et al., 2020)

Third, it makes no sense to approach all port capacity investment projects in the same way. Proper prioritisation is vital, considering that a supply chain is only as strong as its weakest link. In other words,

certain investments may be more urgent than others, if only because eliminating bottlenecks in the port supply chain offers the most significant benefits to the port. The question, therefore, is: how to rank potential investment projects? A commonly used method in the past was cost-benefit analysis (CBA). As the government was often the principal or even the sole financier, port investment was approached mainly from welfare economics. Obviously, this aspect will remain relevant in the future, but one will undoubtedly also have to look at the impact on other participating parties, whose investment decisions depend primarily on considerations such as ROI and cash flow, and the efficiency of cargo and operational flows through the port supply chain.

Fourth, future port capacity planning should systematically incorporate climate adaptation requirements. Port authorities and governments should assess sea-level rise, extreme weather events, flooding risks and other climate-related disruptions when evaluating long-term infrastructure investments. Capacity expansion strategies must ensure that ports remain operational, resilient and economically viable under different climate scenarios.

Fifth, risk is a crucial variable in project financing. As summarized in Aronietis et al. (2010), seaport investment entails various types of risk. The risks preferably to be allocated to the public sector are political and legal risks, and risks arising from archaeological findings. Construction, operation, relationships and third-party risks are a matter for the private sector, as are project finance and design risks except for availability of finance and permits. Finally, the public and private sector should preferably share macroeconomic, natural and social risks. For instance, construction delays or cost overruns are typically private-sector risks, whereas regulatory changes or unexpected archaeological findings are commonly borne by the public sector.

Sixth and last, next to traditional port financing sources, including public or private or public-private funding, one could go a step further and combine project bonds with a public loan; for instance, provided by a national development bank or a supranational institution such as the European Investment Bank, whereby private investors could invest in this kind of long-term infrastructure project at a favourable interest rate.

3. Resilience of port hinterland transport on the TEN-T rail network

3.1 Definition

The “hinterland” of a port can be defined as the “the inland area that produces the majority of the port businesses” (Ferrari et al. 2011), considering that the “hinterland” of a port can be specific for different commodities, transport connections or for temporal aspects (e.g., seasonal impacts) (Blauwens and Van de Voorde, 1988). The hinterland assembles the customers of the port and, thus, requires reliable transport services from and to the terminal.

Two types of hinterlands can be distinguished (see e.g. Rodrigue et al., 2020): first, the fundamental (captive) hinterland that refers to the land area for which a terminal has the best accessibility (e.g., closest or fastest access). Second, the contestable (competitive) hinterland for which a terminal must compete with other terminals.

This section focuses on captive hinterland aspects, namely the resilience of rail freight operations along the European Core Network Corridor North Sea-Rhine-Mediterranean, parts of which serve as the main hinterland arteries for the ports of Rotterdam, Antwerp, Zeebrugge, Genoa and others. As an example of contestable hinterland, competition among ports will be considered in section 4.

3.2 Indicators

To measure the “resilience” of transportation systems, the following properties require consideration (Leobons et al., 2019): robustness, redundancy, resourcefulness and rapidity. Robustness and redundancy properties refer to the transportation system and its ability to maintain a sufficient service (e.g., network connectivity, route capacity, alternative routes, alternative transport modes). Resourcefulness and rapidity relate to the intensity of the incident as well as to the scope and quality of resources available (e.g., time required to start to recover, availability of people and other resources to react, time required to restore normal operation).

A useful “indirect” indicator to measure the scope of resilience are the socio-economic costs which occur if a certain infrastructure element cannot be used or has limited capacity. The additional socio-economic costs embrace are:

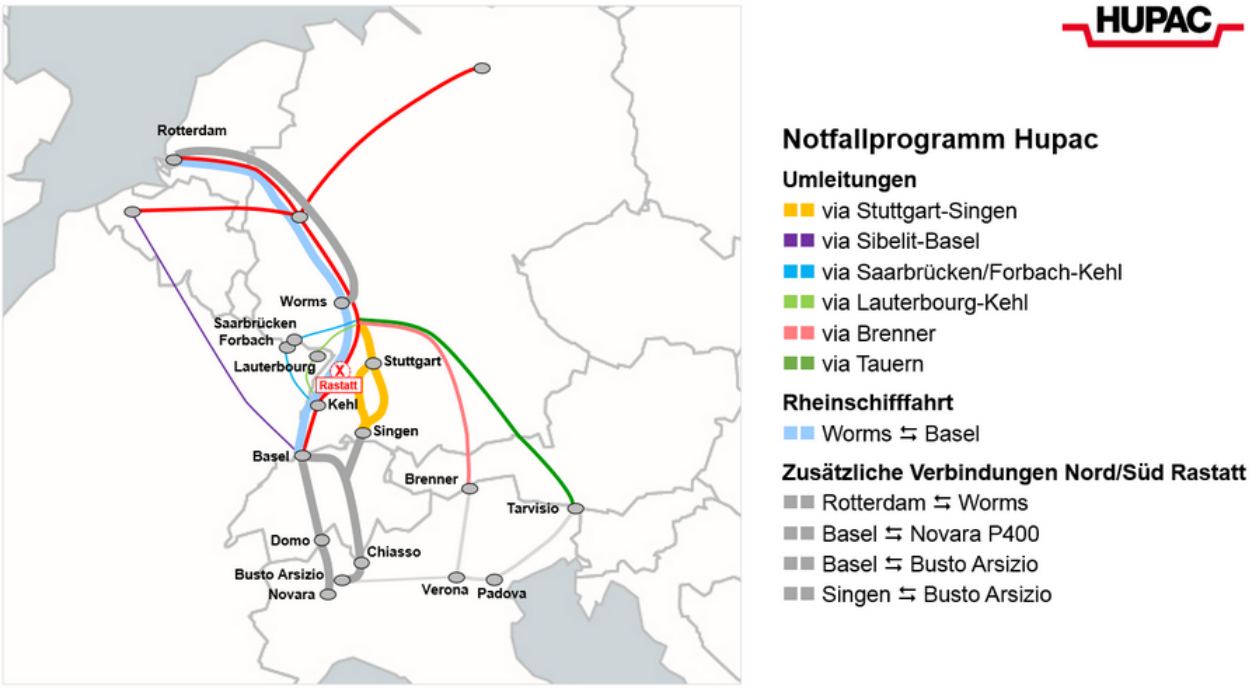
- all costs for short-term alternative logistics solutions and passenger transport (including additional labour costs for personnel and infrastructure managers as well as additional costs for traction, rolling stock and alternative transport modes) (HTC, 2018),
- production loss of the manufacturing industry (HTC 2018),
- additional time costs for passengers,
- socio-economic-costs resulting from a temporary modal shift (e.g., during temporary infrastructural road maintenance) to other modes of transport (e.g., GHG emissions, air pollutants, noise, accidents),
- as well as all socio-economic costs that occur because an incident causes long-term structural or behavioral changes (e.g., enduring modal shift to other modes of transport).

In this section, these general criteria will be applied to a specific case: The “Rastatt incidence” that led to a complete disruption of rail operation on the main European railway corridor, the former TEN-T Core Network Corridor Rhine–Alpine, near the city of Rastatt from 12 August to 2 October 2017.

The interruption was due to a track lowering of the existing double-track line caused by construction works for a new tunnel beneath that line. The interrupted section is highly relevant for regional as well as national and international long-distance passenger transport, particularly for international rail

freight flows serving among others the maritime ports of Rotterdam, Antwerp, Zeebrugge and Genova. The possibility to use nearby bypass routes for international freight trains were severely restricted: the northern part of the parallel line Stuttgart–Singen–Zurich was closed because of infrastructure renewal works, while the central part of this line is only a single-track line with limited capacity for additional trains. The possibility of using the bypass line Lauterbourg–Strasbourg on the French side was restricted by the need to use diesel locomotives and by regulations to have either bi-langual train drivers or interpreters on board. Thus, wider detour options were necessary to maintain rail freight operations. As an example, Figure 9 displays the applied emergency operational programme by Hupac, a Switzerland-based leading network operator in intermodal transport. Rail freight operators could handle only 25% of the usual freight volumes on the bypass routes via Germany, France and Austria (Representatives of the European rail logistics 2017). The emergency programme also included wider use of inland waterway transport on the Rhine.

Figure 9: Emergency operational programme by Hupac



Source: Hupac (n.d.)

Following the study by HTC (2018), the interruption of 51 days caused economic damage of more than two billion Euro: the loss of value creation of railway companies was estimated to be around 970 million Euro, the loss of value creation of manufacturing industries to be around 770 million Euro, and other losses such as process risks and impaired added value by infrastructure managers to more than 300 million Euro. The socio-economic damage due to modal shifts during the interruption phase were estimated to be 5.6 million Euro.

The costs of around two billion Euro do not consider any socio-economic costs of the passenger transport sector (e.g., loss of revenues for passenger transport operators, costs for rail replacement transports, passengers' time loss) nor socio-economic costs because of long-term structural or behavioural changes caused by the incident. Nevertheless, the partial estimation of socio-economic costs from the viewpoint of the freight and logistics sector already reveals the immense damage potential of low resilience of transport infrastructure.

The Rastatt incidence has mainly revealed a lack of redundancy in terms of missing alternative routes due to a lack of capacity and interoperability. This is a bitter irony because the lack of redundancy showed up as a direct, incidental consequence of an attempt to increase redundancy substantially, as the construction works for the new tunnel, which caused the accident, were part of the significant investment project to double the corridor capacity along the line Karlsruhe–Basel.

3.3 Who and how?

Because of the Rastatt incident, a high level of attention has been attached to the progress of rail infrastructure enhancements on the German access lines to the Swiss New Alpine Transversal (NEAT). The Treaty between the German Federal Ministry of Transport and its Swiss counterpart signed in Lugano in 1996 aimed at ensuring sufficient infrastructure capacity and an adequate level of rail service on the German access lines Karlsruhe–Basel, Stuttgart–Zurich and Munich–Zurich. Substantial progress has only been achieved on the latter section, which, however, is only marginally relevant for freight transport, while infrastructure improvements on the other two access lines are strongly delayed. As of September 2026, the corridor Karlsruhe–Basel (length 182 km) – by far the most important one of the three projects – has only been upgraded along a stretch of 67 km, and the last section is planned to be completed only by 2041. The partial double-track upgrade along the German part of the corridor Stuttgart–Zurich was materialized only for a plain section of 6 km length in 2024 (after a long planning and decision-making phase of 15 years), while the planning phases for the other sections to be upgraded in the southern part of this line are still at early stages only.

Furthermore, in February 2020, the German Federal Ministry of Transport and Digital Infrastructure (BMVI) declared a passage of the Lugano Treaty as not binding (Deutscher Bundestag 2020). In 2021, the Lugano Treaty has been replaced by a bilateral agreement, which the Federal State of Baden-Wuerttemberg criticized as being “not worth much”, since it has a non-binding character (SWR 2021). The delays in planning and materialization of rail infrastructure improvements on German access lines to NEAT has revealed a lack of willingness and commitment by the German Federal Government and the rail infrastructure manager DB InfraGo.

In response to the vulnerabilities exposed by the Rastatt disruption and delays on the German access routes to the NEAT, Switzerland promoted the development of an alternative North-South rail freight corridor via Metz and Strasbourg (Stalder 2020). This initiative strengthened political support for upgrading the French access route and contributed to a greater emphasis on resilience within the revised TEN-T corridor framework.

3.4 Future challenges

The Rastatt incident has impressively demonstrated the high socio-economic damage potential of a lack of resilience of the European rail network. While the reason for the corridor interruption close to Rastatt was infrastructure construction works, or, more specific, misfortune during the conduction of a risky construction approach, exogenous causes of infrastructure interruptions are more apparent: increases in extreme weather events because of global warming, natural disasters such as large-scale fires, earthquakes, or terroristic attacks.

The example shows that the enhancement of the resilience of the TEN-T network has different spatial dimensions: first, a more regional dimension, allowing alternative routing in the close or wider proximity of the incident’s location (in our example, alternative routes via Stuttgart–Singen or Lauterbourg–Strasbourg). Second, a European dimension, allowing spatially large-scale alternative routings (in our example, alternative alignments via Metz–Strasbourg–Basel, the Brenner or Tarvisio).

An improvement has been achieved by the 2024 revision of the TEN-T Regulation, which merged the former Rhine–Alpine and North Sea–Mediterranean Corridors into the new North Sea–Rhine–Mediterranean Corridor, partly to enhance coordination and resilience in the common freight market, namely freight flows between the Belgian and Dutch seaports on the one end, and south-western Germany, eastern France, Switzerland, and northern Italy on the other end. As elaborated by Szimba (2008), corridors or infrastructure projects which can serve the same markets, are either in a competitive or a complementary relationship. While the joint implementation of corridors in a competitive relationship will improve the resilience of the transport network, the joint implementation of complementary corridors will raise synergies and thus enhance the efficiency of the transport system. The possibility of using both routing options on the former Rhine–Alpine and North Sea–Mediterranean corridors will not only enhance the resilience of the transport system but also foster competition among operators.

At the same time, infrastructure projects and corridors that serve overlapping markets require careful appraisal to avoid overinvestment in competing facilities whose costs exceed the benefits associated with additional capacity, improved resilience, and increased intra-modal competition (Shayanfar & Schonfeld, 2018; Szimba & Rothengatter, 2012).

3.5 Recommendations

The Rastatt incident has revealed the tremendous importance of a sufficient level of resilience of the TEN-T rail network. A higher level of resilience can be achieved by addressing all aspects of resilience, i. e. robustness, redundancy, resourcefulness and rapidity.

Robustness and redundancy can be enhanced by removing infrastructure bottlenecks which are already known for a long time: the upgrade of the German access lines Karlsruhe–Basel and Stuttgart–Zurich to the Swiss base tunnels requires full political commitment from the German Federal Government and the rail infrastructure manager DB InfraGo to complete in a timely manner planning and implementation of the infrastructure measures which have already been positively evaluated in the German Transport Masterplan (BMVI 2016). The removal of these bottlenecks will significantly enhance capacity and, thus, redundancy and robustness of international rail flows.

Furthermore, although on the stretch between Mainz and Basel, the Rhine River constitutes borders between different German Federal States as well as between France and Germany, the Rhine valley must nevertheless be regarded as a common transport area. Consequently, a corridor management board should be established for the Core Network Corridor North Sea–Rhine–Mediterranean, which in addition oversees the connection Ludwigshafen–Woerth–Lauterbourg–Strasbourg that is not part of the Corridor. Such extended corridor management board would better reflect the idea of this common inter-regional and international transport area along the Rhine River and at the same time improve the robustness and redundancy of trans-European rail freight flows.

With the planned upgrades along the axes Antwerp–Brussels–Luxembourg–Strasbourg–Basel and Karlsruhe–Basel implemented, there will be competing railway infrastructure for important European freight flows that is likely to also foster competition among service providers which will, as always, stimulate business and strive for better quality. Widened EU support to timely completion of the pending construction works along the former Rhine–Alpine and the eastern branch of the former North Sea–Mediterranean Core Network Corridor, while taking additionally into consideration the leg Ludwigshafen–Woerth–Lauterbourg–Strasbourg–Basel, would significantly promote green transport, generate European added value, and enhance the European transport system’s redundancy and robustness.

Furthermore, to ensure a sufficient level of robustness of rail transport during the conduction of infrastructure works (including maintenance), careful and consolidated planning of these construction works at the international level is indispensable to avoid that interdependent network sections which could be used as bypass to each other are blocked at the same time[4].

To strengthen the resilience aspects of **resourcefulness and rapidity**, the establishment of an international Task Force would be beneficial. The Task Force should comprise infrastructure managers, operators, and logistic companies involved in a specific market, i.e. freight flows between Belgian and Dutch seaports on the one end, and south-western Germany, eastern France, Switzerland, and northern Italy on the other end. Closely linked to the corridor management board of the North Sea–Rhine–Mediterranean Core Network Corridors, the Task Force should meet regularly to address issues affecting this transport market, and, in the event of disruption, coordinate a rapid response to restore normal operations or implementing effective alternative operating arrangements.

[4] The fact that during several weekends in Summer 2021, both the German Rhine corridor between Freiburg and Offenburg, and the parallel line between Singen and Stuttgart were simultaneously interrupted due to planned construction works reveals that interdependence aspects of infrastructure works have still not been regarded adequately, despite the negative experiences made during the Rastatt incident.

4. Port competition through the hinterland of big European port hubs: an intermodal transport chain approach

After the theoretical framework (section 4.1), a case study is described in section 4.2.

4.1 The theoretical framework

Competition between ports depends not only on capacity to handle freight volumes at the port level; it also depends on the ports' ability to efficiently forward the cargo volumes handled towards final destinations in the hinterland. The latter depends on the capacity of inland infrastructure networks on the one hand and the supply of reliable and efficient rail and road transport services on the other. The quality of transport services connecting ports with inland final freight destinations is a significant factor of port attractiveness.

Any "continental" final destination can be reached from various ports. Numerous alternative "port choice" solutions are theoretically offered to reach the final destination. They differ from each other as far as combinations of total sea distance and total land distance are concerned, considering the respective travel costs and travel times. Usually, longer routes by the sea offer lower costs per freight unit but longer travel times. On the contrary, shorter sea routes -increasing land routes- allow faster arrival to the final destination with perhaps higher cost, depending on the "critical" freight mass needed in inland networks.

In this context, efficiency refers to the minimisation of total transport costs and transit times across the entire maritime hinterland transport chain, while ensuring reliability and service quality. From the perspective of shippers and logistics operators, ports compete not only on handling capacity, but on their ability to offer efficient end-to-end transport solutions. Consequently, inefficiencies in hinterland connections or intermodal interfaces directly undermine a port's attractiveness, even if seaside operations themselves are highly productive.

Therefore, users' port choice decisions strongly relate to "intermodality" issues. Travel time in maritime transport is somehow given. It is not the same with rail and road transport, in the framework of integrated transport chains. The technical capacity of railway and road networks, associated with interoperability, operational fluidity and reliability of available intermodal rail and road services, defines travel times and service quality on the inland leg. For a substantial extension of ports' hinterland dealing with more than 500 km, railway connections are crucial. Obviously, "interface" performance between seaside and landside at ports related to intermodal transshipment between ships and trains or trucks strongly affects total travel times.

Considering the above, users' optimal port choice solutions depend on the Value of Time (VoT - the opportunity cost of the time or the willingness to pay in order to save time) of various commodities to be transported.

4.2 A case study: competition between the port of Piraeus and ports of northern Europe in revendicating hinterland in Central Europe

4.2.1 Piraeus port evolution and port capacity

Piraeus Container Terminal limited company (PCT S.A.) was founded in November 2009 with the sole purpose of managing and operating the container terminal, following a successful biding procedure initiated under the Greek state. PCT is the only company of COSCO group worldwide that COSCO Shipping Ports totally own with a share of 100%.

Piraeus Port has been doubling its annual container traffic since 2010 when it effectively started its operations at the Port of Piraeus, and it was expected to exceed the critical volume of 4 million TEUs per year by 2016, which would make it one of the biggest European Container Terminals. Eventually, even the most optimistic scenarios have been verified, reaching in 2019 an annual throughput of 5.7 mio TEUs making the terminal the first in Mediterranean Sea (overpassing Valencia in 2019) and the third among European Container Terminals right behind Rotterdam and Antwerp, leaving behind legacy Ports like Hamburg in the North. At the same time Terminal's capacity is lying in top level with a designed capacity of 7.2 mio TEUs. The most impressive figure is the tremendous growth achieved in a ten-year period from 2007 to 2018 0f 257,5% (Source: EMIL, SMU, 2019).

Figure 10: Ranking world ports

Row Labels	2015	2016	2017	2018	2019	2020	2021	% change	Rank
Shanghai	36,54	37,13	40,23	42,01	43,30	43,50	47,03	*7,51%*	0
Singapore	33,92	30,90	33,70	36,60	37,20	36,87	37,50	*1,68%*	0
Ningbo-Zhoushan	20,63	21,60	24,61	26,35	27,53	28,70	31,08	*7,66%*	0
Shenzhen	24,20	23,97	25,20	25,74	25,77	26,55	28,77	*7,72%*	0
Guangzhou	17,57	18,90	20,36	21,92	22,83	23,19	24,18	*4,09%*	0
Busan	19,43	19,85	20,49	21,66	21,90	21,81	22,69	*3,88%*	-1
Qingdao	17,50	18,00	18,30	19,32	21,01	22,00	23,71	*7,21%*	1
Hong Kong	20,08	19,81	20,77	19,60	18,36	17,96	17,80	*-0,90%*	-1
Tianjin	14,11	14,50	15,07	15,97	17,30	18,35	20,26	*9,43%*	1
Rotterdam	12,23	12,39	13,70	14,51	14,81	14,35	15,30	*6,21%*	0
Jebel Ali	15,59	14,80	15,37	14,95	14,10	13,48	13,70	*1,61%*	0
Port Klang	11,89	13,17	9,00	12,32	13,58	13,24	13,70	*3,36%*	0
Antwerp	9,60	10,04	10,45	11,10	11,86	12,03	12,02	*-0,08%*	0
Xiamen	9,18	9,61	10,38	10,70	11,12	11,40	12,05	*5,39%*	0
Kaohsiung	10,26	10,46	10,55	10,45	10,43	9,62	9,86	*2,43%*	0

Source: own compilation various websites

One of the key elements for succeeding in the above figure was the port infrastructure. Regarding civil engineering, the terminal underwent a complete renovation and reinforced the foundations of Pier II. This expansion occurred in 2009, effectively doubling its coverage area by constructing the new Pier IIIs from scratch. The result was impressive operational Quaysides for both piers and a maximum safe draft of 19.5 meters, giving the terminal the capacity to serve concurrently four mother vessels (Giga carriers) and other feeder vessels.

The above investment, along with high-end handling machinery (Super Super Post Panamax (SSPP) QCs new generation 26 rows tandem spreader) (STS cranes, RMGs, ERTGs) and mobile equipment (reach

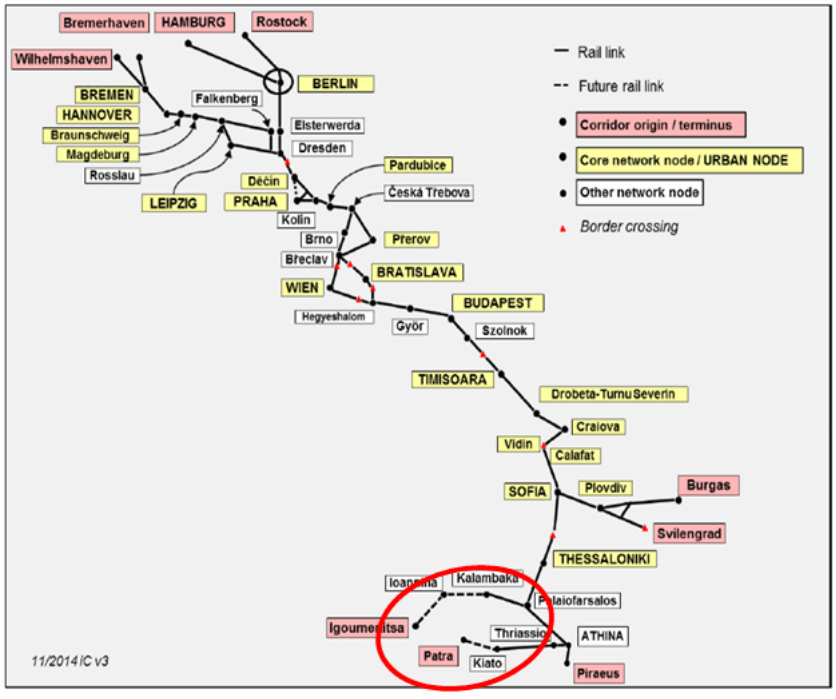
stackers, straddle carriers), gave the operator the needed thrust to boost the operational performance of the terminal.

4.2.2 Defining the Hinterland for the Port of Piraeus

Piraeus port could instead be characterized as a pure transshipment port, as more than 95% of the containers reaching the port are being transshipped to other destinations, mostly via other smaller vessels. Of course, it is of great value the land transport modes that are being used for the forwarding of freight volumes from the port to the inland of Europe i.e. to the areas of consumption. Rail proved to keep a critical role in maintaining tremendous growth in transporting volumes. Key parameter was the finalization of rail infrastructure works in 2013 to complete the rail link between the port and the rail backbone of the country. Since then, when the first freight train left the port with the inauguration date of May 2014 the new line runs its 7th year of operations, connecting PCT with Thriassio Freight Complex and the main railway network. This line already ensures a significant boost in freight activity from the increased absorption of containers transported through the deep-sea port of Piraeus. Terminal's brand-new railway infrastructure enhances intermodality, ensuring reliable, fast and economical transport by introducing in-port standard procedures for loading/unloading containers.

The strategic role of Piraeus as a transshipment hub and gateway to Central and Eastern Europe is further clarified by its geographical position and rail connections, which are illustrated in Figure11.

Figure 11: Orient /East-Med Core Network Corridor



Source: Study on the Orient / East-Med Core Network Corridor, DG MOVE, European Commission - Contractor: iC / ITC / Panteia / Railistics / SYSTEMA / Prodex / UPB / PwC

It is critical for a port to define the hinterland that it effectively can serve. The catchment area is being defined throughout various, sometimes heterogenous, parameters that could be summarized in geopolitical, population, word trade flows, political and economic stability/growth, warfares and others, giving the momentum of a dynamic/non-static image directly.

Legacy northern EU ports (like Hamburg) are acting in the vicinity with the consumption markets of Northern/Central Europe, which is turning rail (and road) very competitive in terms of transit times and tariffs. The range of transport for rail lies within a competitive medium-to-long-distance range (typically beyond 500–600 km), with freight trains operating on mature rail networks that ensure competitive operational speeds and affordable tariffs for end users. Modal shift of about 30% for rail transport following the transshipment is the louder proof of concept the port of Hamburg when establishing METRANS company to undertake the sum of rail business for the port.

However, this was not the case for Piraeus. For a country like Greece, where most of its borders are maritime, and the rest are even with non-EU countries, the whole trade crossing the country is considering Greece acting as a huge island. COSCO undertook the risk of establishing this business from scratch in a non-rail friendly environment, already since 2017 by commencing strategic agreements with rail companies (Rail Cargo, DB SCHENKER, PEARL). Since then, the volumes have been growing for 2017-18 with 32% and 2018-19 with 49% giving to COSCO the opportunity for the acquisition of the majority of shares of the railway operator "PEARL" within 2020 to verticalize the transport business from Far East to Central Europe and vice versa.

4.2.3 Methodological framework for assessing potential of hinterland extension of ports: a generalized cost comparison

The consideration of transport generalized cost (G(D)) allows for the comparison of alternative intermodal routes and the identification of the most competitive option for serving specific hinterland markets. In this framework, the generalized cost functions as a composite indicator of route competitiveness, integrating both monetary and time-related components from the perspective of the freight payer. The generalized transport cost is being built by 2 key operational indicators.

- The pecuniary costs (P) which are related to the price of transport services (e.g. maritime freight rates, rail or road tariffs, handling charges);
- The cost of Time which is composed by the multiplication of
    - Time cost per hour (H) and
    - Time (T) in hours

The equation describing the above is

$$G(D) = P(D) + H*T(D) \qquad (1)$$

In a direct comparison between the two competitor routes for the goods produced in the Far East and Transported to the EU markets of central Europe, the Generalized transport cost for the freight payer is what matters.

Major ocean carriers, namely MAERSK, MSC, COSCO, CMA CGM and others acting as "Lines" for this overseas transport, they usually do not differentiate between each other in terms of commercial prices per TEU (tariffs). Scheduling and real operations are driven by the key element of economies of scale have already driven the sector the last five years to implicate alliances between the "Lines" (e.g. Ocean Alliance, The Alliance, a.o.). The above made them capable of designing and scheduling ocean routes calling legacy major hubs in Northern Europe and others in the Mediterranean.

It will be driven by pure logic for researchers to commence a direct linear relationship between the Generalized Cost (C) incurred by the Carrier and the Transport Distance (D). This assumption reflects the fact that, under stable operational and pricing conditions, transport costs tend to increase proportionally with both cargo volume and distance travelled.

Accordingly, a simple linear cost function is adopted for analytical transparency and comparative purposes:

$$C = a_0 + a_1X + a_2XD,$$

where Xrepresents the volume of cargo transported, $a_0$denotes fixed costs independent of cargo volume and distance (e.g. terminal access, administrative costs), a_1X captures variable costs related solely to cargo handling and unit transport, and a_2XD represents distance-dependent costs such as traction, fuel, and infrastructure usage. All coefficients satisfy $a_0, a_1, a_2 > 0$.

The objective of adopting this functional form is not to predict exact transport prices, but to enable a consistent comparison of alternative intermodal routes and ports when assessing their relative competitiveness and potential for hinterland extension.

However, in the real world, pricing policy for Carriers is a gamechanger, because they alter the bias on which transport route and port choice are made. Verticalization of the transport production made ocean carriers offer all-in-one tariffs for door-to door transport of containers, containing the maritime backbone and long haulage rail shipments along with last mile delivery by trucks. The above led to a phenomenal paradox when the transport between China base ports (e.g. Shanghai, Ningbo) to Central European Dry ports (e.g. Pardubice) is almost equal for both options to reach the hinterland either by calling Piraeus Port or by calling Hamburg Port. Even though the maritime distance between these two ports is significant and in terms of transit-time a container could gain even nine days to shorten its maritime trip, the tariffs are almost equal. The phenomenal paradox could only be explained throughout the generalized cost.

Legacy Northern European ports maintain a close vicinity with the Central Europe consumption markets. Making the rail trip shorten while their maturity in rail operations act as an enabler into maximizing the hinterland. It is worth mentioning that Hamburg port over the decades achieved a modal shift for transshipment that reaches 33% for rail, while Piraeus even after its tremendous growth for the past years, could only reach 10% transport by rail. The above image reflects the operational readiness for the two ports to commence rail transport as a continuation of the maritime backbone. Hamburg Port with the group of companies (HHLA) and dedicated in-house rail carrier (METRANS) already proved able to minimize transshipment delays at the port with multiple train departures per day, effectively servicing practically the whole of Europe. On the other hand, Piraeus, with a very short history in rail (just from 2014), rapidly reaches network capacity constraints and infrastructure bottlenecks in the Balkans, turning rail transport into a hard to achieve mode.

4.2.4 Piraeus port competitiveness in terms of transit time

Sea leg

Considering the importance and perspectives of “One belt-one road” issues, a comparison of sea travel times between services connecting the main Far-East hub ports to the main European container ports is attempted hereafter.

Figure 12 presents the sea travel times (in number of days) between the main Mediterranean container ports (MED) and the Far East (FE).

Figure 12: Transit-times MED-FE



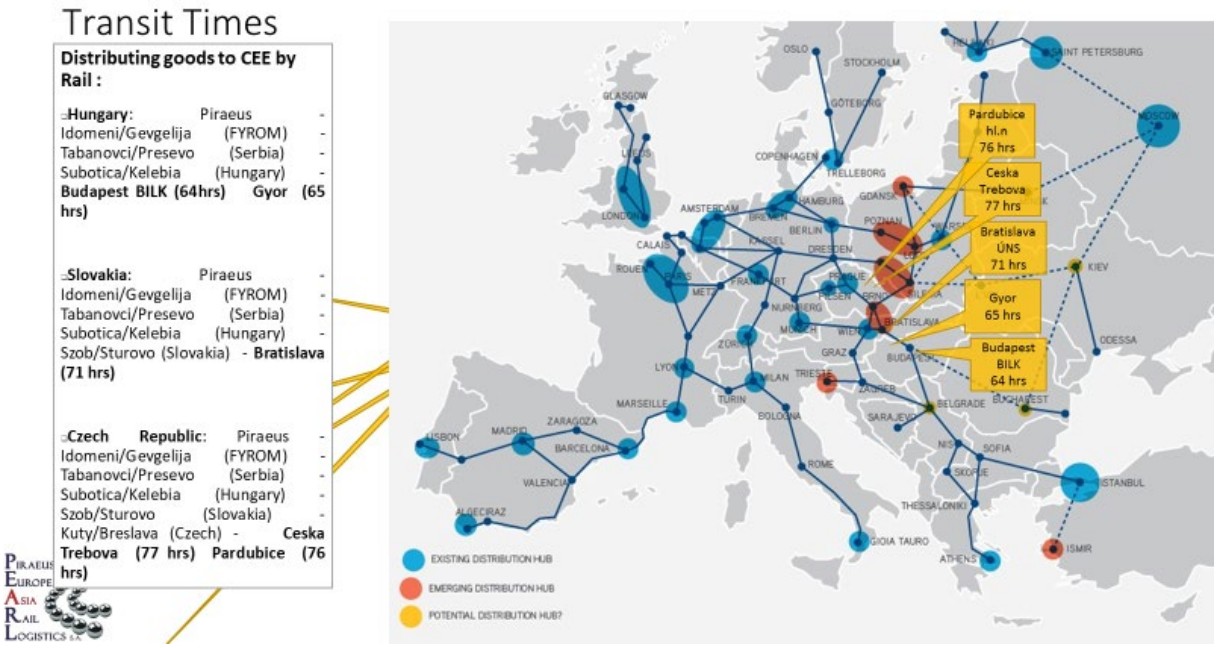
Source: PEARL

It is obvious that connections from Far-East ports to big European ports of the North Sea are much longer in travel time. Indicatively, commercial sea travel times from Shanghai to Rotterdam and Hamburg ports correspond to approximately 40 and 41 days respectively.

Inland leg by rail

Figure 13 presents travel times of the main railway services between maritime ports and indicative hinterland destinations (rail-road intermodal terminals). Travel times from the port of Piraeus are highlighted (in hours).

Figure 13: Transit Times

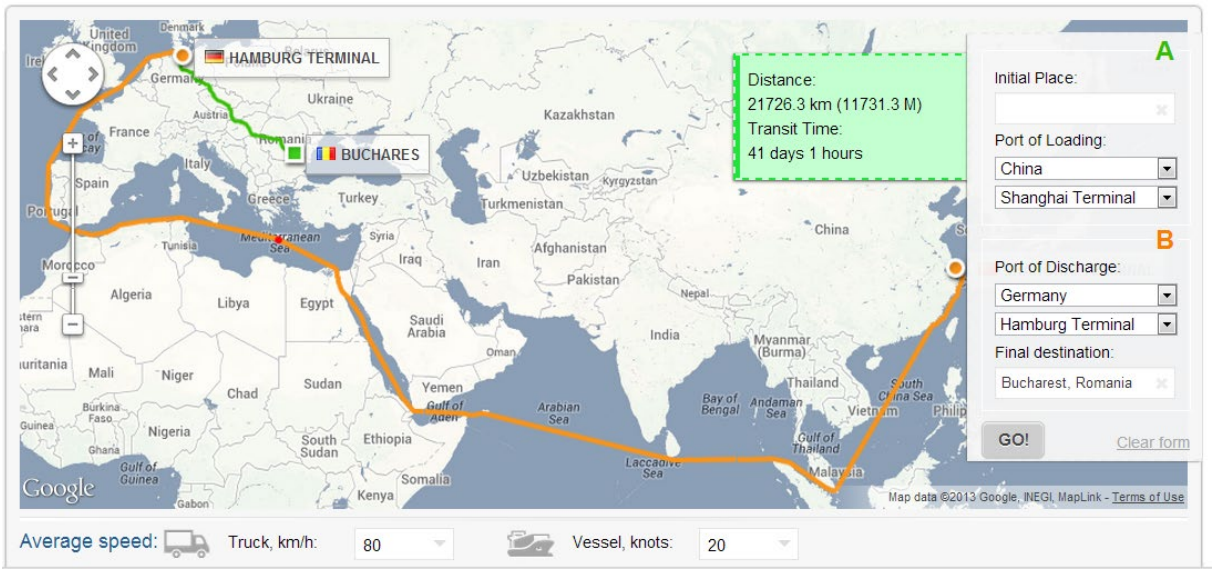


Source: PEARL

According to figures 6 and 7 and compared to other European ports, the port of Piraeus presents an important competitive advantage in terms of total travel time, to reach important final destinations in Central Europe. The main advantage for Piraeus port in regard to its main competitors is the total travel time for a container to reach from Far East to Central Europe for door-to-door transport.

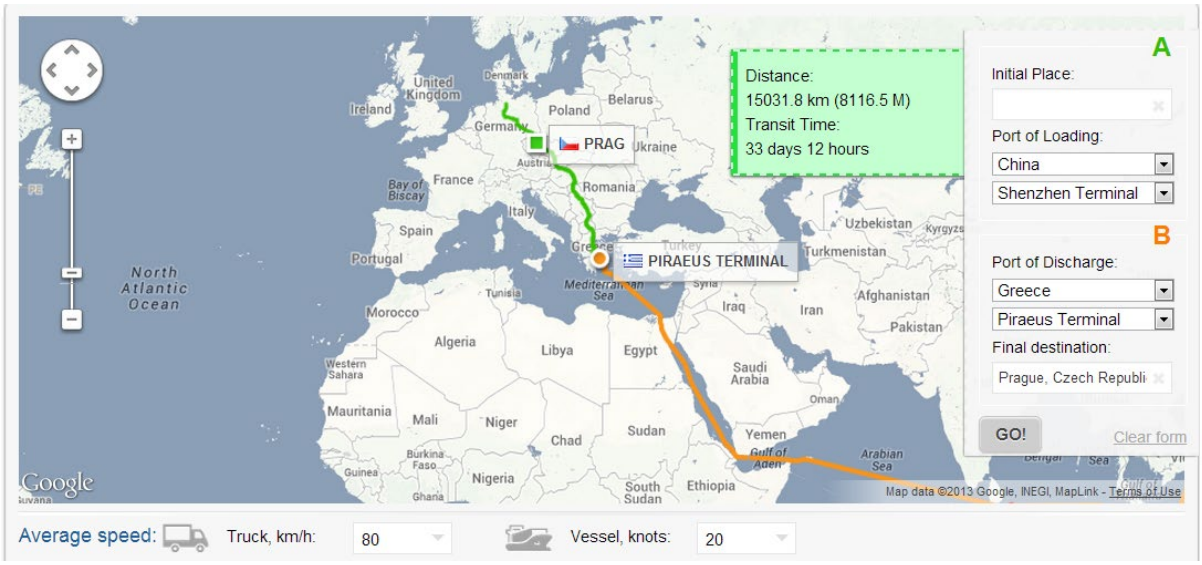
Figures 12 and 13 present respectively two port choice alternatives of ships to reach comparable final destinations, based on existing services offered, namely Bucharest and Prague.

Figure 14: Reaching Bucharest from the port of Hamburg



Source: PEARL

Figure 15: Reaching Prague from the port of Piraeus Problem with the red mar at the mement



Source: PEARL

Final destinations in the two examples above do not coincide, as there are no alternative existing operating services for both final destinations. However, considering "orders of magnitude", the comparison of total travel time of the above intermodal chains shows the competitive potential of the port of Piraeus to extend its range of influence in Central Europe.

The effective hinterland of the port could be visualized in figure 15, covering an extensive range of Balkan countries and then by crossing Hungary and Slovakia to reach Austria, the Czech Republic and eventually Southern Germany.

Figure 16: Hinterland of port of Piraeus



Source: Port of Piraeus

Minimization of transshipment times in the port and affordable lead times for trains to reach central Europe (max six days travel) would give Piraeus the needed tools to initiate global trade flows reformation. Time-sensitive goods and "just in time" logistics reflecting into HVLD goods (like electronics) are lying among the most common cases to be properly transported by using the Piraeus Gate for their entrance to the European market.

4.3 Future research challenges

The present section offers an analysis framework, and a first global picture of port competitiveness in Europe, combining theoretical considerations and strategy identifications with operational data. A systematic data collection is required to proceed to a more detailed analysis, Travel time estimations must be combined with detailed cost data on the sea and inland leg of integrated intermodal transport chains, introducing VoT parameters for the various commodities transported. Based on those, applying the proposed methodology might bring reliable forecasting estimations on the attractiveness potential of various European ports.

4.4 Recommendations

The core policy message it that port competitiveness is increasingly determined by effiicency of hinterland connection rather than by port capacity alone. Therefore, European transport policy should continue to prioritize seamless intermodal chains linking ports to inland markets, especially through alternative transportmodes.

Some key recommendations are formulated

- Prioritize hinterland infrastructure alongside port investments. Investment in quays, cranes and terminal capacity is insufficient if inland connections remain weak. Thus, allocate TEN-T and CEF funding not only to port infrastructure but also to rail access lines, inland terminals, border-crossing infrastructure, freight corridors connecting ports with Central Europe.
- Remove rail bottlenecks on (Southern) European corridors that restrict train frequency, reliability and speed.
- Strengthen interoperability across borders (Harmonize signaling systems (ERTMS deployment), Simplify cross-border operational procedures. Reduce administrative barriers and train handover delays; Promote common standards for rail freight operations).
- Infrastructure decisions should be based on total logistics-chain performance rather than distance alone. TEN-T project appraisal should incorporate: transport cost, transit time, reliability, value of time for different commodities.
- Establish a stronger evidence base for port competitiveness assessments; develop European databases on port dwell times, rail transit times, intermodal costs, and reliability indicators.

European transport policy should shift its focus from ports as isolated nodes to ports as gateways within integrated intermodal corridors. Investments should prioritize rail connectivity, interoperability, inland terminals and efficient port–rail interfaces, particularly on Southern and Balkan corridors. Enhancing the reliability and capacity of hinterland transport networks will allow Mediterranean gateways such as Piraeus to exploit their transit-time advantages and contribute to a more balanced, resilient and sustainable European freight system.

5. Warehouses and logistics

5.1 Contextualisation

Warehousing is an integral part of every logistics system playing a key role in providing the desired level of customer service at the lowest possible total cost. A warehouse is a facility – node of a logistic network – that, along with storage racks, handling equipment and personnel and management resources, enables controlling the differences between the incoming flow of goods (received from suppliers, production centres, etc.) and the outgoing flow of goods (goods being sent to production, sales, etc.) (Reis and Macario, 2019).

In the context of ports and maritime shipping, warehousing and logistics efficiency directly influences the system performance of port operations and transport chains, as it affects cargo dwell times, intermodal transfer efficiency, and the synchronisation between vessel schedules and hinterland transport services. Consequently, efficient warehousing and logistics integration within port systems are essential for enhancing end-to-end transport efficiency and reinforcing the competitive position of ports within global shipping and logistics networks

Over the years, warehousing has developed from a relatively minor facet of a firm's logistics system to one of its most important functions (Lambert et al., 1998). Today, warehouses are a key aspect of modern supply chains and play a vital role in the success, or failure, of businesses. The evolution of warehousing has been constant. Driven by market competition, continuous improvements in the design and operation of distribution networks have required higher performance from warehouses. Furthermore, the adoption of new management philosophies such as Just-In-Time (JIT) or lean production also brings new challenges for warehouse systems. On the other hand, the widespread implementation of new information technologies (IT), such as bar coding, radio frequency communications (RF), and warehouse management systems (WMS), provides new opportunities to improve warehouse operations (Gu et al., 2007).

In addition to these traditional inventory holding roles, warehouses have been evolving to act as cross-docking points (where goods are moved directly from inward to outward vehicles without being put away into inventory), value added service centres (e.g. pricing and labelling goods for customers), production postponement points (configuring or assembling goods specifically to customer demand so that a smaller range of generic products can be held in inventory), returned good centres (for reverse logistics of packaging, faulty goods or end-of-life goods) and many other miscellaneous activities, such as service and repair centres (Baker & Canessa, 2009). Nowadays, the main tasks performed in a warehouse are: receipt of goods, verification of those goods, in-house transport (between different parts of the warehouse), storage and safe keeping of items, preparation of orders and the consolidation of loads, dispatch of goods, general management and processing of information related to the stock, workflows, demand, etc.

In a logistics network, according to Frazelle (2002), a warehouse may play one or more of the following roles:

- Raw material and component warehouses: Hold raw materials at or near the point of induction into a manufacturing or assembly process;
- Work-in-process warehouses: Hold partially completed assemblies and products at various points along an assembly or production line;

- Finished goods warehouses: Hold inventory used to balance and buffer the variation between production schedules and demand;
- Distribution warehouses and distribution centres: Accumulate and consolidate products from various points of manufacture within a single firm or from several firms for combined shipment to common customers;
- Fulfilment warehouses and fulfilment centres: Receive, pick, and ship small orders for individual consumers;
- Local warehouses: Distributed in the field in order to shorten transportation distances to permit rapid response to customer demand.

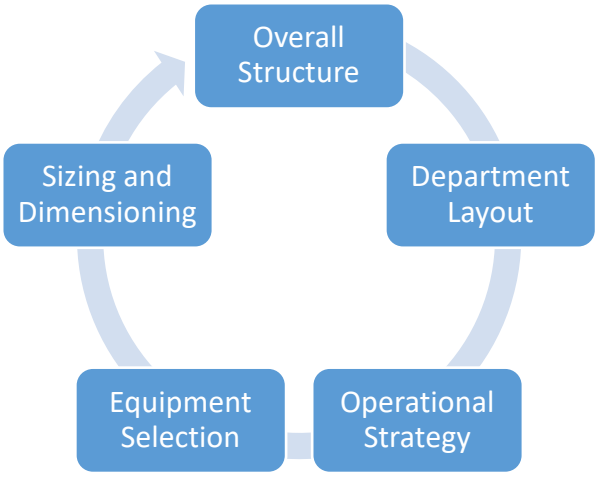
5.2 Design Factors and Dimensioning

In the context of warehouse design, factors refer to the qualitative and operational characteristics that shape warehouse configuration, while dimensioning denotes the process of quantitatively determining the required size, capacity, and layout of warehouse facilities in order to ensure efficient and cost-effective operations.

A number of factors must be taken into account when planning a warehouse, such as the products to be stored, the flow of materials or goods, the space available to house them, the storage equipment – such as racks and handling equipment–, the human factor (personnel), and the company's management system and policies.

Overall, warehouse design involves five major decisions as illustrated in Figure 16 : determining the overall warehouse structure; sizing and dimensioning the warehouse and its departments; determining the detailed layout within each department; selecting warehouse The overall structure (or conceptual design) of a warehouse determines the material flow pattern within the warehouse, the specification of functional departments, (e.g. how many storage departments, employing what technologies, and how orders will be assembled) and the flow relationships between departments. At this stage, the design intends to meet storage and output requirements, and to minimize costs, which may be reduced investment or diminutions in future operation costs (Gu et al., 2010).

Figure 17: Warehouse design factors



Source: Gu et al. (2010)

The sizing and dimensioning decisions not only determine the size and dimension of the warehouse but also the space allocation among the various warehouse departments, resulting in important implications on costs as construction, inventory holding and replenishment, and material handling.

Department layout is the detailed configuration within a warehouse department, for example, aisle configuration in the retrieval area, pallet block-stacking pattern in the reserve storage area, and configuration of an Automated Storage/Retrieval System (Gu et al., 2010).

The layout decisions affect the construction and maintenance cost, material handling cost, storage capacity, space utilization and equipment utilization of the warehouse (Gu et al., 2010).

The equipment selection decisions determine an appropriate automation level for the warehouse and what type of storage and material handling systems should be applied. These decisions are obviously at a strategic level, as they affect almost all the other decisions and the overall warehouse investment and performance.

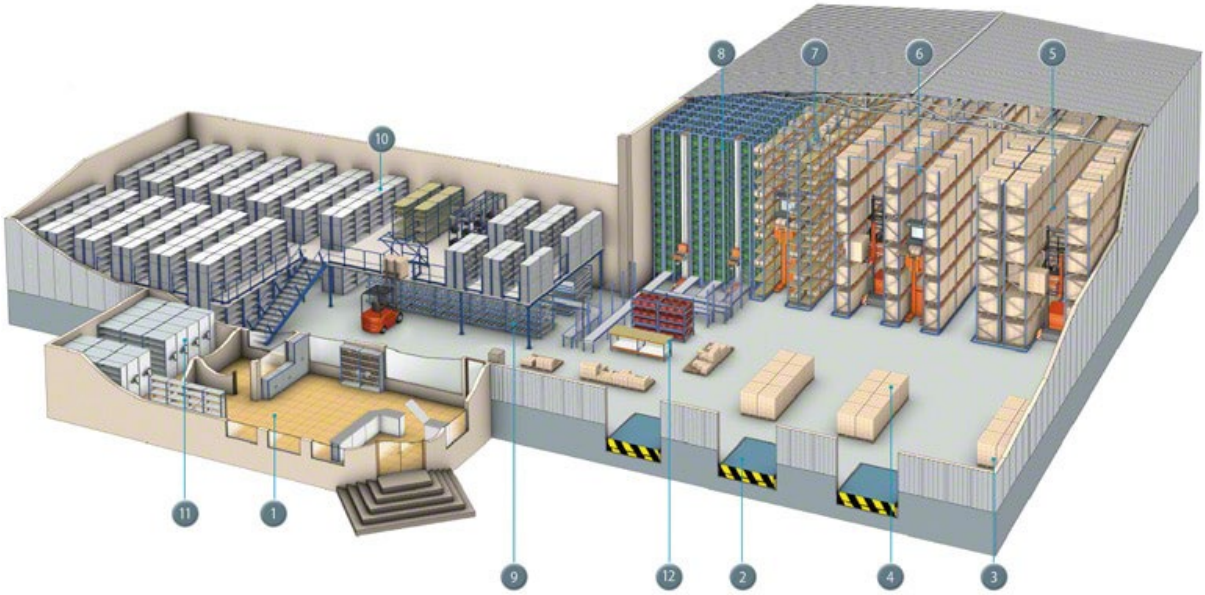
The selection of the operation strategy determines how the warehouse will be operated, for example, with regards to storage and order picking. Operation strategies refer to those decisions about operations that have global effects on other design decisions and therefore need to be considered in the design phase. These strategies, once selected, have important effects on the overall system and are not likely to be changed frequently. Examples of such operation strategies include the choice between randomized storage or dedicated storage, whether to do zone picking, and the choice between sort-while-pick or sort-after-pick.

5.4 Design Function

The actual size and functions of the warehouse will depend on the interplay of these five factors. The simplest warehouses normally have access doors, an open area for manoeuvring and verification, a storage area where the goods are located, a management office for controlling operations, and toilets and changing rooms for personnel. Starting with the simplest configuration, other areas can be added. This includes areas for reception, packaging and consolidation, dispatch, recharging forklift batteries, as well as loading docks. In turn, a warehouse can be divided into sectors according to the product being handled or the work operations. The following diagram illustrates an example of an advanced and complex warehouse (Figure 17). The legend is as follows: (1) Office and customer services, (2) Loading and unloading docks, (3) Reception and verification, (4) Dispatch, (5) High turnover or over-sized product, (6) High turnover picking off pallets, (7) Odd-shaped products, (8) Medium turnover

components, (9) High turnover components, (10) Low turnover components, (11) High-value products, and (12) Packaging and consolidation.

Figure 18: Typical advanced warehouse

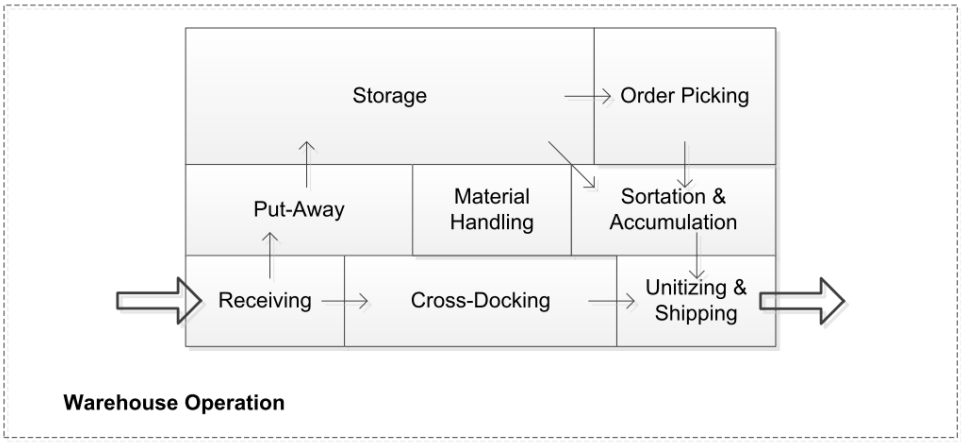


Source: Interlake Mecalux (2020)

The basic requirements in warehouse operations are to receive Stock Keeping Units (SKUs) from suppliers, store the SKUs, receive orders from customers, retrieve SKUs and assemble them for shipment, and ship the completed orders to customers. There are many issues involved in designing and operating a warehouse to meet these requirements. Resources, such as space, labour, and equipment, need to be allocated among the different warehouse functions, and each function needs to be carefully implemented, operated, and coordinated to achieve system requirements in terms of capacity, throughput, and service at the minimum resource cost.

To fulfil these basic requirements, warehouses have a fundamental set of activities in common. These activities, and the flows between them, are presented in Figure 18.

Figure 19: Main Warehouse Operation



Source: Faria (2015)

Receiving consists in the orderly receipt of all materials coming into the warehouse, assuring that the quantity and quality of such materials are as ordered and disbursing materials to storage. Pre-packaging is performed in a warehouse when products are received in bulk from a supplier and subsequently packaged before storage. Put-away is the act of placing merchandise in storage. It includes the material handling, location verification, and product placement. Storage is the physical containment of merchandise while it is awaiting a demand. The storage method depends on the size and quantity of the items in inventory and the handling characteristics of the product or its container. Order picking is the process of removing items from storage to meet a specific demand. It is the basic service a warehouse provides for customers and is the function around which most warehouse designs are based. Packaging and/or pricing may be done as an optional step after the picking process. As in the pre-packaging function, individual items or assortments are boxed (and labelled) for more convenient use (Frazelle, 2002). Sortation of batch picks into individual orders and accumulation of distributed picks into orders must be done when an order has more than one item and the accumulation is not done as the picks are made. Packing and shipping are the final phase of warehouse operations. They usually include a check of the orders' completeness, preparation of the shipping documents, the accumulating of orders by outbound carrier and finally the loading of the transport vehicle.

As for cross-docking, it bypasses the storage activity by transferring items directly from the receiving dock to the shipping dock. A pure cross-docking operation avoids put-away, storage, and order picking. Cross-docking has become commonplace in warehousing because of its impact on costs and customer service. Eliminating the put-away of products reduces costs and the time goods remain at the warehouse, thus improving customer service levels.

Available to assist in the warehouse operations are numerous commercial Warehouse Management Systems. These computational systems help the warehouse manager to keep track of the products, orders, space, equipment and human resources in a warehouse, while also providing algorithms for storage location assignment, order batching or pick routing. Decisions regarding to the warehouse operation are mainly made at the operational level (very common and short-term decisions), but they are strongly influenced by the decision made at the tactical and strategic level.

5.5 Measuring Performance

The implementation of an appropriate Performance Measurement System (PMS) allows the dissemination of relevant information for decision making and for the implementation of actions and

also facilitates the transparency of communication between the various actors in the logistics system, stimulating cooperation between agents and, as a consequence, improving the global performance of organizations (Gunasekaran & Kobu, 2007).

There are numerous references in the literature on measuring performance within organizations, devoting themselves to assessing the performance of the various departments, management incentives or even the contribution of company employees (Schmitz & Platts, 2004). However, the number of detailed academic studies deepening the theme of performance measurement in the relationships and interactions between organizations and their suppliers and outsourcing partners is limited, particularly in the context of logistics.

According to Gunasekaran (2007) and Parker (2000), measuring performance in an organization should make it possible to:

1. identify success;
2. identify whether customer needs are being met;
3. assist the organization in understanding the processes it adopts and in confirming the realities it knows or revealing those it does not know;
4. identify where problems, limitations or waste occur and where improvements should occur;
5. ensure that decisions are based on facts, instead of assumptions, emotions, intuition; and
6. reveal whether the planned progress has taken place.

The importance of measuring performance is unanimous both in the academic community and in the business community. However, some authors point out that performance measurement when not properly guided can give rise to a myopic view of reality, focusing on only a few aspects, those evaluated, distorting the broad view of the whole, that measurement systems of performance should stimulate (Schmitz & Platts, 2004). A determining aspect for the proper functioning of performance measurement systems is related to the clear and unambiguous identification of its objective (function or purpose) in the organizational context in which it is inserted.

The literature brings together a variety of recommendations regarding good performance measurement practices. Maskell (1991) suggests seven principles by which the construction of performance measurement systems should be guided:

1. The performance measurement system must be aligned with the company's strategy
2. Non-financial measures must be taken
3. The measures adopted must be different between departments and companies
4. The measures adopted must change according to the context and circumstances
5. The measures adopted must be simple and easy to understand and use
6. Measures taken should provide immediate feedback
7. The PMS should encourage continuous improvement

Kasilingam (1998a) points out that the basic criterion that must underlie any performance system is simplicity. The same author argues that performance systems should consist of simple performance measures or indicators in terms of measurement, calculation and interpretation. To simplify the measurement of performance, the author stresses that the available information should be used that is easily accessible. This requirement is even more important in the specific case of logistics given the interdisciplinary nature of the interaction of the different actors involved in logistics (transporters, stockists, authorities, etc.), which consequently leads to information sharing. Regarding indicator systems, and in order to make their use more efficient, the author argues that the number of aggregate measures should be as small as possible. Kasilingam (1998b)also states that measures of a similar nature applicable to different activities must equally be compatible with each other. For example, when defining the productivity indicator for storage activity, it is essential to define in the metric in relation to which output one intends to measure productivity, whether in relation to monetary value or in relation to the hourly period. The metric should be reproduced in the same way as other logistical activities.

Beamon (1996) presents four characteristics that PMS must fulfil in order to achieve their greatest efficiency and which, in turn, allow assessing the quality of the systems:

1. Comprehensiveness - measurement of all relevant aspects of the reality under analysis
2. Universality - allow the use of performance indicators in different operating conditions
3. Measurability - the data needed to build performance indicators must be measurable
4. Consistency - performance indicators must be compatible with the organization's goals

The author also argues that in the evaluation of performance measurement systems, the benchmarking method proves to be very useful, as it allows identifying opportunities for improvement. The performance measurement systems are structured in terms of Key Performance Areas (KPA) and Key Performance Indicators (KPI). KPA can be understood as general thematic areas for which it is relevant to measure performance. The performance of a KPA is assessed using a set of KPIs. Hence, the choice of KPI is fundamental to ensure the efficiency and effectiveness of the PMS. In order to help the selection of KPIs, the following question can be followed:

- What to measure?
- How to measure?
- How should the various performance indicators be integrated into a single PMS?
- What is the measurement frequency?
- How and when should the PMS be re-evaluated?

Below is a list of selected KPIs grouped by KPA. The KPAs were defined according to the functional areas of Figure 3 (Glover, 2020; Sunol, 2019; Weiss, 2018):

1. KPA 1: Receiving - warehouse operations begin with this process, and any inefficiencies at this location will have a cascade effect through all the subsequent processes.
    a. KPI 1.1: Cost of Receiving Per Receiving Line: the expense that the warehouse incurs on the receiving process of each receiving line. This includes handling costs as well.
    b. KPI 1.2. Receiving Productivity: Determined in terms of labor by measuring the volume of goods received per warehouse clerk per hour.

c. KPI 1.3. Receiving Accuracy: Percentage of accurate receipts, i.e. the proportion of correctly received orders against purchase orders.

d. KPI 1.4. Dock Door Utilization: Percentage of how many of the total dock doors were utilized.

e. KPI 1.5 Receiving Cycle Time: The time taken to process each receipt.

2. KPA 2: Put-away - Once goods are received, the process of put away begins with placing each item at a designated location selected for most convenient retrieval. Effective put away ensures a smooth picking process, thus significantly reducing lead time.

    a. KPI 2.1. Put away Cost Per Line: Expenses incurred for putting away stock per line, including labour, handling, and equipment costs.

    b. KPI2.2. Put away Productivity: Volume of stock put away per warehouse clerk per hour.

    c. KPI 2.3. Put away Accuracy: Percentage of number of items put away accurately at the designated location.

    d. KPI 2.4. Labour and Equipment Utilization: Percentage of the labour and material handling equipment utilized during the put-away process.

    e. KPI 2.5. Put away Cycle Time: Total time taken during the entire process of each put-away task

3. KPA 3: Storage – this refers to one of the core purposes of any warehouse. To temporary storage goods for future dispatch. Indeed, warehouses serve as buffers to accommodate differences between inbounding and out bounding freight flows.

    a. KPI 3.1. Carrying Cost of Inventory: The cost of storage over a particular span of time, including the cost of inventory, capital costs, service costs, damage costs, and costs of obsolescence. The longer the stock stays in storage, the higher the cost to the warehouse.

    b. KPI 3.2 Storage Productivity: Volume of inventory stored per square foot.

    c. KPI 3.3 Space Utilization: Percentage of space occupied by inventory out of the total space available for storage.

    d. KPI 3.4 Inventory Turnover: The number of times the entire inventory passes through during a period of time.

    e. KPI 3.5: Inventory to Sales Ratio: Measure of stock levels against sales. This helps managers identify monthly increases in inventory against falling sales.

4. KPA 4: Picking & Sorting – picking and sorting processes are responsible for fulfilling order dispatch. Order picking is one of the more complex of activities in a warehouse. An incorrectly picked order means returned items and paying to correct the mistake. These processes have a high impact in logistics costs and customers' satisfaction.

    a. KPI 4.1. Picking Cycle Accuracy: percentage of orders correctly picked up per task.

    b. KPI 4.2: Pick up Cycle Time: total time taken during the entire pick up process.

c. KPI 4.3. Labour and Equipment Utilization: Percentage of the labour and material handling equipment utilized during the picking and sorting processes.

5. KPA 5: Cross Docking – crossdocking is the process of breaking down a large shipment (e.g.: arriving truck) into smaller shipments and/or combining shipments for delivery (e.g. departure trucks) within a reduced window time. Such operations require perfect synchronisation between arrival and departure times of the various trucks and availability of warehouse resources.

    a. KPI 5.1. Cross-docking Cycle Accuracy: percentage of orders correctly transferred per cycle.

    b. KPI 5.2: Cross-docking Cycle Damage: percentage of orders damaged during transfer.

    c. KPI 5.3: Cross Docking Cycle Mislabelling: percentage of orders that are incorrectly labelled at the warehouse.

    d. KPI 5.4: Cross-docking Cycle Time: total time taken to move goods from arriving truck to departure trucks.

    e. KPI 5.5. Labour and Equipment Utilization: Percentage of the labour and material handling equipment utilized during the cross-docking processes.

6. KPA 6: Shipping & Distribution – As the roles and responsibilities of warehouses expand with the growth of always-on supply chain, the added function of distribution exerts additional pressure on warehouse management.

    a. KPI 6.1. Order Lead Time: The average time taken by an order to reach the customer once the order has been placed. This is one of the most crucial KPIs for warehouses and distribution centres.

    b. KPI 6.2 Perfect Order Rate: Number of orders the warehouse delivered without error. It indicates the success rate of the warehouse/distribution centre.

    c. KPI 6.3 Back Order Rate: The rate at which orders are coming in for items that are out of stock. There are situations wherein unexpected spike in demand causes this. However, if this rate is consistently high, it is an indication that there are lapses in planning and forecasting.

    d. KPI 6.4 Rate of Return: The rate at which goods, once sold, are being returned. This is most effectively used when segmented by reason for return.

5.6 Challenges & Recommendations

Warehouses profoundly impact the performance are the logistics networks. They offset imbalances in incoming and outgoing flows, provide an opportunity to add value to goods or satisfy unpredictable variations in demand (downstream). Nowadays, warehouses are moving towards a more integrated approach within the logistics chain that supports transparency and visibility for the warehouses, logistics partners and consumers. Key challenges impacting warehousing include inventory accuracy, inventory location, space utilization/warehouse layout, redundant processes, and picking optimization. These challenges define the way logistics systems and warehouses will evolve in the future.

Although the warehouse of the future cannot be predicted, the likely evolutions based on emerging trends and technological evolutions can be anticipated. As such, key properties that will likely be part of the warehouse of the future include (Blanchard, 2013; 2020; Glynn, 2020):

- *Robotization and automation of warehousing processes*. Increasingly robots are being used in warehouses. Nowadays, robots work along with humans; but we are already seing automated warehouses, in which all (or the vast majority) of the processes are done by robots. By way of example, Amazon has several types of robots currently operational within its warehouses including palletisers, robotic arms with grippers; robo-stow, a robotic arm which lifts pallets to different levels within a fulfilment centre or places them on drive units to be carried to their destination; and drive unit - a robot unit that can transport packages around the fulfilment centres.

- *Automation as a service* in which customers deploy automation on an as needed basis.

- *Artificial Intelligence* is another increasingly relevant technology. Artificial Intelligence can help optimise several KPIs, such as order accuracy, fulfilment time or inventory accuracy. It can also be applied in more general tasks such as safety, productivity or facility damage. By analysing aggregated data from various information systems within the warehouse, Artificial Intelligence can be used to automate tasks and decision-making.

- Artificial Intelligence is supporting technologies such as *Machine Learning and Big Data Analytics*. These technologies can be applied to enhance demand forecasting, inventory location planning, stock demand value, risk reduction, response to supply chain issues, or optimization of picking, storage and more.

- *Augmented Reality (AR) and Virtual Reality (VR)* are two technologies that will likely be part of any warehouse in the future. AR technology can be used to increase the efficiency of the picking process and reduce on-the-job training needs; whereas VR technology can improve the safety and efficiency of the delivery process. VR can also enhance secure delivery and identity verification through facial recognition technology and other advances.

- *On-demand warehousing* is a concept that lets companies with excess warehouse capacity fill their space and provides sellers with temporary or seasonal storage needs to find space without entering into a long-term contract (a kind of Airbnb for logistics).

- *Multi-modal optimisation* through seamless integration with vendors, logistics providers and other supply chain partners, allowing for sophisticated planning across regions, routes, modes of transport and more to easily achieve lead time and cost goals.

- *Drone and Unmanned Arial Vehicles* are also likely to have a role in the warehouse of the future. These vehicles can carry goods in-between places and perform ancillary tasks (such as location of goods).

- *Large scale and advanced sortation systems* to sort parcels in (very) large warehouse. These systems are costly but have superior productivity. They are already being leveraged by some warehouses, and the adoption of these technologies will likely continue to grow for the highest volume largest retailers in the world.

Warehouses have played an integral role in the logistics chains for decades and they are expected to gain increasing relevancy in the coming future. The future looks bright for the industry as innovative,

forward-thinking technologies pave the way for the warehouse of the future by embracing the latest advancements in technology.

Given the abovementioned trends, the following recommendations can be formulated:

- Support smart warehousing and automation investments.
- Strengthen warehouse-port-hinterland integration.
- Promote warehouse digitalization through interoperable WMS platforms.
- Develop multimodal logistics hubs and inland distribution centres.
- Create KPI-based benchmarking systems for warehouse performance

6. Digital capacity

Ever since the coining of paperless office in the 1980s, digitization is seen as the way forward for almost all processes. As a result, today, we are more connected with each other than ever before. The outbreak of Covid-19 (and its variants) and the resulting social distancing has forced even the most reluctant of us to embrace digital methods of connecting. It also showed the limits of our current infrastructure. This section will discuss the presence, impact and barriers for digitization in ports, followed by recommendations for policymakers to be able to smoothen the path. First, a definition of digitization is presented, followed by relevant indicators to assess digitization. Next, a short discussion on the status is given, followed by future challenges and recommendations.

6.1 Definition:

Here, digitization is considered in the broadest sense; it includes (on-line) procedures, autonomous equipment and infrastructure to support this. Different digitization levels can be found over time: Paperless (started in the 80s), Automated (started in the 00s) and Smart (started in the 10s) (Heilig et al., 2017a)

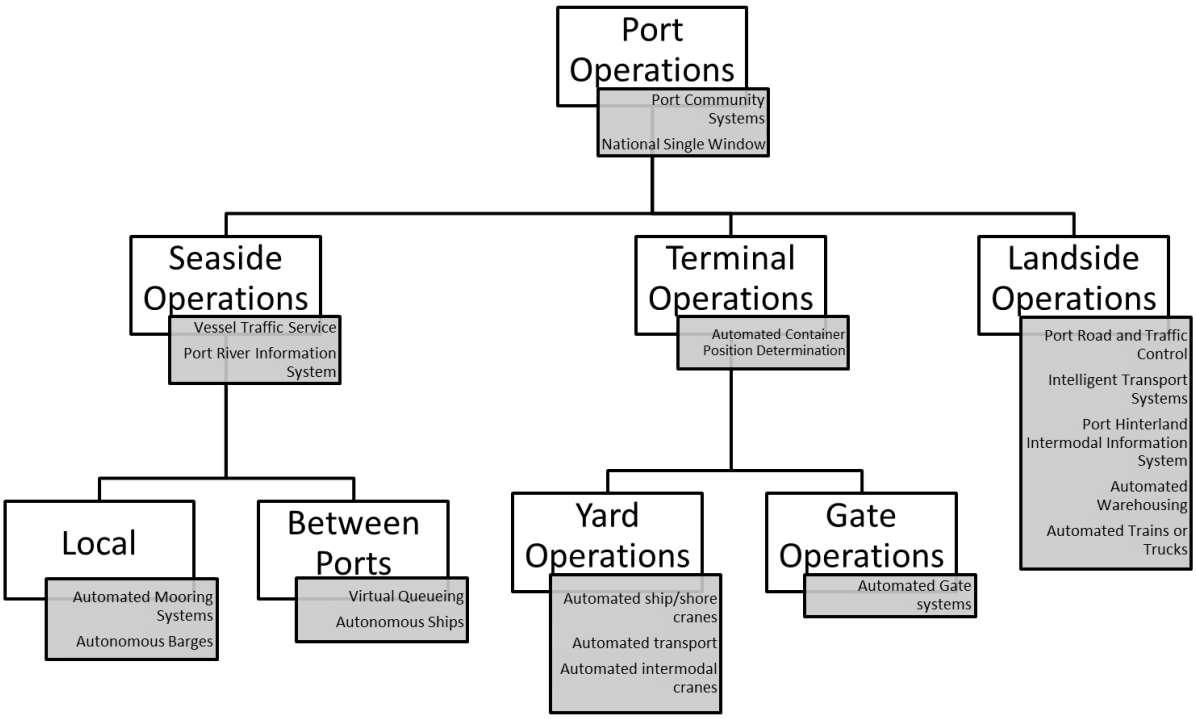
6.2 Who and how?

The potential impact of port digitization on the economy is significant. A study by Jun et al. (2018a) estimates an impact increase of 15-30% for smart ports compared to regular ports. Hence further digitization of procedures and equipment is something to strive for as a port, and as a country as the benefits reach far beyond the port itself.

On the other hand, digitization in ports seems to be discussed far less than digitization in the ships' design, production and operations. In a recent study, it was discovered that 51% of the papers on this subject related to design and shipbuilding, 36% related to shipping only 13% considered ports (Sanchez-Gonzalez et al., 2019). The lack of research might be linked to the fact that most research in this field is production-based, focusing on increasing the output, whereas for ports research into the business processes might be more relevant (Saragiotis, 2019).

Another note to make is that terminals were not considered as part of the ports in the research of Sanchez-Gonzalez et al. (2019). This is strange as there is a lot going on in and around terminals when considering digitization as defined for this policy paper. Especially the container terminals as a crucial part in much larger logistical chains (Anwar, 2019; Fruth & Teuteberg, 2017; Heilig et al., 2015; Heilig & Voß, 2017a, 2017b, 2017c; Sarabia-Jácome et al., 2020).Their work is summarized in the figure 20, showing the identified equipment and procedures for digitization in ports found in literature.

Figure 20: Overview of digitization aspects in Ports



Source: own composition based on (Anwar, 2019; Fruth & Teuteberg, 2017; Heilig et al., 2015; Heilig & Voß, 2017a, 2017b, 2017c; Sarabia-Jácome et al., 2020)

As indicated in section 2, different levels of digitization might occur for the same equipment or procedure. To give an example, the National Single Window is discussed. This is a single point of contact for all administrative aspects of a port call, e.g. a website, could simply be collecting all the information at the paperless level. Every related organization, such as pilot services, customs, tugboats, port authorities, can access this information digitally and contact the owner in another paperless form, such as e-mail. For the second level, the website will actively inform these organizations and require them to provide their input via the same website or portal. This requires further integration and speeds up the process as information between organizations can now also be shared without going via the owner. The portal or website will not ask the organizations for input at the highest level. It will be fully automated, ensuring that with limited input, the owner is offered all relevant services and once selected, these services are planned accordingly. The organizations partaking in this portal will deliver the services and review the process.

Another example from the equipment side would be interterminal transport (Heilig, Schwarze, et al., 2017; Nieuwkoop et al., 2014; Xin et al., 2013; Zheng et al., 2017). Much inter-terminal transport in a port area is performed by trucks, rail and sometimes inland barges. In the more productive ports, this is to a large extend a paperless process already. However, there is room for automation of either trucks, rail locomotives or inland barges performing these transitions, especially as the operational area is limited. A final step would be to automate the transport and the selection of transporters and containers to transport using AI .

Most of the digitization discussed so far will be initiated by the companies operating in the ports. However, the port authorities themselves can stimulate this through two crucial roles. The first is to ensure suitable legislation to support the transition to the next level is in place. The second is ensuring the required infrastructure is there. As for the infrastructure, the general wireless options of Wifi, GSM/4G/5G, Satelite, GPS, RFID and RTLS are important for the data transmissions. Out of these, especially 5G has a lot of interest (Zeebrugge, 2020; EU, 2019; MoNArch, 2019). Of these recent interests, the MoNArch project shows a nice set of use cases covering vessels, road traffic control and advanced connectivity. However, an aspect often overlooked is the fact that all these systems do not only require data but quite often also use a lot of energy; as for reliability, autonomous systems tend to have electrical drives and not internal combustion engines (Xin et al., 2013). A matter to be addressed by ports to ensure both data and energy infrastructure.

6.4 Future challenges

Although the previous section already ended with three challenges for ports (legislation, data infrastructure, energy infrastructure), there are many more general challenges to consider with digitization as well. The first is cyber security. A series of cyber-attacks, of which the first to make the news was an incident with Maersk in 2018 (SAFETY4SEA, 2018). It showed the impact of a cyber-attack on the logistics of a large logistics provider; many more have followed unfortunately. Ships were floating idle, terminals were inoperable and even though it was short lived, and the impact was very large in terms of costs. Fruth and Teuteberg (2017) also mention that cyber security is one of six key challenge for digitization.

Besides security, the integration of digitization should be given attention. The success of the port is strongly linked to the integration of effort. Especially the integration of the port and companies strategies (Heilig, Schwarze, et al., 2017). A shared digitization strategy is key in this aspect. However, due to the increasing complexity of such networks the direct monetary effects of these coordinated actions and investments may be difficult to discern in the short term.

Finally, and most likely, the most crucial aspect of digitization is accepting the solutions by all stakeholders. This is very slow to build up, and with, the large diversity in stakeholders in a port, also difficult to address. The biggest risk is the delivery of a solution no one is using.

6.5 Recommendations

To ensure, the successful advancement of digitalization, several key actions are recommended.

- Acceptance and stakeholder engagement: A critical factor in the success of digital initiatives is the acceptance by all stakeholders involved. This can be fostered through targeted training programs, workshops, and early, broad involvement of relevant actors. By actively engaging stakeholders throughout the development and implementation phases, the likelihood of adoption and effective use of digital solutions is significantly increased.

- Strategic alignment: Develop common and comprehensive strategy (using provided KPI and overview, where do you want to be, which level, define further than KPI currently does).

- Take the lead in infrastructure, and integration: create an enabling environment that supports seamless data exchange and coordinated operations.
- Support digital development within and between companies: Encouraging collaboration, knowledge sharing, and joint innovation efforts will help accelerate the transition toward more advanced levels of digitization.

7 Regulatory and institutional aspects

7.1 Context

In the 21st century, the institutional and market environment surrounding ports is determined by five forces (Porter, 1990) that shape the landscape where governments, port authorities and port services providers interact. These are:

- The rivalry among existing competitors.
- The threat of new competitors.
- The potential for global substitutes.
- The bargaining power of port users.
- The bargaining power of port service

Irrespective of size and management model, these forces impact in all types of ports, condition the requirements for their development, and put pressure on the port capacity to attract and retain customers. Different types of ports have a differentiated impact on the local economy. The port is often a driver of the local economy; good examples are the European biggest Ports of Rotterdam and Antwerp-Bruges-. According to the World Bank (PPIAF.org/toolkit), the Port of Rotterdam created, over the past decade, more than 45.000 man-years in temporary employment and 17.500 man-years in permanent employment in the Netherlands. Paradoxically, although the strategic decision of placing a port in the supply chain is a government (national or regional) decision, the dynamism of the respective supply chains determines the port's success. Many changes have occurred in the last decade in port development, namely in the port operation business, in the diversity of stakeholders involved, in the complexity of the logistics chain, in the new technologies enabling significant gains in port efficiency.

The complexity of the supply chain, not independent from globalization, influences the distribution patterns and the international hierarchy of ports. It is thus a fundamental policy aspect, in any country, to define the strategic objectives to be achieved and what are the processes supporting them. Over the years, world economies have become more interactive due to increasing trade and growing globalization. Most countries have seen an increase in trade and exports as a share of GDP, and there has been an increase in vertical specialization (World Bank, 2017, WPS 7978).

Moreover, environmental and sustainability targets, and safety and security concerns lead the ports to impose regulations and provide a level of services in facilities that may never be paid back from commercial returns.

7.2 Definitions

To clarify the scope of this section, two concepts need to be defined: policy and institutional setting. Both wrap up all governance and regulatory decisions and actions in the port sector.

Policy

Policy is not an abstract outcome, at the opposite is a particular strategic purpose of action. Any purpose of action regarding a port or a port system is conditioned by the position aimed by that port(s) in the supply chain, and its role as a main player in exports and imports for a country and/or region.

Policymaking targets the future, either as a reaction to some particular outcome or proactive action to achieve a specific objective. Consequently, policy-making always takes place in conditions of uncertainty, flux, unpredictability and variation (Parsons, 1995) to serve distributive, redistributive, regulative and constituent purposes (Lowi, 1964). This is the main characteristic that enforces the

utilization of a continuous monitoring and feedback channels so that policies can be permanently assessed and adjusted as required in the path and sometimes also in the objectives.

Institutional setting

North (1990) defined institutions as "the rules of the game in a society, or, the humanly devised constraints that shape human interaction". A similar but extended definition is provided by Alexander (2007), who defines institutional design as the devising and realization of rules, procedures, and organizational structures that will enable and constrain behaviour and action to accord with held values, achieve desired objectives, accomplish set purposes or execute given tasks. By this definition, institutional design is pervasive at all social deliberation and action levels, including legislation, policymaking, regulation, planning and program design, and implementation.

Many scholars provide classifications of the institutions based on various attributes, such as formal and informal institutions (North, 1990), slowly and continuously ("slow-moving" – technology and culture, including values, beliefs and social norms) or rapidly and irregularly ("fast-moving" – political institutions) changing (Roland, 2004), etc. According to our perception, the classification of technology in the slow-moving institutions needs further discussion, and a deeper analysis of inner dynamics of the institutional setting.

The next step of institutional analysis is the identification of arrangements among institutions. Williamson (2000) provides a contextual framework of the institutional design issue, which we present in Figure 10. Although, it tackles the issue from a broader perspective than usual transport-related analyses, we consider it constitutes the appropriate base for this paper's analysis. Furthermore, the hierarchy and feedback elements of the system are also important since higher levels impose constraints on lower levels and lower levels ''feedback'' to higher levels to provide adaptation to (Stone, 2008). Under this approach, the element of regulation is contextually positioned primarily in the rules of the game, governance and levels of resource allocation.

Figure 21: Economics of Institutions

	Level	Frequency (years)	Purpose	Theory
L1	**Emdeddedness:** *informal institutions, customs, tradition, norms, religion*	100 to 1000	Often noncalculative; spontaneous	**Social theory**
L2	**Institutional environment:** *formal rules of the game, esp. property (polity, judiciary, bureaucracy)*	10 to 100	Get the institutional environment right. *1st order economizing*	**Economics of property rights / positive political theory**
L3	**Governance:** *Play of the game, esp. contract (aligning governance structures with transactions)*	1 to 10	Get the governance structures right. *2nd order economizing*	**Transaction cost economics**
L4	**Resource allocation and employment:** *(prices and quantities; incentives alignment)*	continuous	Get the marginal conditions right. *3rd order economizing*	**Neoclassical economies / Agency theory**

Source: Williamson, 2000

Concerning transportation, a significant part of authors uses a more focused definition of institutions, referring primarily to the formal actors that influence the "game" and corresponds to the governance level (L3) of Williams´ framework. In contrast, the formal rules of the game (L2) are usually referred to as legal and/or regulatory environment that complements the institutional setting it formulates and supports. Decision-making also plays a vital role in institutional arrangements, whilst the structure of the decision-making process (centralization, state intervention) is a strategic characteristic that can influence and, to an extent, impose the features of the decision-making process (i.e., interest group influence, conflict resolution, knowledge and information availability etc) (Zografos et al., 2009).

The regulatory landscape and settings.

The regulatory landscape defines the setting where the different economic agents move and interact with the various public entities, like economic and technical regulators. It should give a clear snapshoot of who does what in a particular context (e.g. city or region or sector) and that transparency is a critical element to provide trust to all agents interacting in the field.

The regulatory setting varies significantly across countries, but the largest and most relevant commercial ports are public owned and managed by Port Authorities on a regime of concession (mostly managed by private companies) or based on a management contract (mostly the case of public management). Port Authorities are in any case subordinated to Economic and Technical Regulators although they enjoy a significant measure of regulatory powers related to port activities. The contractual instrument that materializes the partnership is rather complex and can have several formulations for the risk sharing. Today contractual regimes are a science of its own with numerous learning cases of success and failure, with incentives and penalties adjusted to the configuration and underlying regime of the contract and terms of the concession.

It is thus fundamental to have a clear view of the regulatory and institutional setting in which each port is embedded, so that the best instruments are used for incentives and penalties to boost port performance, and for private investors to understand their opportunities and risks, the major always being the situation of lack of control (Ostrom, 2005), which are, unfortunately, not as rare as desirable.

As often highlight by Ostrom (ibidem) trust is by far the main requisite for a good regulatory and institutional relationship between Port Management, Authorities and Economic and Technical Regulators, as Ports are the type of infrastructure with heavy sunk costs and long-life cycle. Relationship trust is a critical aspect for investors, given the uncertainty always associated to future scenarios and to the instability of public policies, consequence of rotational politics and electoral processes.

However different, and not to be confused is the fact, that some countries, like UK, use the same word to designated business oriented Ports, that own themselves, which is a concept within the private spectrum of possible Port ownership, where all profits are returned to the Port as reinvestment for the development of its own business, also for the benefit of the Port value, and as such of the stakeholders (www.britishports.org.uk, no date)

In the European Union, Member States are required to notify the European Commission regarding the handling of complains and the definition of (Articles 16 and 17 of Regulation (EU) 2017/352 of the European Parliament and of the Council of 15 February 2017) which establishes a framework for the provision of port services and common rules on the financial transparency of ports. In Europe a total of 329 seaports is integrated in the Trans-European Networks for Transport, including transport of freight and passengers, all subordinated to the EU regulatory rules of competition, safety and security, transparency, etc.

Institutional change

From a public policy perspective, North (1993) identified five propositions on institutional change:

1. The continuous interaction between institutions and organizations in the economic setting of scarcity and hence competition is the key to institutional change.
2. Competition forces organizations to continually invest in skills and knowledge to survive. The kinds of skills and knowledge individuals and their organizations acquire will shape evolving perceptions about opportunities and hence choices that will incrementally alter institutions.
3. The institutional framework provides the incentives that dictate the kinds of skills and knowledge perceived to have the maximum pay-off.
4. Perceptions are derived from the mental constructs of the players.
5. The economies of scope, complementarities, and network externalities of an institutional matrix make institutional change overwhelmingly incremental and path dependent.

How these propositions are implemented in the port sector depends on the country context and institutional design (centralized, decentralized, etc) and cannot have a one-fits-all solution (Macário, 2010).

Therefore, any preparation of port institutional reform encompasses (World Bank, 2007):

- Identifying the critical public functions and public responsibilities that will define the role of the national and local public authorities in charge of the port sector.
- Identifying the assets needed to support each function and category of service, assessing the adequacy of these assets, and determining which services and related assets to package together and which among these to tender to private investors or operators.

7.2 Indicators and key questions

Indicators for policy monitoring and regulations are related to the effectiveness and efficiency of achievement of objectives strategically defined (i.e. the purpose of action). The most complex aspect of policymaking is the fact that for the same problem many solutions can be proposed leading to identical merit results but following different, and even opposite, streams of thought or philosophical stance. The time horizon considered is a critical issue, and good and popular outcomes in the short term can turn into disastrous results and impacts, in medium and long term respectively.

There is a wide diversity of typologies of indicators in the literature. To support the rationale presented herewith, the following typology is adopted:

- Resource indicators, which cover the inputs used by the system, providing information on the financial, human, material, organizational and regulatory means used, and also the ones left available for future use;
- Process indicators, which cover the efficiency and effectiveness of the processes organized to transform inputs into outputs;
- Output indicators, which cover the outcomes obtained;
- Result indicators, which measure the advantages for the beneficiaries and for the offended, that is winners and losers of any action or policy;
- Impact indicators, which represent the anticipated consequences beyond the direct and indirect effect over the ones affected by the system. These indicators should contemplate positive and negative impacts and, whenever possible (on an ex-post basis), should also cover unanticipated impacts that are spin-offs of the system evolution. Besides, special care should be taken to ensure compatibility and avoid redundancies with previous indicators.

In the other sections of this paper, operational indicators will be illustrated for these categories.

7.3 Who and how?

The World Bank (2007) recommends a set of key questions to lead the process of defining a purpose of action (i.e. a policy) for the Port sector taking into consideration the local specificities, the institutional setting, and the desired strategic placement in the international supply chains for different products. Following the World Bank (2007) and Notteboom et al (2022), these are :

Rivalry among Existing Competitors

- Which other ports have access to my hinterland market?
- Is future supply and demand for port services in the region expected to be in balance?
- Are competing ports able to absorb losses through cross-subsidizing services?
- Who has the greatest stakes at risk in maintaining and growing traffic volume?
- Where do we have a comparative advantage over our competitors?
- What actions can we take to attract and lock in customers?

Threat of New Competitors

- Are new ports being planned in the region that potentially access my market?
- What is the status of these plans and the likelihood the project will proceed?
- Will changes in distribution patterns create a new form of competitor?
- What actions can we take to minimize the impact on our existing market base?
- Which other companies are potential service competitors in the port?
- Can switching costs and other barriers be created to prevent market entry?

Potential for Global Substitutes

- Are there other sources for products being exported through our port?
- Have ultimate users of cargo through our port the ability to use substitute products?
- Can manufacturers and assemblers be shipping through the port shift to other sites?
- Are there potential developments that could impact the ability to substitute globally?
- How significant is port cost in determining the market competitiveness of port customers?
- What barriers or incentives can prevent port customers from switching products or sites?

Bargaining Power of Port Users

- To what degree do individual port users control traffic through the port?
- What is the potential for business realignments or alliances among customers in our ports
- How would these realignments or alliances change their bargaining power?
- To what extent can the services provided by our port be replicated elsewhere?
- What are the bargaining strengths and weaknesses of the port and port users?
- How can the port's bargaining strength be improved?

Bargaining Power of Service Providers

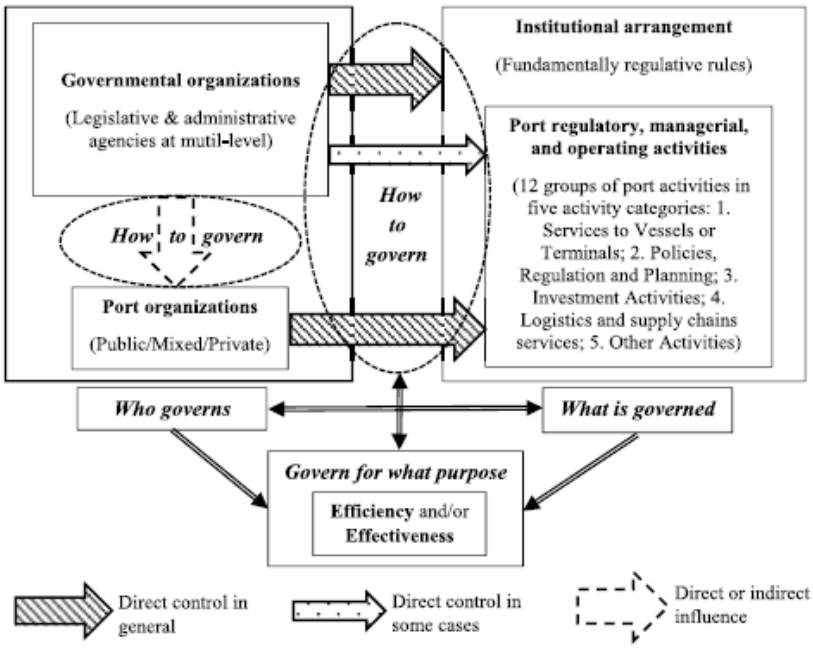
- Which service providers are potential choke points in the port?
- What options are available to the port if negotiations with specific service providers fail?
- Has the service provider or port the greater capability to absorb port downtime?
- Does the service provider bring financing capability to negotiations with the port?
- Are there interrelationships between service providers and port users?
- What legal rights have been conveyed to the service provider by the port?

The most recent literature on port competition highlights the struggle between logistic supply chains (Notteboom et al., 2022) , a good successful example is provided by the ports in the Hamburg-Le Havre range, while at the opposite the Mediterranean ports have a more peripheral and less capable of confirming relevant position in important supply chains. The discussion over the five forces referred above will enable to define the ambition of each port concerning its position in the international

network (e.g. hub, relay, interline, etc) and where competition and cooperation should apply as the maritime sector is one of the most globalized industries

Since the 1990s, a lot of studies have been published about port governance, however, there is little consensus on its definition and scope. Within the main authors addressing this issue are Zhang et al (2018) who have identified governmental organizations and port organization trying to answer two questions - who governs, and what is governed? - (see Figure 21) and Zhang et al. (2019) who supplemented the previous by answering to how it is governed and for what purpose. Interesting analysis can be summarised from these studies in table 6, extracted from Zhang et al. (2019).

Figure 22: Relationship between the four basic questions of port governance



Source: Zhang et al., 2018 & 2019

Table 5: The main governance tools identified at institutional, strategical, and managerial levels)

Analytical level	Governance Level	General Description
Institutional level	Port Devolution	A part of a larger attempt by governments to apply New Public Management (NPM) concepts to the port sector. Governments devolve ports by transferring the port authorities functions to a lower level government or to a new entity.
	Port re-centralization	Unlike port devolution, the upper governments centralize the port administration through the legislation or government decrees.
Strategic level	Port co-opetition	The combination of port cooperation and competition.
	Port regionalization	Port regionalization represents an evolutionary stage in port development, where efficiency is derived with high levels of integration of inland freight distribution centers/intermediate hubs.
	Port Integration	Strictly speaking, port integration is one of the forms of port cooperation. However, compared with other forms of cooperation, integration means the closest partnership between cooperative parties. It usually manifests itself through mergers and acquisitions
Managerial level	Port Pricing	Port pricing mainly includes the design of port tariff structure and port service charges.
	Port concession	A concession is a grant by a government or port authority to a (private) operator for providing port services (normally cargo handling) within a limited period. The optimal concession contracts are determined by port authorities' goals to a great extent.

	Port user/ customer relationship management	Port user/customer relationship management refers to the principles, practices and guidelines that a port organization follows when interacting with port services users (e.g. shipping lines).
	Monitoring and measuring	Monitoring and measuring is a continuous assessment process that helps improve port performance and achieve expected results.
	Regulatory control	Regulatory control is a mandatory tool used to establish a stable framework to guide the port activities in a transparent, predictable, and accountable manner.
	Port security management	Port security management mainly aims to ensure the port operational safety by various means, such as a security plan for ships and port facilities, etc.
	Information and Communication Technologies (ICTs)	In port governance sector, ICT is applied in the form of information systems in port operations.

Source: own composition based on Zhang et al. (2019)

7.4 Future challenges

"*We are living in a VUCA World*". The sentence is well known among businesspeople. VUCA is the acronym of Volatile, Uncertainty, Complex and Ambiguity. It represents the fundamental dynamic and properties of today's world. These characteristics present how organizations view their current and future state. They present boundaries for planning and policy management. The four traits come together in ways that either confound decisions or sharpen the capacity to look ahead, plan and move ahead (Macário, 2005). The current pandemic situation is a paradigmatic evidence of such a situation.

This also means that forecasting and anticipation are increasingly complex and unrealistic, calling for different approaches, such as plausible futures or scenario analysis. Regardless, five underlying megatrends may be identified, being:

i) demographics and social changes (e.g., unbalanced population dynamics, shortage of qualified human resources, shifting in demand, or new geographies with rise of mega and middleweight cities),
ii) resources scarcity (e.g., need for alternative energy sources and vectors, need of reduce energy & water consumption, different environmental protection regulations and contexts, or fluctuations in prices of energy, raw materials and products),
iii) inequalities (e.g., concentration of wealth leads to profound changes in power, unemployment faced by many professionals irrespective of geography or education due to automation, wages are decreasing in many regions, or access to education and health services is a privilege in many regions),
iv) volatility, scale and complexity (e.g.; time compression, ubiquity, lower costs, raise of AI, or automation and robotics), and
v) enterprising dynamics with new business models – shared economy, digital based, social driven –reshaping how businesses work, and new, agile start-ups defying incumbents.

Figure 23: VUCA Categories



Source: https://hbr.org/2014/01/what-vuca-really-means-for-you

Currently (2024) port market sector is characterised by fast paced technological development, growing connectedness, scale, and convergence between the physical and the digital. Challenges are as never before, emerging and revolving chaotically, and evolving at an unprecedented rate. The stakes are peaking bright, unique solutions to unravel complexity and bring sustained competitive advantage that are needed. Several aspects are reported in the literature as main concerns in the domain of port policy and governance. Herewith, the most relevant to frame a policy decision are selected (Acciaro et al., 2018), being:

- Potential retreat globalization;
- Digitalization;
- Security;
- Foreland port competition;
- Labour disruptions;
- Interaction with other modes of transport;
- Environmental issues;
- Flexible capacity expansion.

Depending from where the analyst stands, these issues will have a different impact over two main axles of policy definition, being the port placement in the international network and the degree of decentralization in port policy and governance. The Port Reform Toolkit is a remarkable tool to guide reforms of public institutions regulating port services in developing countries. However, there is now the need to develop a new tool with the aim of guiding Port strategies and policies in the globalized environment. Research must pursue this avenue is straight collaboration with Port Management at different stages of development.

8. Port supply chain: how to ensure sufficient capacity?[5]

The TransportNET policy paper aimed to answer the question 'port supply chain: how to ensure sufficient capacity?'. Under the term 'sufficient capacity' is understood the combination of physical, digital, institutional and social elements that enable the maritime supply ecosystem to function efficiently, reliably and without major interruptions or severe delays. Capacity can be viewed from two complementary perspectives: (1) the capacity currently available within the system and (2) the maximum capacity that can be achieved through improved utilisation, coordination and optimisation of existing resources.

Answering this question before the covid19 era, the debate on accommodating growth and facilitating a modal shift towards more sustainable transport modes such as rail and inland waterways. Capacity expansion decisions at ports were frequently driven by throughput growth expectations, while the ability of hinterland transport systems to absorb additional flows was often insufficiently considered. The disruptions experienced in global supply chains, including congestion at major gateway ports and their hinterland networks, demonstrated that capacity must be assessed at the level of the entire supply chain rather than at individual nodes alone.

In the post-pandemic context, the emphasis has shifted from expansion alone towards prioritisation and resilience. Key questions concern the identification of bottlenecks, the most effective allocation of resources, the feasibility and desirability of new investments, and the optimal balance between infrastructure expansion and the more efficient use of existing assets. Capacity planning should therefore not only focus on accommodating demand growth, but also on improving system robustness, flexibility and sustainability.

The analysis conducted throughout this policy paper demonstrates that ensuring sufficient capacity in European port supply chains requires a systemic perspective. Capacity is not merely a question of port infrastructure. It is determined by the performance of interconnected physical, digital and institutional components, including terminals, hinterland transport networks, warehouses, information systems and governance structures. As in any supply chain, overall performance is constrained by its weakest link.

Three overarching policy conclusions emerge from the analysis.

First, ports should no longer be treated as isolated infrastructure assets but as nodes within integrated maritime and logistics ecosystems. Investments in port infrastructure must therefore be coordinated with investments in hinterland connectivity, warehousing, digital systems and regulatory frameworks.

Second, future competitiveness will increasingly depend on the ability to ensure seamless multimodal transport chains. Efficient rail and inland waterway connections, interoperable cross-border transport systems, advanced warehousing solutions and digital integration are essential to support sustainable growth and preserve the attractiveness of European ports.

Third, capacity expansion should be assessed simultaneously against resilience, competitiveness and decarbonization objectives. Infrastructure projects should not only provide additional capacity but also

[5] This section is based upon the outcomes of the 8th BNP Paribas Fortis Port Co.Innovation Café on the topic 'Integration of the maritime chain: it's all about capacity' (https://www.uantwerpen.be/en/research-groups/transport-and-regional-economics/bnp-paribas-fortis-chair/ - June, 16th, 2020).

strengthen the ability of transport systems to withstand disruptions, support modal shift objectives, and contribute to the European Green Deal and climate neutrality ambitions.

The recommendations presented in this paper can therefore be grouped around five complementary pillars:



Only an integrated approach combining these five dimensions will allow European ports to remain competitive, resilient and sustainable in an increasingly uncertain global environment.

While this policy paper identifies a set of practical recommendations for policymakers and industry stakeholders, important research gaps remain. Future research should focus on:

- Improved long-term port throughput forecasting under conditions of economic, geopolitical and climate uncertainty
- Developing integrated models of generalized transport costs that incorporate reliability and the value of time for different cargo categories
- Assessing the resilience benefits of alternative investments in ports, hinterland transport networks and logistics infrastructure
- Analysing the impact of digitalisation, automation and artificial intelligence on effective port and logistics capacity
- Developing methodologies to evaluate climate adaptation measures, including sea-level rise and extreme weather impacts on port infrastructure
- Improving performance measurement frameworks linking port–warehouse–hinterland transport systems
- Strengthening the empirical evidence base on port competitiveness through harmonised European datasets on costs, transit times, reliability and service quality

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