Proceedings of the Hamburg International Conference of Logistics (HICL) – 30

Nicole Nellen, Moritz Poeting, Kristina Bschorer, Carlos Jahn, and Uwe Clausen

Impact of Port Layouts on Inter-Terminal-Transportation Networks

Published in: Data science in maritime and city logistics
Carlos Jahn, Wolfgang Kersten and Christian M. Ringle (Eds.)
ISBN: 978-3-753123-47-9 , September 2020, epubli

Impact of Port Layouts on Inter-Terminal Transportation Networks

Nicole Nellen [1], Moritz Poeting [2], Kristina Bschorer [2], Carlos Jahn [1], and Uwe Clausen [2]

1 – Hamburg University of Technology, Institute of Maritime Logistics

2 – TU Dortmund University, Institute of Transport Logistics

Purpose: Major seaports consist of several terminals with different functions. The different locations of terminals in relation to each other influences the organization of inter-terminal transportation as well as transports into the hinterland. The focus of this study is to understand how terminals are arranged in relation to each other to draw conclusions about the effect of the terminal locations on processes and transports.
Methodology: The paper provides a comprehensive overview for the locations of terminals and depots within a port. Based on this, a detailed analysis is carried out to develop a classification scheme for ports, which categorizes them according to their geographical characteristics.
Findings: Based on the examples of characteristic ports and terminals, we provide findings regarding advantages as well as barriers to transport containers within ports**.** The aim is to determine the impact of geographical characteristics of ports for handling port-internal traffic.
Originality: The existing literature provides an overview of ports and maritime networks, as well as various port concepts. Furthermore, different approaches for the design of container transports between terminals are discussed. However, there is no overview of the geographical location of terminals and depots in ports and their impact on inter-terminal transportation.

First received: 20. Mar 2020 Revised: 25. Jun 2020 Accepted: 31. Aug 2020

1 Introduction

Global maritime trade keeps growing and underlines its importance for the global economy. The United Nations Conference on Trade and Development (UNCTAD) expects average annual growth of 3.4 percent between 2019 and 2024, largely driven by the increase in containerized goods (UNCTAD 2019). In this context, a sustained growth in the size of container vessels has been taking place in the last few years. By deploying even larger vessels, shipping companies are profiting from the economies of scale by saving operating and personnel costs. As a result, only selected container terminals (CT) in the major seaports, which have sufficient space and depth on the quay as well as suitable equipment for handling the container giants, can be called at. However, large seaports typically consist of multiple terminals with different handling equipment as well as different types of hinterland connection (Tierney et al. 2014). Terminals that are suitable for handling large container vessels often serve as so-called transshipment nodes, from where the containers are transported to adjoining terminals for onward shipment. These transports between terminals as well as terminals and other logistics nodes in a port are called inter-terminal transportation (ITT), in which trucks are the dominant transportation mode (Kopfer et al. 2016).

A further consequence of growing vessel sizes is the decrease in frequency of terminal calls and the increase in handling volume per call, which results in an additional coordination effort to handle ships in the terminals. In addition, different geographical and structural characteristics affecting intra and inter terminal operations have to be taken into account when handling container vessels at terminals (Ramírez-Nafarrate et al. 2017).

This paper compares and classifies large seaports with regard to their geographical structures and creates an approach to draw conclusions about ITT based on this classification. First, chapter 2 provides drivers for the development of seaport container terminals and gives an overview of the relevant literature. The method by which the relevant seaports are selected is introduced in Chapter 3. Chapter 4 presents the literature classification, including possible forms of the individual categories. Furthermore, the analysis of seaports is given in chapter 4, followed by a detailed presentation of selected ports in chapter 5. The paper closes with an analysis of the results obtained by applying them to the performance of ITT. At the end, a conclusion is given and future research topics are outlined.

2 Seaport Container Terminals

Seaports with their container terminals are a central part of this research. Chapter 2 introduces the development of seaports in port industries to analyze the relationship between the terminals and to identify useful categories for classification. This includes the presentation of relevant papers and related works.

2.1 Developments of seaport terminals in port economics and competition

Seaport Container terminals are important nodes in the maritime supply chain and operate as an interface between the modes of transport water, rail, and road (Gharehgozli et al. 2016). Especially large seaports are in tough international competition with each other. The performance of a seaport depends on its contribution to the successful operation of the overall supply chain. One criterion for success is the competitiveness of ports, which is strongly determined by their accessibility, besides other factors (Notteboom et al. 2005). However, increasing handling volumes also require an adjustment of port management and hinterland processes. There are three main aspects that are currently influencing the port industry (UNCTAD 2019):

(1) Globalization and supply chain integration of the port industry

(2) Pressure to reduce costs and optimize processes

(3) Trend of growing ship size

Ship routes mainly run along large hubs. Even though ports have been upgraded in recent years and new CT have been built in many areas, the number of dominant ports is limited. The position of a seaport in international competition is also determined by its vertical integration of upstream and downstream logistics processes (Ducruet 2015).
The existing competition between terminals requires fast and smooth handling of containers to and from ships. Due to the continuing growth of global maritime trade, many terminals worldwide are operating at their capacity limits and at the same time there is considerable pressure to increase terminal throughput and shorten ship turnaround times. To overcome the geographical limitations of many ports, a continuous optimization of their performance is necessary. Thus, the relevance of optimizing terminal internal processes is constantly increasing (Bish et al. 2005).
Aspects such as the ability to handle ultra-large container ships are increasingly important. The largest container ships currently have a loading capacity of just under 24,000 TEU (Moore 2020), although an end to the size trend is still not in sight. Experts estimate that the ships could reach a size of up to 30,000 TEU by 2025 (Malchow 2017).

2.2 Background

Several publications have dealt with different aspects of the development of seaports and terminals in port economies and in the field of competition. A well-known conceptual model of port development is Bird's Anyport Model, which describes the spatial and temporal development of traditional ports. According to this model, port development takes place in three phases: settlement, expansion and specialization. Historically, most ports were built adjacent to the city center and have been increasingly expanded through maritime development and improved cargo handling facilities. Due to the specialization in cargo handling and the incipient growth in ship sizes, the areas had to be further expanded and, due to lack of space, extended to remote locations (Bird 1980). This model has been extended over time by various scientists, such as Notteboom et al. (2005), to include additional phases.

A number of publications also deal with competition between terminals or seaports. For example, Malchow and Kanafani (2004) examine the question of which factors influence the choice of ports and how ports compete with each other. In addition, the authors analyze in their paper which strategies ports pursue in order to increase their market share. Furthermore, Notteboom (2016) examines the capacity expansion of container terminals along rivers to maintain their competitiveness (Notteboom 2016). Sanchez et al. (2011) investigated the attractiveness of ports based on a factor analysis, whereas Ng (2006) applied an extended survey analysis (Ranking and causes of inefficiency of container seaports in South-Eastern Europe).

Geerlings et al. (2017) offer a general overview of ports and maritime networks including definitions, functions and the presentation of different port concepts. Steenken et al. (2004), or Gharehgozli et al. (2016) give an overview of the operation of seaport container terminals and describe their logistical processes and procedures including further information on transport and handling equipment.

In addition, several studies have examined container transport within ports and container terminals (see Heilig and Voß 2017; Gharehgozli et al. 2017; Tierney et al. 2014).

3 Methodology

Given the background described in the last section, this paper addresses the follow-ing research question:

(1) Which regional similarities and differences exist in the structure of container ports?

(2) How do regional characteristics effect transports between the terminals (ITT)?

In this section we present the procedure by which we have selected and analyzed the most important global container ports.

The most important trade routes in global container traffic run along the east-west container trade lane. The three main trade routes as shown in Figure 1 are Asia-Europe, the Trans-Pacific route, and the Transatlantic route (UNCTAD 2019). This can also be seen from the location of the major container ports (Figure 2).

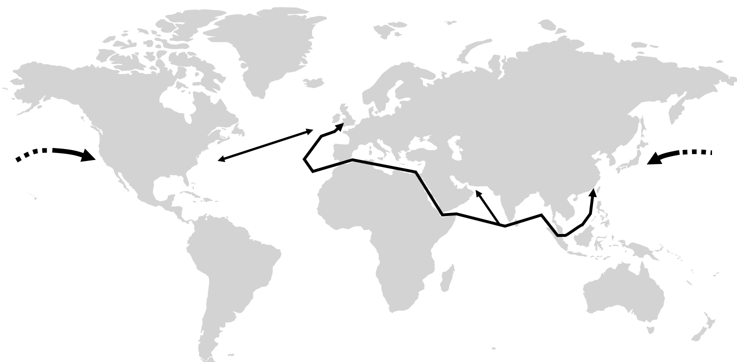

Figure 1: Main global trade routes

Both figures illustrate that Asia plays a central role in global maritime trade. Accordingly, 15 of the top 20 container ports are located in Asia. In order to obtain a comprehensive overview of the characteristics of container terminals, we analyzed the major seaports of the world. The study focuses on industrial and emerging countries whose ports have a state-of-the-art standard in terms of handling volume and technical equipment. As there are large regional differences in the volume of containers handled, we have structured the analysis according to continents. The 10 largest ports in Asia, Europe and America, as well as the four largest ports in Australia, are taken into account. On the African Continent, we chose the three most relevant ports. Figure 2 illustrates the location and shipping volumes of each port included in the investigation (Lloyd's List 2019).

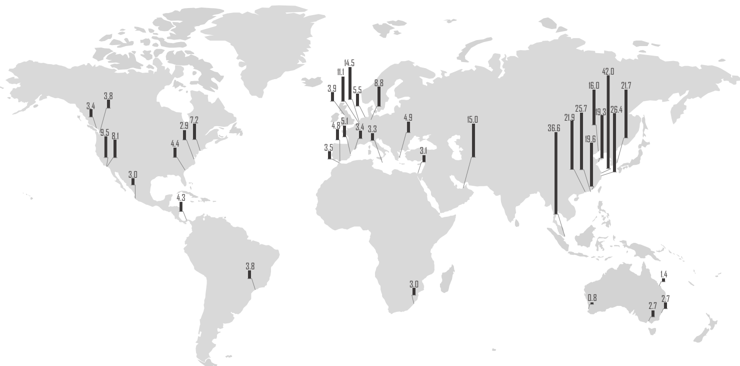

Figure 2: Selected ports and their TEU throughput in 2018 (in million TEU)

The methodology of the paper is structured as follows: The first step was to carry out a data analysis, in which the total transshipment volumes of ports on each continent were determined by TEU. Thus, the 10 ports with the highest turnover per continent could be determined. For Africa and Australia, we identified three, respectively four ports which showed a significant transshipment volume. All the collected datasets refer to the reference year 2018. Datasets were collected for each of the 37 ports. In the second step we used satellite images using material from OpenStreetMap (Openstreetmap 2020). The analysis of the satellite images was supported by online search, i.e. by visiting the homepages of each port. Based on our findings we have developed a classification scheme with individual characteristics for each category.

4 Analysis of Port Layouts

This section shows the classification of the analyzed container ports, so that a continental comparison can be made. The classification scheme is divided into six categories, shown in Table 1. The individual specifications of the categories are assigned to numbers, which are used in the classification table. Whenever several criteria are applicable (e.g. a port has terminals at the river and the coast), the criterion with the highest level of agreement is highlighted and the other criterion is marked with a dotted line.

Table 1: Classification categories with their specifications

Category	#	Specification	Category	#	Specification
Number of CT	1	Less then four	*Positioning of CT*	1	Adjoining
	2	Four to six		2	Lined up
	3	More than six		3	Spread out
Annual container volume (Million TEU)	1	Less then five	*Average distance (km) between CT*	1	Less then ten
	2	Five to ten		2	Ten to twenty-five
	3	Ten up to twenty		3	More than twenty-five
	4	Twenty or more			
Location of CT	1	Along coast / river	*Infrastructure between CT*	1	Mostly public
	2	Around bay		2	Mostly dedicated

The **Number of CT** is categorized in up to three terminals, four to six and more than six. The largest port (Busan) contains ten container terminals.
The **Annual Container Volume in TEU** gives an overview of the shipping volumes per year. We categorized them in the following clusters: Less than 5m TEU; 6m-10m. TEU; 10m-20m TEU; more than 20m TEU.
The **Location of the CT** can be classified depending on whether they are located on the coast-side or a river. Some ports have terminals that match

with both categories. In these cases we have marked the criterion that the majority of terminals meet and the other criterion is marked as being partially fulfilled.

With regard to the **Positioning of the CT**, three main types can be distinguished. The first type consists of a continuous row of terminals, this means that there are no clear lines between the terminals and the terminals appear as one large terminal. However, most of these types involve different operators and have several entrances and exits. The second type comprises connected terminals. We defined terminals as generally connected when they are located in less than 1 km linear distance to each other. Above 1 km distance, we considered the terminals as spread out.

The **average distance between CT** considers the distance when using transport infrastructure, i.e. road transport. We categorized the terminals in the clusters: less than 10 km; 10-25 km; more than 25 km.

Furthermore, we categorized the terminals whether the used infrastructure is public or private (**Infrastructure between CT**).

In the following, the individual ports, sorted by continent, are analyzed in detail (see Table 2 to Table 6).

Container port handling in Africa will grow by 1.8 percent in 2018 compared to 2017 (UNCTAD 2019). Nevertheless, African ports play a subordinate role in international container traffic, as can be seen in Table 3. Africa has three major ports with more than one container terminal, all of them with annual throughput of around 3m TEU in 2018.

Tangier Med, Africa's largest container port is located in Morocco on the Strait of Gibraltar and has four lined up container terminals. Port Said is notable for its location and the distance between its terminals. Durban is the only port in Africa considered to have dedicated infrastructure between terminals (see Table 2).

Table 2: Classification of African ports

	Annual container volume (Million TEU)				Number of CT			Location of CT		Positioning of CT			Average distance between CT			Infrastructure between CT	
	1	2	3	4	1	2	3	1	2	1	2	3	1	2	3	1	2
Marokko / Tager Med	■					■		■			■		■			■	
Port Said	■				■			■				■			■	■	
Durban	■				■			■			■		■				■

Comparing the ports of America, it is apparent that container handling on the continent is largely dominated by the United States: Six of the ten largest ports are US ports. These include New York/New Jersey, Savannah and Virginia on the Atlantic coast and Los Angeles, Long Beach on the Pacific coast. With regard to the annual transshipment volume, none of the ports meets the category 3 or 4 (10m. or more TEU per year) (UNCTAD 2019). Most of the ports have few terminals – Los Angeles is the only port that contains 7 CT. The terminals at the port of Savannah are located in line and directly adjacent to each other. Therefore, the terminals are connected via non-public roads. Every other port uses public infrastructure for inter-terminal transportation (see Table 3).

Table 3: Classification of American ports

	Annual container volume (Million TEU)				Number of CT			Location of CT		Positioning of CT			Average distance between CT			Infrastructure between CT	
	1	2	3	4	1	2	3	1	2	1	2	3	1	2	3	1	2
Los Angeles		■					■		■	■			■			■	
Long Beach		■				■			■	■			■			■	
New York/ New Jersey		■				■			■			■		■		■	
Savannah	■				≡			■			■		≡				■
Colòn	■				■				■			■	■			■	
Santos	■					■		■				■		■		■	
Seattle	■					■			■	■			■			■	
Vancouver	■					■			≡			■		■		■	
Manzanillo	■				■				■			■	■			■	
Virginia	■					■			■			■	■			■	

In recent years, Asian ports have grown rapidly. In 2018, Asian container ports will increase at a rate of 4.4 percent, with throughput rising by 7.6 percent compared to 2017. With Shanghai, Asia has the largest container port in the world. In 2018 Shanghai had an increase of 2m TEU in container port traffic (UNCTAD 2019).

The importance of the Asian ports is highlighted by the container throughput in 2018. Six of the ten ports in Asia have an annual container throughput greater than 20m TEU. Shanghai has by far the largest throughput with 42m TEU, followed by Singapore with a throughput of 36.6m TEU. Ports seven to ten still have a high container throughput with a minimum of 14.95m TEU (Dubai) (Lloyd's List 2019).

It can be seen that the Asian ports all have more than four container terminals and almost half of the analyzed ports have more than six (see Table). The terminals are mainly spread out, which can be explained by the growth in throughput and the associated expansion or relocation of ports. Thus, average distances of more than 25 km between the ports occur in some cases. Only three of the ports analyzed have (mainly) dedicated infrastructure between them, as shown in Table 4.

Table 4: Classification of Asian ports

	Annual container volume (Million TEU)				Number of CT			Location of CT		Positioning of CT			Average distance between CT			Infrastructure between CT	
	1	2	3	4	1	2	3	1	2	1	2	3	1	2	3	1	2
Shanghai				■			■	■				■			■	■	
Singapore				■			■	■				■	■				■
Ningbo-Zhoushan				■		■		■				■		■		■	
Shenzen				■		■			■			■		▤		■	
Guangzhou				■		■		■				■			■	■	
Busan				■			■		■			■	▤				▤
Hong Kong, China			■				■	■		■			■				■
Qingdao			■			■			■	■			■			■	
Tianjin			■			■			■			■	▤			■	
Dubai			■			■		■				■		▤		■	

As shown in Table 5, the major Australian container ports have a comparably small container throughput. Melbourne, Australia's largest container port, is ranked 59th in the world in 2018 with a throughput of 3,018,671 TEU.

In total, Australia has only four container ports with more than one terminal. However, all Australian ports have less than four terminals, which are located close to each other. The terminals in each port are linked by public roads (see Table 5).

Table 5: Classification of Australian ports

	Annual container volume (Million TEU)				Number of CT			Location of CT		Positioning of CT			Average distance between CT			Infrastructure between CT	
	1	2	3	4	1	2	3	1	2	1	2	3	1	2	3	1	2
Melbourne	■				■			▤				■	■			■	
Botany	■				■				■	▤			■			■	
Brisbane	■				■			■			■		■			■	
Fremantle	■				■			■			■		■			■	

The ten largest ports for container handling in Europe are listed in Table 6. The largest port is Rotterdam (Netherlands) with 14.51m TEU in 2018 followed by Antwerp (Belgium) with 11.1m TEU (UNCTAD 2019). Both ports are located at river mouths on the North Sea coast of their countries. In addition, the ports are located relatively close to each other - the distance between the ports is slightly less than 100 km via the main transport routes. The ports of Hamburg, Bremerhaven, Felixtowe also have a connection to the North Sea and are located close to economically strong regions in Central Europe (e.g. Greater London in Britain or the Ruhr Area in Germany). The ports of Valencia, Piraeus, Algeciras, Barcelona and Marsaxlokk, on the other hand, are located in the Mediterranean and thus have a direct connection to the important sea route to Asia via the Suez Canal. Except the port of Rotterdam, which has two small terminals located in the city center and most of its deep-sea terminals at the coast, all of the European ports have terminals that are located less than 10 km to each other.

Table 6: Classification of European ports

	Annual container volume (Million TEU)				Number of CT			Location of CT		Positioning of CT			Average distance between CT			Infrastructure between CT	
	1	2	3	4	1	2	3	1	2	1	2	3	1	2	3	1	2
Rotterdam			■				■		≡			■		■		■	
Antwerp			■			■		■				■	■			■	
Hamburg		■				■		■				■	■			■	
Bremerhaven		■			≡			■			■		≡				■
Valencia		■			■			■		■			■			■	
Piräus	■				■			■		■			■				■
Bahía de Algeciras	■				■				■	■			■			■	
Felixstowe	■				≡			■			■		≡				■
Barcelona	■					■		■		■			■			■	
Marsaxlokk	■				■				■	■			■				■

5 Selected Terminal Examples

In chapter 5, one selected seaport each from Asia, America and Europe is presented in detail. The positioning of CT has a major influence on logistic activities, like the ITT. Differences in the ITT occur because of the properties of a seaport, e.g. positioning, location, infrastructure between CT. In order to underline the impact on the ITT, specific characteristics of the seaports are discussed and the location of the terminals is illustrated in detail. Furthermore, local concepts for the ITT are outlined by means of the given examples.

5.1 Port of Rotterdam

The Port of Rotterdam is the largest port in Europe. It contains seven container Terminals. Five of the terminals (1-5) are located on a man-made peninsula at the mouth of the river Nieuwe Maas which is part of the Rhine delta (Figure 3).

Figure 3: Location of Container Terminals in the Port of Rotterdam

The terminals 6 and 7 are located near the city center. The average distance between the terminals at the peninsula is 7.2 km. Including the terminals 6 and 7, the average distance increases to 20.3 km.
The deep sea terminals are connected to the city of Rotterdam via the N15 highway. The N15 then becomes the A15 motorway, which forms an important link between the port of Rotterdam and the German Ruhr area. The A15 is an important import and export axis and is therefore used to a large extent by commercial traffic. Furthermore, over 400 international rail connections run from and to Rotterdam. Especially for the transport of containers, general cargo, dry bulk and, chemical products the rail connection is suitable. The goods can be transferred directly onto a train at various terminals.
Short transit times also make the connection attractive. By rail, the goods reach the German border within 3 hours. Other European destinations can be reached within 24 hours. Within Rotterdam, the port offers a neutral rail solution for the exchange of containers between the deep sea terminals and the intermodal terminals (Port Shuttle service). For the exchange of containers between the deep sea terminals, the port is currently constructing a container exchange route that links the container companies and further reduces the costs of container exchange. The container exchange route is used to transport containers on the Maasvlakte using a dedicated road network. Autonomous vehicles move the containers between all terminals, container depots, and distribution centers and customs facilities through the dedicated network. The container exchange route is expected to handle over one million containers per year when it opens in late 2021. (Port of Rotterdam Authority 2020)

5.2 Port of Busan

Busan Port is located on the southeastern tip of the Korean Peninsula. With a throughput of 21.7 million TEU, Busan Port is the largest container port in Korea and the sixth largest container port in the world in 2018. The Port of Busan has ten container terminals in total, divided into two areas: Five of the terminals are located in Busan New Port (1-5) and five in Busan North Port (6-10) (see Figure 4).

Figure 4: Location of Container Terminals in the Port of Busan

Due to lack of space and limited geographical expansion possibilities of Busan North Port, Busan New Port was opened in 2006. The distance between the two port areas is 25 km straight line. Busan New Port is located to the west of the Naktong River estuary in a deep, protected bay, outside

the city center, and Busan North Port is located to the east of the river estuary in the middle of the city center of Busan.
A "hinterland road" connects both port areas. It runs from Busan New Port to Busan North Port via the South Port Bridge and the North Port Bridge. Both bridges were built especially for port traffic, the overall hinterland road runs outside the city. In addition, Busan New Port has its own road and rail network for the transportation of containers.

5.3 Port of Savannah

The Port of Savannah is the fourth largest port in America, behind the ports of Los Angeles, Long Beach and New York/ New Jersey, with a throughput of 4.1m TEU in 2018. The port is located at the east coast of the USA in the state Georgia at the Savannah River. It consists of one CT, the Garden City Terminal, which includes nine berths. The berths are lined-up along the river over an approximate length of 3.2 km and connected through a road network.

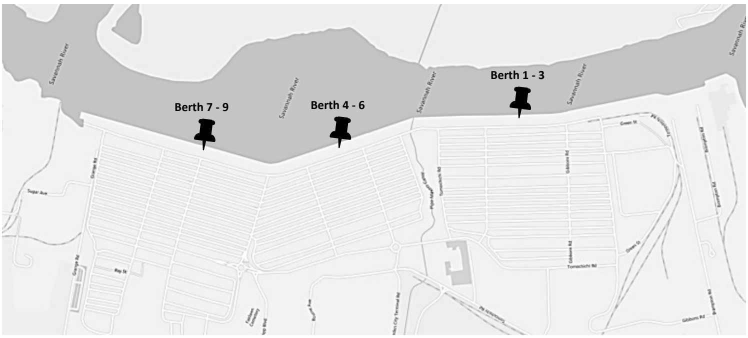

Figure 5: Location of Container Terminals in the Port of Savannah

Transports between berths take place via internal transports, no additional processes like registration and weighting are necessary (Georgia Ports 2020). The layout features of the Port of Savannah represent the category ‘lined up’ which are designated because of their private road network and united resource usage. However, lined up ports differ in the amount of operators. In the Port of Savannah one authority is responsible for the terminal. The Port of Bremerhaven and Felixstowe are further examples of this category of ports.

From the container terminal of the Port of Savannah the interstate 16 (east/west) and interstate 95 (north/ south) are reached within a few kilometers. In addition, an on-terminal railway service is available for transports e.g. to Atlanta or Chicago. Per week the Port of Savannah handles 35 trains of import and export containers (Georgia Ports 2020). The port of Savannah is planning an expansion of the ports capacity of 45 percent over the next decade. The increase in capacity includes enhanced container storage capacities, further container cranes as well as an improvement of the berths.

6 Impact on ITT

Based on the classification of the world's largest seaports, the influence of port layouts on ITT in ports is discussed below. Overall, the analyzed ports show a wide variety in terms of size or handling volume, number of terminals, location and dis-tance between terminals. These differences can be observed both between conti-nents and within continents.
The classification shows that container throughput is significantly higher in the top ten Asian ports than in the other ports. All analyzed Asian ports reach at least level three; the first six ports were even classified as level four, corresponding to an annu-al throughput of more than 20 million TEU. In contrast, only two European ports were able to reach level three in this category, which means an annual throughput of more than 10 million TEU. The throughput of ports in Africa, America and Australia is clearly behind. Furthermore, it is noticeable that Asian ports all have four or more CT, whereas in Australia none of the ports has more than three terminals. Overall, a correlation between annual container throughput and number of terminals can be seen. Besides, there are probably more additional nodes in large ports, such as empty container depots or packing stations. Between these nodes, containers will also be transported. Accordingly, the infrastructure network around the ports is affected by different levels of pressure, depending on the volume of cargo handled, the number of terminals and the number of other service nodes.
Especially in Asia, the terminals are spread around the port, whereas in European ports the terminals are often in line or adjoining. This could be because European ports play a historic role in maritime transport and have grown continuously with the increasing handling volumes. On the other

hand, the growth of Asian ports has only begun in recent years, so that existing space and resources are no longer suffi-cient and locations have to be expanded or alternative locations with sufficient space availability have to be built. Large port areas or geographically separated terminals within a port area complicate the performance and coordination of ITT. The plannability of container transports by truck decreases with distance and at the same time the risk of delays increases. One possibility to improve planning reliability and minimize the risk of delays is to use dedicated infrastructure for container transports in the port. The classification shows that 28 out of the 37 analyzed ports use public roads for ITT. Only nine ports (partly) have dedicated infrastructure for ITT and four of the nine ports are located in Europe. It is notable that a dedicated infra-structure in Africa, America and Europe is only used in ports with less than four CT. Here the distances between terminals with such infrastructure are limited to less than 10 km. In Asia, ports with more than four terminals are also connected by a (partially) dedicated infrastructure. Apart from the fact that a dedicated infrastruc-ture in ports is less sensitive to traffic congestion, autonomous systems can be used to transport containers. Especially ports that fall into the categories "lined up" and "adjoining" with regard to the position of their CT are suitable for a connection through a dedicated infrastructure using autonomous vehicles. It should be noted that autonomous systems usually mean structural challenges for the port and the terminals. In addition, these concepts often have a strong impact on port processes. Overall, a lack of available space on route sections, geographical or structural barri-ers and long distances between terminals make the integration more difficult.

All in all, it shows that the performance of ITT depends strongly on the geographical characteristics of the ports. No general solution can be found. In fact, the systems and their organization have to be adapted to the specific situation.

7 Conclusion and Outlook

Seaports are facing great competitive pressure due to increasing transport volumes, which makes it necessary to optimize internal terminal processes as well as the processes that run along the maritime supply chain. This paper has provided an approach to identify geographical similarities and specifications in the design of container ports. Based on comprehensive research, a classification scheme was developed to classify the ports. Later on, the impact of port layouts on ITT networks were examined.

In total 37 seaports from Asia, America, Australia, Africa, and Europe could be classified. The amount of annual container throughput and the number of container terminals were taken into account for the selection of the ports. Thus, only the largest seaports of each continent or seaports with more than one container terminal are relevant for the classification. In summary, ports are characterized by great diversity in terms of size or volume of container handling, number of terminals, location, and distance between terminals.

It can be seen that the major ports are located in Asia and Europe. Furthermore, it is noticeable that the terminals are mostly located close to each other and are connected by public infrastructure. Overall, it is shown that terminals located far away from each other can have negative effects on ITT. The ability to plan road transports decreases with distance and the risk of delays increases. It can be seen that a dedicated infrastructure only exists between terminals that are close together. Therefore, autonomous vehicles can be used for the transport of containers between terminals and further nodes in the port, as it is planned in Rotterdam.

For future research, the function of the port could be taken into account. It will be interesting whether the structure of transshipment ports differs from typical import - export ports. Furthermore, the preferred mode of transport for ITT, as well as the expansion of the rail network and the share of rail transport in the port area, should be included. It should also be examined how "value added services" can be located in ports in order to optimize ITT. Finally, it is to mention that we have only analyzed container terminals. The inclusion of other terminals in the study could also be interesting.

References

Bird, J. (1980): Seaports and seaport terminals. London: Hutchinson University Library.

Bish, Ebru K.; Chen, Frank Y.; Leong, Yin Thin; Nelson, Barry L.; Ng, Jonathan Wing Cheong; Simchi-Levi, David (2005): Dispatching vehicles in a mega container terminal. In *OR Spectrum* 27, pp. 491–506.

Ducruet, César (2015): Global maritime connectivity: a long-term perspective. In *Port Technology International* (65), pp. 34–36.

Geerlings, Harry; Kuipers, Bart; Zuidwijk, Rob (2017): Ports and Networks. Abingdon, Oxon, New York, NY : Routledge, 2018.: Routledge.

Georgia Ports (Ed.) (2020): Garden City Terminal. Available online at https://gaports.com/facilities/port-of-savannah/garden-city-terminal/#interchange-lanes.

Gharehgozli, Amir Hossein; Koster, René de; Jansen, Rick (2017): Collaborative solutions for inter terminal transport. In *International Journal of Production Research* 55 (21), pp. 6527–6546.

Gharehgozli, Amir Hossein; Roy, Debjit; Koster, René de (2016): Sea container terminals: New technologies and OR models. In *Marit Econ Logist* 18 (2), pp. 103–140.

Heilig, Leonard; Voß, Stefan (2017): Inter-terminal transportation: an annotated bibliography and research agenda. In *Flex Serv Manuf J* 29 (1), pp. 35–63. DOI: 10.1007/s10696-016-9237-7.

Kopfer, Herbert; Jang, Dong-Won; Vornhusen, Benedikt (2016): Scenarios for Collaborative Planning of Inter-Terminal Transportation. In Ana Paias, Mario Ruthmair, Stefan Voß (Eds.): Computational Logistics, vol. 9855. Cham: Springer International Publishing (Lecture Notes in Computer Science), pp. 116–130.

Lloyd's List (2019): One Hundred Container Ports 2019. Available online at https://lloydslist.maritimeintelligence.informa.com/one-hundred-container-ports-2019.

Malchow, Matthew B.; Kanafani, Adib (2004): A disaggregate analysis of port selection. In *Transportation Research Part E: Logistics and Transportation Review* 40 (4), pp. 317–337.

Malchow, Ulrich (2017): Growth in containership sizes to be stopped? In *Maritime Business Review*.

Moore, Rebecca (2020): HMM unveils world’s largest container ship. Available online at https://www.rivieramm.com/news-content-hub/news-content-hub/hmm-unveils-worlds-largest-container-ship-59174, updated on 5/24/2020.

Ng, Koi Yu (2006): Assessing the attractiveness of ports in the North European container transhipment market: an agenda for future research in port competition. In *Marit Econ Logist* 8, pp. 234–250.

Notteboom, Theo (2016): The adaptive capacity of container ports in an era of mega vessels: The case of upstream seaports Antwerp and Hamburg. In *Journal of Transport Geography* 54, pp. 295–309.

Notteboom, Theo; Notteboom *, Theo E.; Rodrigue, Jean-Paul (2005): Port regionalization: a new phase in the spatial and functional development of ports and port systems // Port regionalization: towards a new phase in port development. In *Maritime Policy & Management* 32 (3), pp. 297–313.

Openstreetmap (2020): Openstreetmap. Available online at http://www.openstreetmap.org.

Port of Rotterdam Authority (Ed.) (2020): Facts and Figures. Available online at https://www.portofrotterdam.com/sites/default/files/facts-and-figures-port-of-rotterdam.pdf.

Ramírez-Nafarrate, Adrián; González-Ramírez, Rosa G.; Smith, Neale R.; Guerra-Olivares, Roberto; Voß, Stefan (2017): Impact on yard efficiency of a truck appointment system for a port terminal. In *Annals of Operations Research* 258 (2), pp. 195–216.

Sanchez, Ricardo J.; Ng, Adolf K. Y.; Garcia-Alonso, Lorena (2011): Port selection factors and attractiveness: the service providers’ perspective. In *Transportation journal* 50 (2), pp. 141–161.

Steenken, Dirk; Voß, Stefan; Stahlbock, Robert (2004): Container terminal operation and operations research-a classification and literature review. In *OR Spectrum* 26 (1), pp. 3–49.

Tierney, Kevin; Voß, Stefan; Stahlbock, Robert (2014): A mathematical model of inter-terminal transportation. In *European Journal of Operational Research* 235 (2), pp. 448–460.

UNCTAD (2019): Review of Maritime Transport 2018. United Nations.