# CHAPTER 8

# The Global Maritime Network in Container Shipping: Liner Service Design, Network Configuration and Port Centrality

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**Abstract**

After a brief background about the development of containerization in recent decades, this chapter reviews the current characteristics of liner shipping networks under three main themes. First, it provides an overview of the different service types of shipping lines and dynamics in liner service configuration and design. Second, a global snapshot of the worldwide liner shipping network is proposed by means of vessel movement data. The changing geographic distribution of main inter-port links is explored in the light of recent reconfigurations of liner shipping networks (e.g. multiplication versus rationalisation of port calls). We also discuss the position of seaports in liner shipping networks referring to concepts of centrality, hierarchy, and selection factors. The chapter concludes by elaborating on the interactions and interdependencies between seaport development and liner shipping network development notably under current economic changes.

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## 1. INTRODUCTION: BACKGROUND ON LINER SHIPPING

Container liner shipping has a relatively short history. In 1956 Malcolm McLean launched the first containership Ideal X. Ten years later the first transatlantic container service between the US East Coast and North Europe marked the real start of long distance scheduled container liner services. The first specialized cellular containerships were delivered in 1968. In the 1970s the containerization process expanded rapidly due to the adoption of standard container sizes and the awareness of industry players about the advantages and cost savings containerization brought (Rodrigue and Notteboom, 2009; Levinson, 2006). Although container shipping occupies a relatively minor share of the whole maritime fleet (about 12 per cent), it is the fastest growing sector and currently concentrates more than half of world trade value, regularly expanding to other commodities (e.g. neo bulks).

The world container traffic, the absolute number of laden containers being carried by sea, increased from 28.7 million TEU in 1990 to about 100 million TEU in 2008 with a further growth to 155 million TEU in 2018 (UNCTAD, 2019 based on figures of MDS Transmodal). Worldwide container port throughput increased from 36 million TEU in 1980 and 88 million TEU in 1990 to 237 million TEU in 2000, 545 million TEU in 2010 and 771 million TEU in 2018 (figures Drewry). A comparison between world container traffic and world container port throughput reveals a container on average is handled (loaded or discharged) 3.5 times between the first port of loading and the last port of discharge. This figure amounted to 3 in 1990. The rise in the average number of port handlings per box is the result of more complex configurations in liner service networks as will be explained later in this chapter. Furthermore, the centre of gravity of these liner service networks has shifted to Asia. The dominance of Asia is reflected in world container port rankings. In 2018 fifteen of the twenty busiest container ports came from Asia, mainly from China (Table 8.1). In the mid 1980s there were only six Asian ports in the top 20, mainly Japanese load centres. The emerging worldwide container shipping networks helped to reshape global supply chain practices and supported the globalization in production and consumption. New supply chain practices in turn increased the requirements on container shipping service networks in terms of frequency, schedule reliability/integrity, global coverage of services and rate setting.

[ Insert Table 8.1 about here ]

This chapter analyses liner service networks as configured by container shipping lines. In a first section we discuss the drivers of and decision variables in liner service design as well as the different liner service types. Next, the chapter provides a global snapshot of the worldwide liner shipping network based on vessel movement data. The changing geographic distribution of main inter-port links is explored in the light of recent reconfigurations of liner shipping networks. Third, we zoom in on the position of seaports in liner shipping networks referring to concepts of centrality, hierarchy, and selection factors. The chapter concludes by elaborating on the interactions and interdependencies between seaport development and liner shipping network development notably under current economic changes.

## 2. CONFIGURATION AND DESIGN OF LINER SHIPPING SERVICES

### 2.1. The configuration of liner shipping services and networks

Liner shipping networks are developed to meet the growing demand in global supply chains in terms of frequency, direct accessibility and transit times. Expansion of traffic has to be covered either by increasing the number of strings operated, or by vessel upsizing, or both. As such, increased cargo availability has triggered changes in vessel size, liner service schedules and in the structure of liner shipping.

When designing their networks, shipping lines implicitly have to make a trade-off between the requirements of the customers and operational cost considerations. A higher demand for service segmentation adds to the growing complexity of the networks. Shippers demand direct services between their preferred ports of loading and discharge. The demand side thus exerts a strong pressure on the service schedules, port rotations and feeder linkages. Shipping lines, however, have to design their liner services and networks in order to optimize ship utilization and benefit the most from scale economies in vessel size. Their objective is to optimize their shipping networks by rationalizing coverage of ports, shipping routes and transit time (Zohil and Prijon, 1999; Lirn et al., 2004). Shipping lines may direct flows along paths that are optimal for the system, with the lowest cost for the entire network being achieved by indirect routing via hubs and the amalgamation of flows. However, the more efficient the network from the carrier’s point of view, the less convenient that network could be for shippers’ needs (Notteboom, 2006).

Bundling is one of the key drivers of container service network dynamics. The bundling of container cargo can take place at two levels: (1) *bundling within an individual liner service* and (2) *bundling by combining/linking two or more liner services*.

[ Insert Figure 8.1 about here ]

The objective of *bundling within an individual liner service* is to collect container cargo by calling at various ports along the route instead of focusing on an end-to-end service. Such a line bundling service is conceived as a set of x roundtrips of y vessels each with a similar calling pattern in terms of the order of port calls and time intervals (i.e. frequency) between two consecutive port calls. By the overlay of these x roundtrips, shipping lines can offer a desired calling frequency in each of the ports of call of the loop (Notteboom, 2006). Line bundling operations can be symmetric (i.e. same ports of call for both sailing directions) or asymmetric (i.e. different ports of call on the way back), see Figure 8.1. Most liner services are line bundling itineraries connecting between two and five ports of call scheduled in each of the main markets. The Europe–Far East trade provides a good example. Most mainline operators and alliances running services from the Far East to North Europe stick to line bundling itineraries with direct calls scheduled in each of the main markets. Notwithstanding diversity in calling patterns on the observed routes, carriers select up to five regional ports of call per loop. Shipping lines have significantly increased average vessel sizes deployed on the route. In October 2019, the average container vessel on the Asia - North Europe trade measured 16,100 TEU compared to 11,711 TEU in 2015, 9,444 TEU in 2012, 6,164 TEU in 2006 and 4,250 TEU in 2002 (data Blue Water Reporting and Alphaliner and Notteboom et al., 2017). These scale increases in vessel size for a long time put a downward pressure on the average number of European port calls per loop on the Far East–North Europe trade: 4.9 ports of call in 1989, 3.84 in 1998, 3.77 in October 2000, 3.68 in February 2006, 3.35 in December 2009 and 3.48 in April 2012. In the past years, however, the number of port calls has slightly increased mainly driven by carriers' focus on increasing vessel utilization. As a result, the average number of European port calls per loop on the Far East–North Europe trade reached 4.52 in July 2015, 4.59 in April 2017 and 4.11 in June 2019. Two extreme forms of line bundling are round-the-world services and pendulum services.

[ Insert Figure 8.2 about here ]

The second possibility is to *bundle container cargo by combining/linking two or more liner services.* The three main bundling options in this category include a hub-and-spoke network (hub/feeder), interlining and relay (Figure 8.2). The establishment of global networks has given rise to hub port development at the crossing points of trade lanes. Intermediate hubs emerged since the mid-1990s within many global port systems: Freeport (Bahamas), Salalah (Oman), Tanjung Pelepas (Malaysia), Gioia Tauro, Algeciras, Taranto, Cagliari, Damietta, Tanger Med and Malta in the Mediterranean, to name but a few. The role of intermediate hubs in maritime hub-and-spoke systems has been discussed extensively in literature (see for instance Baird, 2006; Fagerholt, 2004; Guy, 2003; McCalla et al., 2005). The hubs have a range of common characteristics in terms of nautical accessibility, proximity to main shipping lanes and ownership, in whole or in part, by carriers or multinational terminal operators. Most of these intermediate hubs are located along the global beltway or equatorial round-the-world route (i.e. the Caribbean, Southeast and East Asia, the Middle East and the Mediterranean). These nodes multiply shipping options and improve connectivity within the network through their pivotal role in regional hub-and-spoke networks and in cargo relay and interlining operations between the carriers' east-west services and other inter- and intra-regional services. Container ports in Northern Europe, North America and mainland China mainly act as gateways to the respective hinterlands.

Two developments undermine the position of pure transhipment/interlining hubs (Rodrigue and Notteboom, 2010). First of all, the insertion of hubs often represents a temporary phase in connecting a region to global shipping networks. Hub-and-spoke networks would allow considerable economies of scale of equipment, but the cost efficiency of larger ships might be not sufficient to offset the extra feeder costs and container lift charges involved. Once traffic volumes for the gateway ports are sufficient, hubs are bypassed and become redundant (see also Wilmsmeier and Notteboom, 2011). Secondly, transhipment cargo can easily be moved to new hub terminals that emerge along the long distance shipping lanes. The combination of these factors makes that seaports which are able to combine a transhipment function with gateway cargo obtain a less vulnerable and thus more sustainable position in shipping networks (Notteboom et al., 2019).

In channelling gateway and transhipment flows through their shipping networks, container carriers aim for control over key terminals in the network. Decisions on the desired port hierarchy are guided by strategic, commercial and operational considerations. Shipping lines rarely opt for the same port hierarchy in the sense that a terminal can be a regional hub for one shipping line and a secondary feeder port for another operator.

The liner service configurations in Figures 8.1 and 8.2 are often combined to form complex multi-layer networks. The advantages of complex bundling are higher load factors and/or the use of larger vessels in terms of TEU capacity and/or higher frequencies and/or more destinations served. Container service operators have to make a trade-off between frequency and volume on the trunk lines: smaller vessels allow meeting the shippers' demand for high frequencies and lower transit times, while larger units will allow operators to benefit from economies of vessel scale. The main disadvantages of complex bundling networks are the need for extra container handling at intermediate terminals and longer transport times and distances. Both elements incur additional costs and as such could counterbalance the cost advantages linked to higher load factors or the use of larger unit capacities. Some have suggested that the most efficient east/west pattern is the equatorial round-the-world, following the beltway of the world (e.g. Ashar, 2002 and De Monie, 1997). This service pattern focuses on a hub-and-spoke system of ports that allows shipping lines to provide a global grid of east/west, north/south and regional services. The large ships on the east/west routes will call mainly at transhipment hubs where containers will be shifted to multi-layered feeder subsystems serving north/south, diagonal and regional routes. Some boxes in such a system would undergo as many as four transhipments before reaching the final port of discharge. The global grid would allow shipping lines to cope with the changes of trade flows as it combines all different routes in a network.

Existing liner shipping networks feature a great diversity in types of liner services and a great complexity in the way end-to-end services, line bundling services and transhipment/relay/interlining operations are connected to form extensive shipping networks. Maersk Line, MSC and CMA-CGM operate truly global liner service networks, with a strong presence also on secondary routes. Especially Maersk Line has created a balanced global coverage of liner services. The networks of CMA-CGM and MSC differ from the general scheme of traffic circulation through a network of specific hubs (many of these hubs are not among the world's biggest container ports) and a more selective serving of secondary markets such as Africa (strong presence by MSC), the Caribbean and the East Mediterranean. Notwithstanding the demand pull for global services, a large number of individual carriers remains regionally based. Asian carriers such as Japanese carrier ONE (Ocean Network

Express) and South Korean carrier HMM mainly focus on intra-Asian trade, transpacific trade and the Europe – Far East route, partly because of their huge dependence on export flows generated by the respective Asian home bases. Evergreen and Cosco Shipping are among the exceptions frequenting secondary routes such as Africa and South America. Profound differences exist in service network design among shipping lines. Some carriers have clearly opted for a true global coverage, others are somewhat stuck in a triad-based service network forcing them to develop a strong focus on cost bases. Alliance structures (cf. THE Alliance, Ocean Alliance and 2M) provide its members easy access to more loops or services with relatively low-cost implications and allow them to share terminals.

## 2.2. The process of designing a liner service

Figure 8.3 summarizes the liner service design process. Before an operator can start with the actual design of a regular container service, he will have to analyse the targeted trade route(s). The analysis should include elements related to the supply, demand and market profile of the trade route. Key considerations on the supply side include vessel capacity deployment and utilization, vessel size distribution, the configuration of existing liner services, the existing market structure and the port call patterns of existing operators. At the demand side, container lines focus on the characteristics of the market to be served, the geographical cargo distribution, seasonality and cargo imbalances. The interaction between demand and supply on the trade route considered results in specific freight rate fluctuations and the overall earning potential on the trade.

[ Insert Figure 8.3 about here ]

The ultimate goal of the market analysis is not only to estimate the potential cargo demand for a new liner service, but also to estimate the volatility, geographical dispersion and seasonality of such demand. These factors will eventually affect the earning potential of the new service. Once the market potential for a new service has been determined, the service planners need to take decisions on several inter-related core design variables. These design variables are indicated in dark gray/shaded boxes in Figure 8.3 and mainly concern (1) the liner service type, (2) the number and order of port calls in combination with the actual port selection process, (3) vessel speed, (4) frequency and (5) vessel size and fleet mix.

The array of liner service types and bundling options available to shipping lines was discussed in the previous section.

Limiting the number of port calls shortens round voyage time and increases the number of round trips per year, thereby minimizing the number of vessels required for that specific liner service. However, fewer ports of call mean poorer access to more cargo catchment areas. Adding port calls can generate additional revenue if the additional costs from added calls are offset by revenue growth. The actual port selection is a complex issue. Traffic flows through ports are a physical outcome of route and port selection by the relevant actors in the chain. The most relevant service-related and cost factors explaining port selection by the main players of the transport chain (e.g. shippers, ocean carriers, and forwarders) are identified in the scientific literature on port choice, see e.g. Murphy et al.(1992), Murphy and Daley (1994), Malchow and Kanafani (2001), Tiwari et al. (2003), Nir et al. (2003), Chou et al. (2003), Song and Yeo (2004), Guy and Urli (2006) and Wiegmans et al. (2008). Port choice has increasingly become a function of the overall network cost and performance. Figure 8.3 incorporates the approach of Notteboom (2009) to group port selection factors together in the demand profile of the port, the supply profile of the port, and the market profile of the port. Human behavioural aspects might impede carriers from achieving an optimal network configuration. Incorrect or incomplete information results in bounded rationality in carriers' network design, leading to sub-optimal decisions. Shippers sometimes impose bounded rational behaviour on shipping lines, e.g. in case the shipper asks to call at a specific port. Wiegmans et al. (2008) argue that port selection by shipping lines can also be heavily influenced by the balance of power among the shipping lines of the same strategic alliance, or the carrier's objective to make efficient use of its dedicated terminal capacity in specific ports.

The choice of vessel speed is mainly affected by the technical specifications of the vessel deployed (i.e. the design speed), the bunker price (see Notteboom and Vernimmen, 2009), environmental considerations (e.g. reduction of $CO_2$ through slow steaming) and the capacity situation in the market (i.e. slow steaming can absorb some of the vessel overcapacity in the market, see e.g. Cariou and Notteboom, 2011 and Notteboom et al., 2010).

The number and order of port calls, the total two-way sailing distance and the vessel speed are the main determinants of the total vessel roundtrip time. The theoretical/optimal roundtrip time will seldomly be achieved in practice due to delays along the route and in ports giving rise to schedule reliability problems. Low schedule integrities can have many causes ranging from weather conditions, delays in the access to ports (pilotage, towage, locks, tides) to port terminal congestion or even security considerations (Notteboom, 2006). A shipping line can insert time buffers in the liner service to cope with the chance of delays. Time buffers reduce schedule unreliability, but increase the vessel roundtrip time.

When it comes to the service frequency, carriers typically aim for a weekly service. The service frequency and the total vessel roundtrip time determine the number of vessels required for the liner service. Carriers have to secure enough vessels to guarantee the desired frequency. Given the number of vessels needed and the anticipated cargo volume for the liner service, the shipping line can then make a decision on the optimal vessel size and fleet mix. As economies of vessel size are more significant on longer distances, the biggest vessels are typically deployed on long and cargo-rich routes.

Decisions on all of the above key design variables will lead to a specific slot capacity offered by the new liner service. The resulting slot capacity should be in line with the actual demand as to maximize average vessel utilization (given expected traffic imbalances, cargo dispersion patterns and cargo seasonality and volatility).

## 3. SHIPPING ROUTES, NETWORK PATTERNS, AND PORT CENTRALITY

The aforementioned services altogether form a global maritime network within which local, regional and global links among ports become interconnected through the establishment of hub, interlining and relay ports. In this section, we provide a global perspective of the spatial distribution of maritime container flows and zoom into port centrality and functional specialization using vessel movement data obtained from *Lloyd's List Intelligence* (LLI), a world leader in marine insurance and shipping consultancy. The database covers the entire world fleet of fully cellular containerships and its actual port-to-port call sequences over the period 1977-2016. The database covers no less than 2,565,790 vessel movements in total spread over four complete months each year. This dataset has the advantage of covering real flows and to include smaller vessels (more local activity) that are not reported by other data such as the shipping schedules of major shipping companies. The data is also more reliable than Automated Information System (AIS) or radar / data in the sense that it does not distort the true ports of call along vessel trajectories (Ducruet, 2017).

## 3.1 The distribution of container flows

The weight and growth of major trade routes measured in TEUs provides evidence about the imbalanced structure of the global liner shipping network based on the offer of liner services (Table 8.2). The distribution shows the predominance of the transpacific (Asia-North America) link in terms of volume, closely followed by Asia-Europe and the trans-Atlantic (Europe-North America) link. This confirms the study by Frémont and Soppé (2005) of the global container shipping network through the mapping of the top shipping lines' service schedules among world regions. They explain the dominance of Asia by the role of the Newly Industrialised Countries (NICs) that provide consumers goods to industrialized countries, thus intensifying trans-Pacific flows at the expense of transatlantic flows. They also calculated that in 2002, such relations among the main economic poles of the "Triade" concentrated about 67 per cent of total service capacity, 22 per cent only remaining for North-South relations with these poles, and South-South relations being negligible in size. Transpacific flows are imbalanced due to low US exports, posing severe logistical issues like the repositioning of empty containers.

[ Insert Table 8.2 about here]

Another method for measuring the weight of links is to trace the worldwide circulation of container vessels (Table 8.3). Each time a vessel calls at one port, its capacity (in deadweight tonnage, DWT) is added to the port and to the inter-port link. The yearly total is thus an expression of the frequency and capacity of the links formed on various levels (i.e. ports, regions, continents) in an origin-destination matrix.

The global pattern appears even more explicit, with some variants, however, as the Asia-Europe and trans-Atlantic links appear at the second and sixth rank in 2016, respectively. The divergence between Table 8.2 and Table 8.3 comes from the higher shipping frequency of certain North-South links such as Europe-Africa and Latin-America, which are also based on geographic proximity and history. Another deviation from the pattern obtained using schedule data is the high rank of the Africa-Asia route. Africa as a whole has been increasingly integrated within Asian trades not only for bulk cargoes but also for manufactured goods as shown for the mid-1990s and early 2000s (Ducruet and Notteboom, 2012).

[ Insert Table 8.3 about here]

Vessel movements can also reveal different patterns of regional circulation. We calculated that on average, over the 1977-2016 period, Asia had the highest share of intra-regional flows, i.e. about 90 per cent, followed by Europe (85 per cent) and Oceania (80 per cent), all of them being very stable overtime. Latin America shifted from about 40 per cent in the late 1970s to 75 per cent in the late 1980s, with this share continuously rising up to 80 per cent in the latest period. North America kept the lowest share, oscillating around 5 per cent up to the mid-1990s and around 10 per cent up to 2016. This level and evolution are certainly due to geographic factors (land separation between East and West coasts) but also to technology (late Panama Canal expansion motivating sea-land transhipment at US and Canadian ports) and regulation. In the latter case, the Jones' Act (1920) excludes from US cabotage all foreign flag ships, giving an incentive to transhipment activities at Caribbean ports such as Puerto Rico, the Bahamas and Jamaica to name but a few. The intensity of intra-regional traffic in total traffic can thus be explained by various factors, also including the presence of hub ports and the level of trade integration within the region. Regions with high internal connectivity through the extensive use of hub-and-feeder systems, such as Asia and Europe, often have a high share of intra-regional traffic.

[ Insert Figure 8.4 about here ]

Although maritime transport does not use an infrastructure of tracks like in road or rail transport, we calculated that the overall length of the network (in nautical miles) steadily increased between 1977 and 2016, along with the number of nodes (ports) and inter-port links (edges) and in line with global trade growth (Figure 8.4). Unlike interregional flows, network size has not been affected, apparently, by the 2008/9 global financial crisis. Contrastingly, the average length of inter-port links as well as network density (i.e. the share of existing links in the maximum possible number of links) gradually diminished until the early 2000s, then increased, and decreased again from the mid-2000s. Such results reveal the contemporary transformation of maritime transport, with increasing returns to scale in liner shipping (Clark et al., 2004). The aforementioned emergence of mega-ports exerting hub-and-spokes functions resulted in fewer links relative to the number of ports in order to make the whole system more efficient and fluid. Yet the diffusion and current pattern of container flows across world ports can be seen as path- and place-dependent, since it is, among other traffic types, the most overlapped with other types on links and on nodes, compared with liquid bulk or passenger flows that are more concentrated on certain links and nodes. Container flows are thus, on average, a good marker of functional diversity for ports (Ducruet, 2013), except for the category of “pure transhipment hubs” (i.e. container ports with an elevated transhipment incidence).

In addition to these results, Ducruet and Notteboom (2012) also underlined that about 80 per cent of total worldwide traffic concentrates over inter-port links of 500 km or less, while links of 100 km or less support more than half. Besides the influence of coastal morphology and the necessity following successive calls in relative proximity, such figures can be explained by some local service configurations, as in the case of adjacent seaports serving shared hinterlands (e.g. Le Havre-Hamburg range) or acting as dual hubs (e.g. Busan and Gwangyang), which often receive multiple calls for the same vessels or liner services. The noticeable increase of the longest links was explained by stronger trans-Pacific ties (the China effect) and also by rapid technological progress in the shipping industry, allowing longer sailing distances between two ports.

The extent to which the strategies of shipping lines are reflected on the topological structure of the network can also be verified by applying some measures from graph theory and complex networks. On a world level, Hu and Zhu (2009) were the first to confirm that container shipping networks belong to the category of so-called “scale-free” and “small-world” networks, i.e. where a limited number of nodes have the majority of links, the latter’s frequency being distributed along a power-law, and with high cluster densities among smaller nodes outside hubs. Although Kaluza et al. (2010) contradict Deng et al. (2009) about the extent to which the global maritime network is more or less “efficient” (i.e. low average number of stops between two nodes) than other transport networks such as airlines, we denote in Figure 8.4 an increase in efficiency as the Average Shortest Path Length (ASPL) has gradually diminished, especially since the early 2000s. Besides the expansion of the global liner shipping network, this effect of scale economies is compensated by regional integration dynamics, as seen with the increase of the average clustering coefficient on nodes and on links. This means that route rationalization goes hand in hand with an increase of local/regional density, which may in turn be interpreted in terms of regional integration backed by the multiplication of links served by coastal and shortsea shipping.

Another important trend topologically speaking is the decreasing hierarchical structure of the network, as revealed by the slope of the power-law fit between degree centrality and its probability (EXP). Thus, three trends affected the evolution of the global liner shipping network: expansion, regional consolidation, and polarization. Such trends may contradict each other but our analysis suggests that they are in fact concomitant. Integration processes (multiplication of intraregional links, new direct calls and multi-port services using shortsea shipping), as in the small-world model, may benefit from diseconomies of scale in large gateway and hub ports, while competition is fierce between existing and emerging hub ports. Shipping lines may use both types of ports to build their services, resulting in the concentration of links among fewer hubs as in the scale-free model. This is in line with the empirical literature on complex networks where it has been increasingly recognized that spatial networks are in fact both small-world and scale-free, i.e. which structure and growth being dictated by the existence of dense communities connected internally and externally by a few large nodes.

### 3.2 The centrality of container ports

The impact of liner shipping network's operation on container ports is often analysed in terms of throughput, the most widely available indicator of port performance in official statistics. Table 8.1 shows the classic port hierarchy with regard to the number of containers (TEUs) handled by top ports since the 1970s, regardless of the function of ports in the maritime network. However, the network perspective allows for calculating the connectivity of ports, which long remained missing in the related literature (Ducruet, 2015). In this chapter, we compare three measures of centrality based on the configuration of inter-port links in a binary port-to-port matrix (i.e. presence or absence of links between two given ports). First, *betweenness centrality* counts the number of positions of a node on possible shortest paths among all nodes in the entire network (Ducruet and Rodrigue, 2019). It is a measure of accessibility or reachability on the global scale (see Table 8.4), reflecting upon ports' uneven ability to be positioned along major routes and/or crossroads. Second, the *average clustering coefficient of connected* links, which is named here intermediary, corresponds to the capacity of ports to connect communities with each other, or in the maritime world, to act as a bridge hub between different port regions. Values close to 0 indicate a high bridging or interlining role, while those closer to 1 mean that such ports are better situated within such port regions. Thirdly, the clustering coefficient is the proportion of connected neighbours (thus forming triangles or "cliques") in the maximum possible number of links among adjacent neighbours. The lower the value, the more likely is the port in the middle of a star-shaped or "hub-and-spokes" system whereby it centralizes flows to/from secondary nodes. Higher values underline the position of the port within a dense network with more numerous options to circulate.

These measures originating from network analysis across all fields of investigation from physics to sociology can provide answers to theoretical configurations provided by Fleming and Hayuth (1994) on the centrality and intermediacy of transportation hubs and about the aforementioned liner service configurations (Figures 8.1 and 8.2). These measures can reveal other dimensions than sole throughput, with which they also can be more or less correlated. In particular, Table 8.4 looks at how the world's top 25 ports (in terms of betweenness centrality) exert these three functions simultaneously, interpreted in terms of scale: global reach, regional intermediacy, and local hubbing.

[ Insert Table 8.4 about here ]

A first look at the linear (Pearson) correlation between centralities and vessel traffic (DWT) at selected years for the whole world sample of ports shows a relatively low significance overall, with an $R^2$ around 0.30 for intermediate centrality (declining significance), around 0.50 for global - betweenness - centrality (growing significance), and about the same for local (hub) centrality (stable significance). The weak relationship between centralities and deadweight traffic is interesting as it suggests that each port function works differently and has different impacts on the final product, total port activity measured by volume. This is the first time that such functions are compared with each other and the following analysis will only concentrate on the specialization effects among the top 25 ports. Our analysis of different centralities may search for correspondence between them, as in the case of the global liner shipping network where degree centrality (or number of adjacent neighbours) fits well nodes' strength (or weighted degree centrality, total traffic), but also divergence, as in the case of airline networks where very central airports (betweenness) may have few direct connections (degree centrality or number of direct neighbours) (Guimera et al., 2005).

In 1977, Piraeus stands out by it strong regional and local centrality, being at that time the leading Mediterranean hub linking East, West, and the Black Sea with each other along the Europe-Asia trunk line. Thus, Piraeus, like Rotterdam for North Europe, is an exemplary case of a triple hub, centralizing flows at all scales, resulting in high throughput volumes. Singapore as well is particularly well scoring in such a category, confirming its overwhelming transhipment function, which reaches more than 80 per cent of its total throughput nowadays. Another example is Surabaya in 2006, which developed inter-island services across Eastern Indonesia or Reykjavik at a smaller scale in 1996. In more recent years, Piraeus lost its pivotal role to other Mediterranean hubs such as Gioia Tauro (Italy), although the latter is more a local hub than an intermediary hub in 2006 and 2016, like Marsaklokk (Malta) and Tanger Med. At the opposite side of the coin, it is possible to detect gateway ports in Table 8.4, which may be well positioned along trunk lines made of pendulum and deep-sea services, but with a lower transhipment function regionally and locally. Typical examples are Los Angeles, Marseille Fos, Genoa in 1977, New York, Charleston, London, Tokyo in 1986; ports which became even somewhat peripheral in the network due to the emergence of hub ports from the 1990s onwards.

This would suggest that network indicators are very good tools for understanding overall port performance, although they do not include land-based dimensions of hinterland connectivity (see Berli et al., 2018) and other aspects of performance such as technical standards and the availability, quality, size, and cost of terminal handling facilities and services. At the top of the hierarchy, large gateway ports such as Shenzhen and Yokohama may have less betweenness centrality than transhipment hubs, while ports combining both functions may rank high in the three indicators. Overall, the position of ports in shipping networks seems to explain a large part of their overall activity.

## 5. CONCLUSIONS

The extensive worldwide container shipping networks are key to globalization and global supply chains. The requirements on container shipping service networks have tightened in terms of frequency, schedule reliability/integrity, global coverage of services and rate setting. The evolutionary path of liner shipping networks and port operations is characterised by drastic changes as well as permanencies. Shipping lines have embraced a wide range of bundling concepts and liner service configurations to drive container service network dynamics. As global trade expands in economical and geographic terms, despite difficult conjunctures such as the global financial crisis, new ports and new shipping networks are regularly created to cope with demand. Shipping lines logically adapt to such trends as well as influence them, sometimes by refining their services through rationalization or by creating new service configurations through a combination of line bundling itineraries and transhipment/relay/interlining operations at pivotal ports of the network.

This chapter provided evidence about the increasing complexity and number of cargo movements that occurs in parallel with increased concentration and polarisation, depending on the measures and methodologies applied for revealing such trends. It discussed some fundamental aspects, such as the economic and geographic dimension of the variety of services offered by the industry, as well as the functional specialization of maritime centrality for container ports, although in this simple equation, hinterland connectivity and port efficiency are not included. Looking at the distribution of main trading routes as well as disaggregated interregional and inter-port shipping links, the latter being compared with kilometric distance, we observed that the overall network is growing in size and length notably thanks to a catching-up of South-South linkages versus North-North and North-South linkages. However, most worldwide traffic still concentrates over very short distances, that is more specific to maritime transport than to air transport due to adjacent calls between ports.

In light of our results, further research on container shipping networks should go deeper in the analysis of the causal relationship between throughput and centrality for container ports, while better identifying specific cases and outliers. Another avenue of future research would be to test the impact of the global financial crisis on the overall structure of regional and global liner shipping networks, as well as on the position of individual container ports, which would complement the classic view of shipping based on aggregated cargo flows among major trade routes. The global database on vessel movements has been expanded to back to the 19$^{th}$ century (see Ducruet and Wang, 2018) looking at the urban dimension and other types of vessels so as to better appreciate the changing determinants of network structure and growth, but these elements may be further investigated to test the effects of port competition, port system formation, urban congestion, and port migration. Last but not least, the analysis of the situation of ports and cities within the all-encompassing supply chain including other modes

(Robinson, 2015) would prove helpful for the study of logistics chains, the hinterland-foreland continuum, intermodal transport systems, and port competitiveness.

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## Table 8.1. Top 25 container ports 1970-2018 (000s TEUs)

| Rank | 1970 | | 1980 | | 1990 | | 2000 | | 2009 | | 2014 | | 2018 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Oakland | 336 | New York | 1947 | Singapore | 5224 | Hong Kong | 18098 | Singapore | 25866 | Shanghai | 35290 | Shanghai | 42010 |
| 2 | Rotterdam | 242 | Rotterdam | 1901 | Hong Kong | 5101 | Singapore | 17040 | Shanghai | 25002 | Singapore | 33870 | Singapore | 36600 |
| 3 | Seattle | 224 | Hong Kong | 1465 | Rotterdam | 3667 | Busan | 7540 | Hong Kong | 20983 | Shenzen | 24030 | Shenzen | 27740 |
| 4 | Antwerp | 215 | Kaohsiung | 979 | Kaohsiung | 3495 | Kaohsiung | 7426 | Shenzhen | 18250 | Hong Kong | 22230 | Ningbo | 26350 |
| 5 | Belfast | 210 | Singapore | 917 | Kobe | 2596 | Rotterdam | 6280 | Busan | 11955 | Ningbo | 19450 | Guangzhou | 21870 |
| 6 | Bremen/Br. | 195 | Hamburg | 783 | Los Angeles | 2587 | Shanghai | 5613 | Guangzhou | 11190 | Busan | 18650 | Busan | 21660 |
| 7 | Los Angeles | 165 | Oakland | 782 | Busan | 2348 | Los Angeles | 4879 | Dubai | 11124 | Qingdao | 16620 | Hong Kong | 19600 |
| 8 | Melbourne | 158 | Seattle | 782 | Hamburg | 1969 | Long Beach | 4601 | Ningbo | 10503 | Guangzhou | 16160 | Qingdao | 18260 |
| 9 | Tilbury | 155 | Kobe | 727 | New York | 1872 | Hamburg | 4248 | Qingdao | 10260 | Dubai | 15250 | Tianjin | 16000 |
| 10 | Larne | 147 | Antwerp | 724 | Keelung | 1828 | Antwerp | 4082 | Rotterdam | 9743 | Tianjin | 14050 | Dubai | 14950 |
| 11 | Virginia | 143 | Yokohama | 722 | Yokohama | 1648 | Shenzhen | 3994 | Tianjin | 8700 | Rotterdam | 12300 | Rotterdam | 14510 |
| 12 | Liverpool | 140 | Bremen/Br. | 703 | Long Beach | 1598 | Port Klang | 3207 | Kaohsiung | 8581 | Port Klang | 10950 | Port Klang | 12320 |
| 13 | Harwich | 140 | Baltimore | 663 | Tokyo | 1555 | Dubai | 3059 | Port Klang | 7310 | Kaohsiung | 10590 | Antwerp | 11100 |
| 14 | Gothenburg | 128 | Keelung | 660 | Antwerp | 1549 | New York | 3050 | Antwerp | 7310 | Xiamen | 10130 | Kaohsiung | 10450 |
| 15 | Philadelphia | 120 | Busan | 633 | Felixstowe | 1418 | Tokyo | 2899 | Hamburg | 7010 | Dalian | 10130 | Xiamen | 10000 |
| 16 | Sydney | 118 | Tokyo | 632 | San Juan | 1381 | Felixstowe | 2853 | Los Angeles | 6749 | Hamburg | 9730 | Dalian | 9770 |
| 17 | Le Havre | 108 | Los Angeles | 621 | Bremen/Br. | 1198 | Bremen/Br. | 2752 | Tanjung Pelepas | 6000 | Antwerp | 8980 | Los Angeles | 9460 |
| 18 | Anchorage | 101 | Jeddah | 563 | Seattle | 1171 | Gioia Tauro | 2653 | Long Beach | 5068 | Tanjung Pelepas | 8500 | Tanjung Pelepas | 8960 |
| 19 | Felixstowe | 93 | Long Beach | 554 | Oakland | 1124 | Melbourne | 2550 | Xiamen | 4680 | Los Angeles | 8330 | Hamburg | 8730 |
| 20 | Kobe | 90 | Melbourne | 513 | Manila | 1039 | Durban | 2497 | Laem Chabang | 4622 | Long Beach | 6820 | Long Beach | 8090 |
| 21 | Hamburg | 72 | Le Havre | 507 | Bremerhaven | 1030 | Tanjung Priok | 2476 | New York | 4562 | Laem Chabang | 6580 | Laem Chabang | 8070 |
| 22 | Zeebrugge | 70 | Bordeaux | 453 | Bangkok | 1018 | Yokohama | 2317 | Dalian | 4552 | Tanjung Priok | 5770 | Tanjung Priok | 7640 |
| 23 | Montreal | 68 | Honolulu | 441 | Tacoma | 938 | Manila | 2292 | Bremen/Br. | 4536 | New York | 5770 | New York | 7200 |
| 24 | Hull | 59 | San Juan | 428 | Dubai | 916 | Kobe | 2266 | Jawah. Nehru | 4061 | Yingkou | 5770 | Colombo | 7050 |
| 25 | Tokyo | 54 | Sydney | 383 | Nagoya | 898 | Yantian | 2148 | Tanjung Priok | 3800 | Colombo | 4910 | Yingkou | 6500 |
| Total 25 ports | | 3551 | | 19483 | | 49168 | | 120820 | | 242417 | | 340860 | | 384890 |
| World total | | 4423 | | 34806 | | 84642 | | 235569 | | 432018 | | 625000 | | 771000 |
| Share 25 ports | | 80% | | 56% | | 58% | | 51% | | 56% | | 55% | | 50% |

Source: Containerisation International, The Journal of Commerce, Lloyd's List and AAPA

**Table 8.2. World's major trade routes in 2018**

| Main route | Transpacific | | Europe-Asia | | Transatlantic | |
|---|---|---|---|---|---|---|
| | East Asia-North America | North America-East Asia | East Asia-Europe | Europe- East Asia | North America-Europe | Europe-North America |
| Cargo flows (million TEUs) | 20.9 | 7.4 | 17.4 | 7.0 | 3.1 | 4.9 |
| Growth 2017-2018 (per cent) | 7.0 | 0.9 | 5.7 | -1.3 | 6.8 | 6.4 |

Source: UNCTAD (2019), based on data from MDS Transmodal

## Table 8.3. Distribution of interregional container flows, 1977-2016 (million DWT)

| Region | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Asia-North America | 4.8 | 6.4 | 6.3 | 8.3 | 5.4 | 8.9 | 10.0 | 11.7 | 13.8 | 12.9 | 16.0 | 17.0 | 17.4 | 19.7 | 18.6 | 20.9 | 22.5 | 25.3 | 27.1 | 26.2 |
| Africa-Europe | 0.2 | 1.0 | 0.7 | 1.9 | 0.9 | 2.1 | 2.3 | 2.3 | 2.5 | 2.3 | 2.9 | 2.9 | 3.1 | 3.8 | 4.7 | 4.6 | 4.7 | 5.7 | 5.9 | 6.9 |
| Asia-Europe | 0.6 | 0.7 | 3.2 | 4.7 | 3.9 | 5.0 | 6.1 | 7.1 | 6.8 | 6.4 | 5.9 | 10.0 | 12.0 | 10.4 | 10.3 | 12.1 | 14.2 | 14.5 | 12.0 | 14.1 |
| Latin America-North America | 1.8 | 1.5 | 1.7 | 1.9 | 1.4 | 2.3 | 1.9 | 2.5 | 3.1 | 3.6 | 3.5 | 3.6 | 4.4 | 4.9 | 5.7 | 8.0 | 8.1 | 9.3 | 11.2 | 15.0 |
| Africa-Asia | 0.1 | 0.1 | 0.1 | 0.2 | 0.3 | 0.7 | 0.6 | 0.5 | 0.6 | 0.5 | 0.7 | 0.8 | 1.0 | 1.9 | 2.9 | 2.7 | 3.1 | 4.6 | 5.4 | 5.9 |
| Europe-North America | 4.0 | 5.0 | 4.6 | 5.9 | 4.1 | 5.8 | 6.4 | 6.5 | 7.5 | 7.6 | 8.4 | 9.3 | 9.9 | 9.7 | 9.9 | 10.5 | 10.6 | 12.8 | 13.2 | 12.7 |
| Asia-Oceania | 0.9 | 0.9 | 0.9 | 1.4 | 0.8 | 1.7 | 1.7 | 1.7 | 1.7 | 1.9 | 2.1 | 2.3 | 2.5 | 2.7 | 2.6 | 3.5 | 3.5 | 4.1 | 4.2 | 4.8 |
| Europe-Latin America | 0.3 | 0.3 | 0.2 | 0.6 | 0.4 | 0.7 | 0.4 | 0.8 | 1.0 | 1.1 | 1.3 | 1.5 | 1.4 | 1.6 | 1.6 | 2.2 | 2.1 | 2.6 | 2.8 | 3.2 |
| Asia-Latin America | 0.0 | 0.1 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.2 | 0.5 | 0.4 | 0.5 | 0.0 | 0.1 | 0.1 | 0.0 | 0.2 | 0.0 | 0.3 | 0.5 | 1.0 |
| Africa-Latin America | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 | 0.1 | 0.2 | 0.0 | 0.0 | 0.1 | 0.1 | 0.1 | 0.4 | 1.1 | 1.3 |
| Africa-North America | 0.1 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.2 | 0.2 |
| North America-Oceania | 0.5 | 0.7 | 0.7 | 0.8 | 0.7 | 1.0 | 0.6 | 0.6 | 0.6 | 0.8 | 0.9 | 0.9 | 0.8 | 1.0 | 1.1 | 0.9 | 1.1 | 1.3 | 1.3 | 1.3 |
| Latin America-Oceania | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 |
| Africa-Oceania | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.1 | 0.2 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.3 | 0.6 | 0.7 | 0.6 |
| Europe-Oceania | 0.2 | 0.2 | 0.6 | 0.7 | 0.7 | 0.8 | 0.5 | 0.9 | 0.8 | 0.9 | 0.7 | 0.7 | 0.8 | 0.6 | 0.7 | 0.5 | 0.5 | 0.6 | 0.3 | 0.7 |

| Region | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Asia-North America | 30.1 | 31.9 | 35.9 | 42.0 | 45.1 | 48.0 | 52.6 | 56.9 | 64.5 | 71.2 | 73.7 | 74.0 | 60.4 | 63.7 | 65.5 | 64.0 | 68.1 | 69.9 | 71.1 | 66.8 |
| Africa-Europe | 7.3 | 8.6 | 9.3 | 8.7 | 9.8 | 12.4 | 13.9 | 14.6 | 13.6 | 14.8 | 19.2 | 22.5 | 29.0 | 35.3 | 45.8 | 47.7 | 49.8 | 53.8 | 55.3 | 60.4 |
| Asia-Europe | 15.2 | 17.2 | 17.2 | 18.5 | 20.6 | 25.4 | 27.9 | 29.4 | 30.9 | 29.7 | 32.5 | 32.3 | 73.4 | 78.0 | 77.7 | 81.3 | 79.9 | 81.6 | 82.4 | 55.1 |
| Latin America-North America | 17.9 | 23.3 | 23.7 | 25.8 | 23.7 | 26.5 | 31.7 | 31.9 | 33.5 | 34.7 | 34.3 | 34.8 | 31.1 | 31.0 | 41.7 | 43.5 | 44.1 | 44.5 | 49.8 | 52.8 |
| Africa-Asia | 7.4 | 8.1 | 9.2 | 10.7 | 10.9 | 11.8 | 14.6 | 12.9 | 14.0 | 15.8 | 20.3 | 21.9 | 27.2 | 27.5 | 36.4 | 37.1 | 41.2 | 44.5 | 46.4 | 45.8 |
| Europe-North America | 14.5 | 16.6 | 13.7 | 14.5 | 17.0 | 17.1 | 18.0 | 15.5 | 15.6 | 19.2 | 20.4 | 17.2 | 19.3 | 18.5 | 22.7 | 23.7 | 23.6 | 25.0 | 26.2 | 23.2 |
| Asia-Oceania | 6.1 | 7.3 | 8.2 | 8.4 | 8.5 | 9.1 | 9.6 | 10.3 | 11.0 | 12.0 | 13.6 | 14.5 | 12.8 | 13.8 | 15.2 | 14.7 | 15.6 | 18.2 | 18.0 | 17.8 |
| Europe-Latin America | 3.7 | 4.0 | 3.6 | 4.1 | 5.1 | 6.2 | 8.2 | 7.4 | 7.7 | 8.9 | 9.6 | 10.5 | 15.7 | 15.4 | 16.0 | 17.2 | 15.7 | 16.2 | 17.6 | 16.4 |
| Asia-Latin America | 1.2 | 1.8 | 1.6 | 2.4 | 3.6 | 4.9 | 5.1 | 7.4 | 8.3 | 8.8 | 10.6 | 11.0 | 8.7 | 8.6 | 11.3 | 10.8 | 8.7 | 9.1 | 11.4 | 14.3 |
| Africa-Latin America | 1.7 | 2.1 | 1.9 | 1.6 | 2.2 | 3.0 | 3.4 | 4.1 | 5.2 | 6.0 | 3.6 | 3.1 | 4.4 | 4.0 | 3.4 | 3.3 | 3.2 | 3.2 | 4.1 | 3.9 |
| Africa-North America | 0.4 | 0.5 | 0.5 | 0.4 | 0.5 | 0.5 | 0.8 | 0.7 | 0.5 | 0.7 | 0.8 | 1.1 | 0.7 | 0.8 | 1.4 | 2.1 | 2.6 | 1.6 | 2.4 | 2.0 |
| North America-Oceania | 1.4 | 1.6 | 1.5 | 1.4 | 1.4 | 1.2 | 1.2 | 1.3 | 1.2 | 2.1 | 2.8 | 1.8 | 1.0 | 1.0 | 1.1 | 1.3 | 1.5 | 1.6 | 1.4 | 1.6 |
| Latin America-Oceania | 0.2 | 0.4 | 0.1 | 0.3 | 0.6 | 0.6 | 0.8 | 0.6 | 0.6 | 0.7 | 0.3 | 0.3 | 0.5 | 0.7 | 0.7 | 0.7 | 0.9 | 0.9 | 1.1 | 1.4 |
| Africa-Oceania | 0.8 | 0.7 | 0.6 | 0.9 | 0.8 | 0.7 | 0.8 | 0.3 | 0.3 | 0.6 | 0.5 | 0.6 | 0.2 | 0.2 | 0.5 | 0.9 | 0.9 | 1.3 | 0.9 | 1.2 |
| Europe-Oceania | 0.6 | 0.6 | 0.3 | 0.5 | 0.4 | 0.3 | 0.3 | 0.5 | 0.5 | 0.1 | 0.2 | 0.0 | 0.5 | 0.6 | 0.3 | 0.3 | 0.1 | 0.1 | 0.3 | 0.5 |

Source: own elaboration based on LLI data

*N.B. calculated based on direct calls between regions*

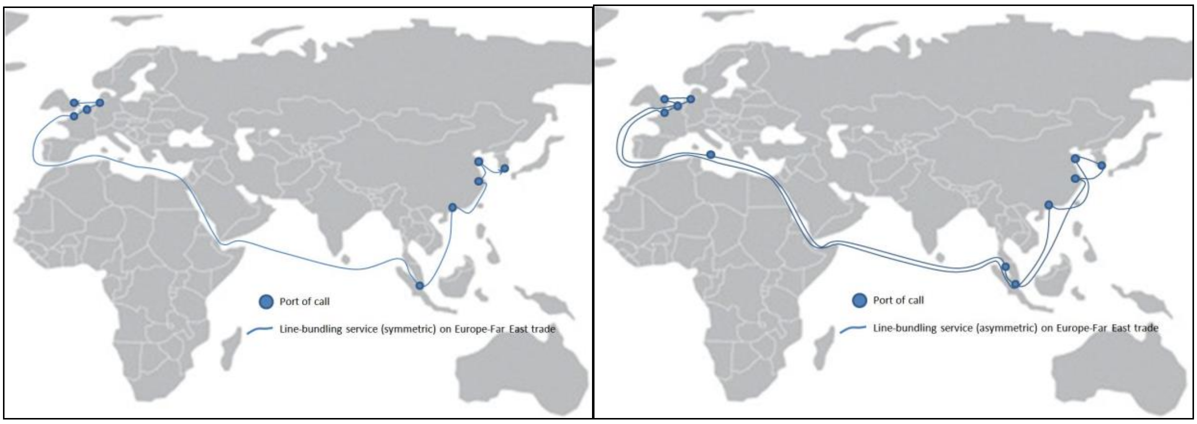
## Table 8.4. Maritime centrality of top 25 ports at selected years, 1977-2016

| | 1977 | | | | 1986 | | | | 1996 | | | | 2006 | | | | 2016 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Port | Global | Intermediary | Local | Port | Global | Intermediary | Local | Port | Global | Intermediary | Local | Port | Global | Intermediary | Local | Port | Global | Intermediary | Local |
| 1 | Rotterdam | 25665 | 0,39 | 0,11 | Rotterdam | 29654 | 0,48 | 0,13 | Singapore | 76289 | 0,24 | 0,09 | Singapore | 77394 | 0,28 | 0,10 | Rotterdam | 119301 | 0,31 | 0,10 |
| 2 | Los Angeles | 15573 | 0,69 | 0,24 | Hong Kong | 27750 | 0,30 | 0,10 | Hong Kong | 41494 | 0,30 | 0,12 | Hong Kong | 56035 | 0,33 | 0,12 | Busan | 118527 | 0,31 | 0,11 |
| 3 | New York | 11777 | 0,67 | 0,19 | Kobe | 20862 | 0,43 | 0,15 | Rotterdam | 29473 | 0,42 | 0,13 | Busan | 51241 | 0,32 | 0,13 | Singapore | 113269 | 0,34 | 0,11 |
| 4 | Kobe | 9787 | 0,49 | 0,18 | New York | 16205 | 0,64 | 0,18 | Le Havre | 25146 | 0,63 | 0,19 | Rotterdam | 45748 | 0,36 | 0,12 | Hamburg | 58193 | 0,38 | 0,12 |
| 5 | Liverpool | 8142 | 0,59 | 0,16 | Jeddah | 15445 | 0,62 | 0,18 | Europoort | 21411 | 0,46 | 0,16 | Bremerhaven | 28376 | 0,37 | 0,14 | Antwerp | 57061 | 0,45 | 0,13 |
| 6 | Singapore | 7737 | 0,42 | 0,14 | Hamburg | 13724 | 0,58 | 0,17 | Yokohama | 21089 | 0,44 | 0,17 | Hamburg | 25948 | 0,34 | 0,12 | Algeciras | 43888 | 0,49 | 0,14 |
| 7 | Hong Kong | 7455 | 0,70 | 0,24 | Piraeus | 12844 | 0,60 | 0,18 | Busan | 20788 | 0,35 | 0,16 | Algeciras | 25183 | 0,56 | 0,17 | Hong Kong | 42878 | 0,49 | 0,16 |
| 8 | Antwerp | 5951 | 0,49 | 0,19 | Antwerp | 12018 | 0,46 | 0,14 | Felixstowe | 18939 | 0,57 | 0,18 | New York | 24299 | 0,75 | 0,24 | Surabaya | 41974 | 0,39 | 0,15 |
| 9 | Fos | 5779 | 0,69 | 0,26 | Melbourne | 11073 | 0,56 | 0,17 | New York | 16468 | 0,74 | 0,23 | Port Klang | 24197 | 0,43 | 0,15 | Port Klang | 35761 | 0,51 | 0,16 |
| 10 | Le Havre | 4793 | 0,59 | 0,21 | Los Angeles | 10977 | 0,63 | 0,20 | Algeciras | 16417 | 0,75 | 0,24 | Shanghai | 24049 | 0,47 | 0,17 | Shanghai | 34654 | 0,50 | 0,18 |
| 11 | Yokohama | 4453 | 0,56 | 0,24 | Santos | 10877 | 0,58 | 0,18 | Antwerp | 15071 | 0,59 | 0,19 | Antwerp | 22791 | 0,52 | 0,17 | Tangier-Med | 34444 | 0,52 | 0,14 |
| 12 | Piraeus | 4184 | 0,37 | 0,13 | Le Havre | 10276 | 0,72 | 0,21 | Hamburg | 15033 | 0,46 | 0,18 | Kingston | 21951 | 0,60 | 0,18 | Jakarta | 30242 | 0,48 | 0,18 |
| 13 | Nagoya | 4114 | 0,52 | 0,23 | Yokohama | 9112 | 0,46 | 0,18 | Bremerhaven | 12855 | 0,50 | 0,20 | Valencia | 19435 | 0,64 | 0,20 | Kingston | 27013 | 0,60 | 0,17 |
| 14 | Houston | 3849 | 0,46 | 0,20 | Port Klang | 8871 | 0,56 | 0,18 | Los Angeles | 12342 | 0,67 | 0,22 | Barcelona | 19174 | 0,64 | 0,21 | Bremerhaven | 26931 | 0,47 | 0,15 |
| 15 | Auckland | 3786 | 0,75 | 0,27 | Genoa | 8207 | 0,69 | 0,22 | Kaohsiung | 11951 | 0,55 | 0,22 | Gioia Tauro | 18815 | 0,61 | 0,21 | Marsaxlokk | 26216 | 0,56 | 0,17 |
| 16 | Leghorn | 3586 | 0,72 | 0,24 | Houston | 7714 | 0,60 | 0,18 | Colombo | 11394 | 0,63 | 0,24 | Marsaxlokk | 18235 | 0,52 | 0,18 | Balboa | 25758 | 0,70 | 0,20 |
| 17 | Melbourne | 3390 | 0,67 | 0,24 | Leghorn | 6866 | 0,73 | 0,22 | Melbourne | 10683 | 0,51 | 0,18 | Le Havre | 17925 | 0,70 | 0,22 | Jebel Ali | 25743 | 0,55 | 0,17 |
| 18 | Genoa | 3355 | 0,63 | 0,25 | Tokyo | 6776 | 0,66 | 0,32 | Santos | 10566 | 0,57 | 0,19 | Surabaya | 17197 | 0,32 | 0,16 | Shenzhen | 23986 | 0,66 | 0,25 |
| 19 | Greenock | 3347 | 0,64 | 0,22 | Valencia | 6768 | 0,72 | 0,24 | Reykjavik | 9951 | 0,38 | 0,11 | Shenzhen | 16074 | 0,67 | 0,23 | Valencia | 23715 | 0,59 | 0,17 |
| 20 | Helsinki | 3321 | 0,38 | 0,21 | Kaohsiung | 6418 | 0,72 | 0,24 | Lisbon | 9417 | 0,60 | 0,20 | Santos | 15505 | 0,70 | 0,23 | Cartagena | 23208 | 0,61 | 0,18 |
| 21 | Hamburg | 3041 | 0,69 | 0,25 | Felixstowe | 6236 | 0,67 | 0,19 | Charleston | 9404 | 0,80 | 0,25 | Manzanillo | 14145 | 0,65 | 0,21 | Gioia Tauro | 22813 | 0,58 | 0,18 |
| 22 | Tokyo | 3016 | 0,67 | 0,27 | London | 6066 | 0,69 | 0,24 | Durban | 9263 | 0,68 | 0,22 | Jebel Ali | 14124 | 0,57 | 0,22 | Tanjung Pel. | 22606 | 0,66 | 0,21 |
| 23 | Port Klang | 3011 | 0,69 | 0,29 | Busan | 5530 | 0,61 | 0,23 | Auckland | 8846 | 0,52 | 0,17 | Kaohsiung | 12902 | 0,60 | 0,23 | Piraeus | 22168 | 0,66 | 0,22 |
| 24 | Charleston | 3001 | 0,76 | 0,28 | Gothenburg | 5260 | 0,55 | 0,23 | Rio Haina | 8624 | 0,66 | 0,24 | Halmstad | 11007 | 0,43 | 0,16 | Colombo | 19959 | 0,64 | 0,20 |
| 25 | Valencia | 2837 | 0,67 | 0,23 | Savannah | 5240 | 0,72 | 0,23 | Abidjan | 8519 | 0,61 | 0,24 | Cartagena | 10796 | 0,67 | 0,22 | Kaohsiung | 19841 | 0,66 | 0,25 |
| | Correl. DWT | 0,55 | 0,40 | 0,51 | | 0,56 | 0,32 | 0,52 | | 0,51 | 0,32 | 0,51 | | 0,59 | 0,28 | 0,59 | | 0,62 | 0,28 | 0,52 |

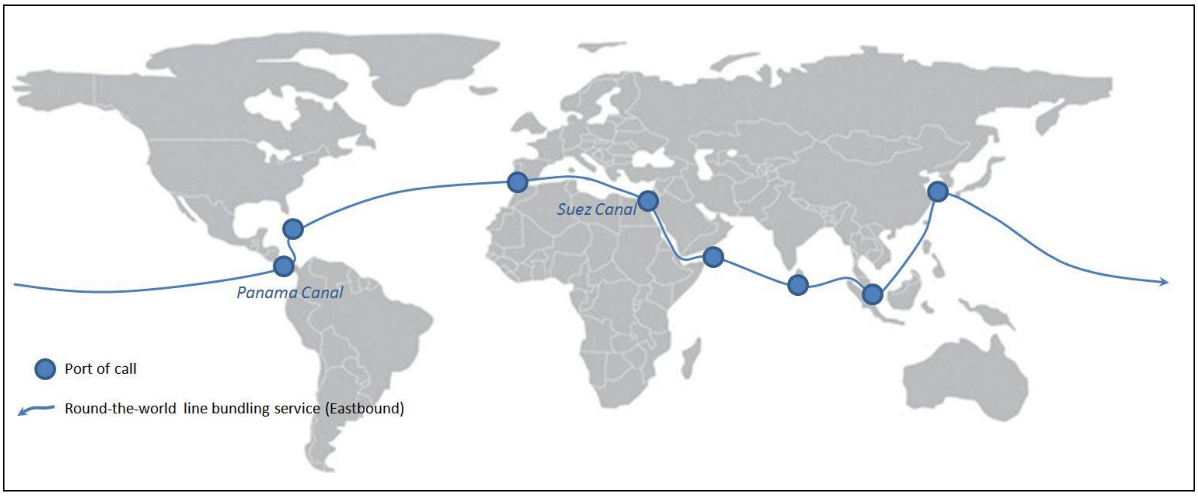
Source: own calculation based on LLI data

**Figure 8.1: Bundling within an individual liner service**

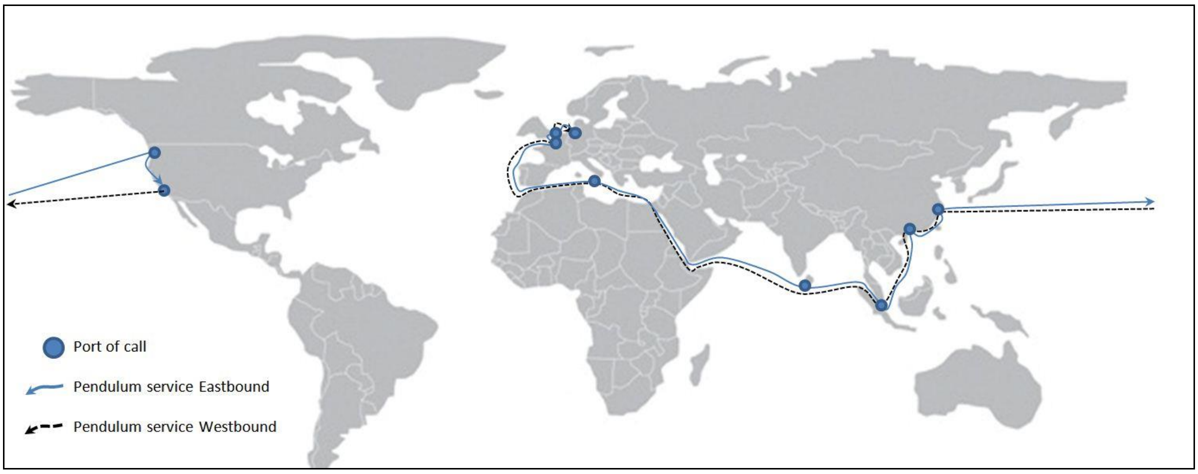
## Line bundling service (symmetric and asymmetric)




## Round-the-world service

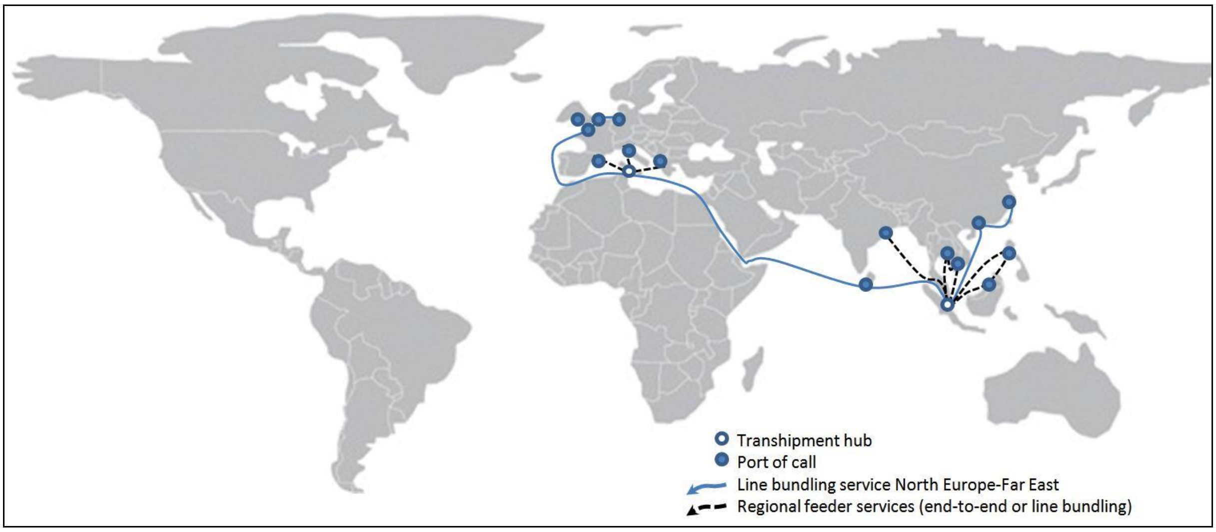



## Pendulum service

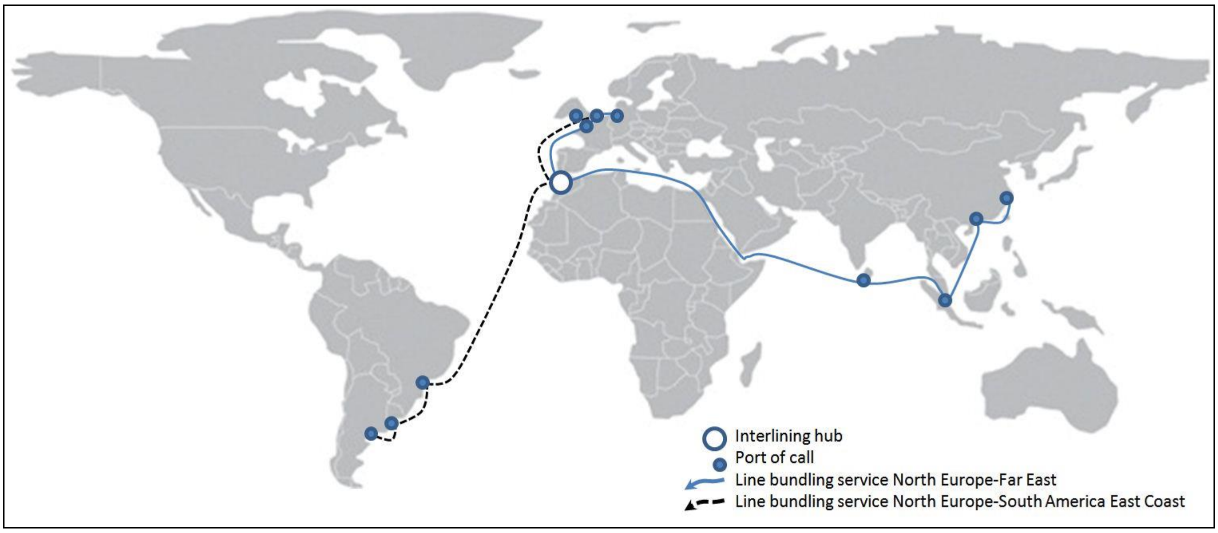


## Figure 8.2: Bundling container cargo by combining/linking two or more liner services

**Hub/feeder (hub-and-spoke) network**




**Interlining**




**Relay**

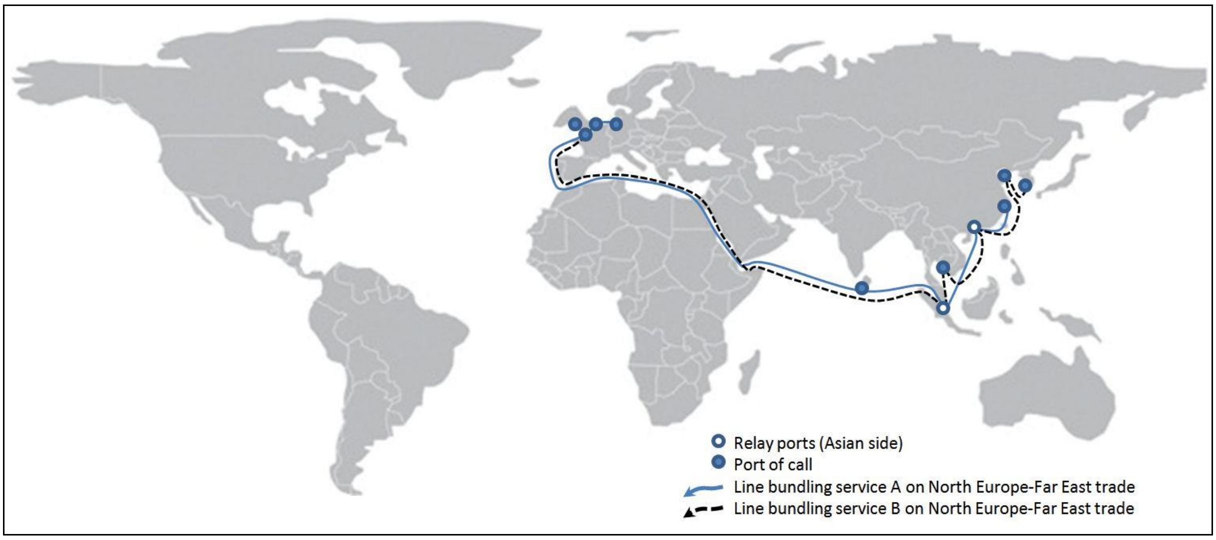
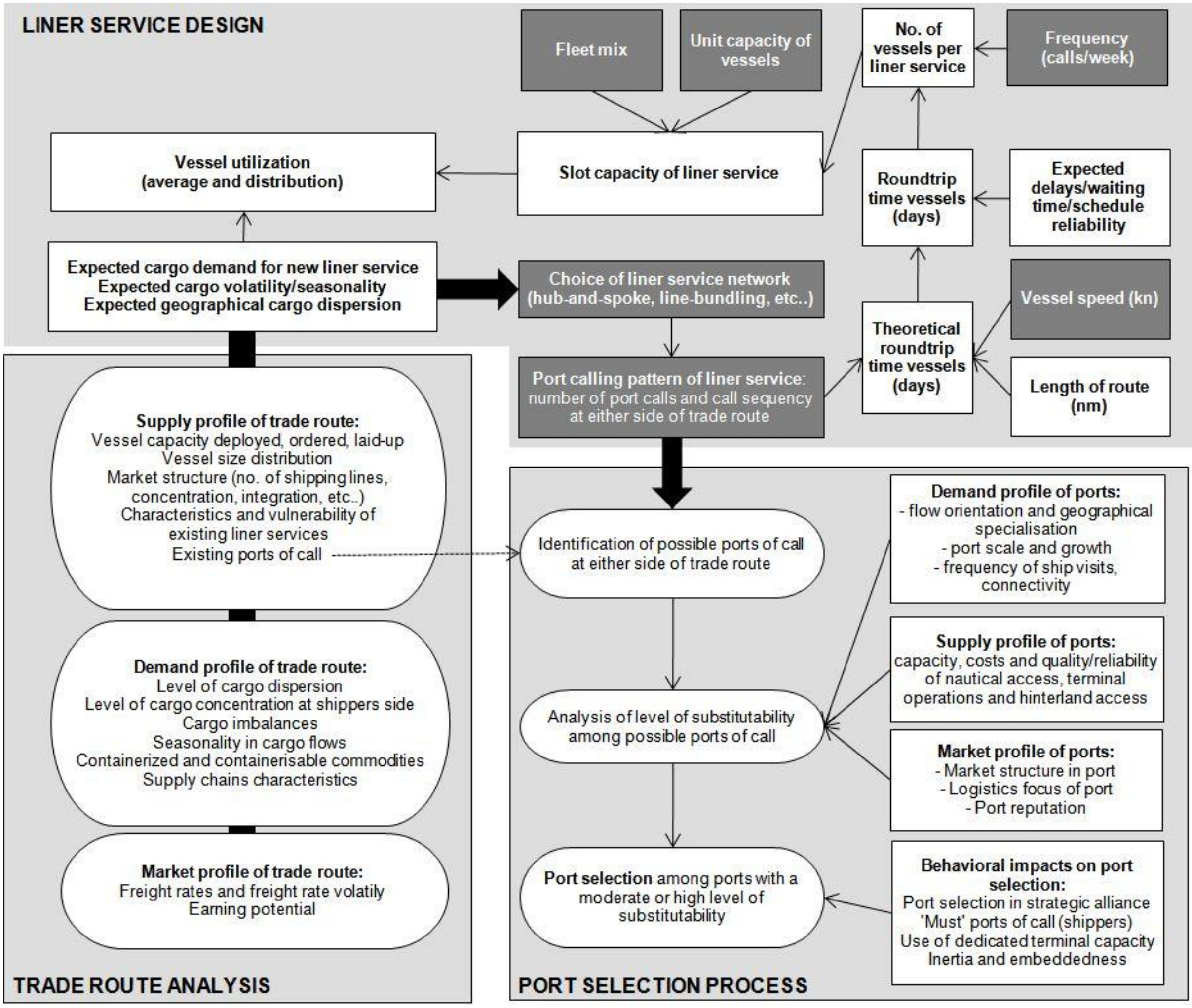


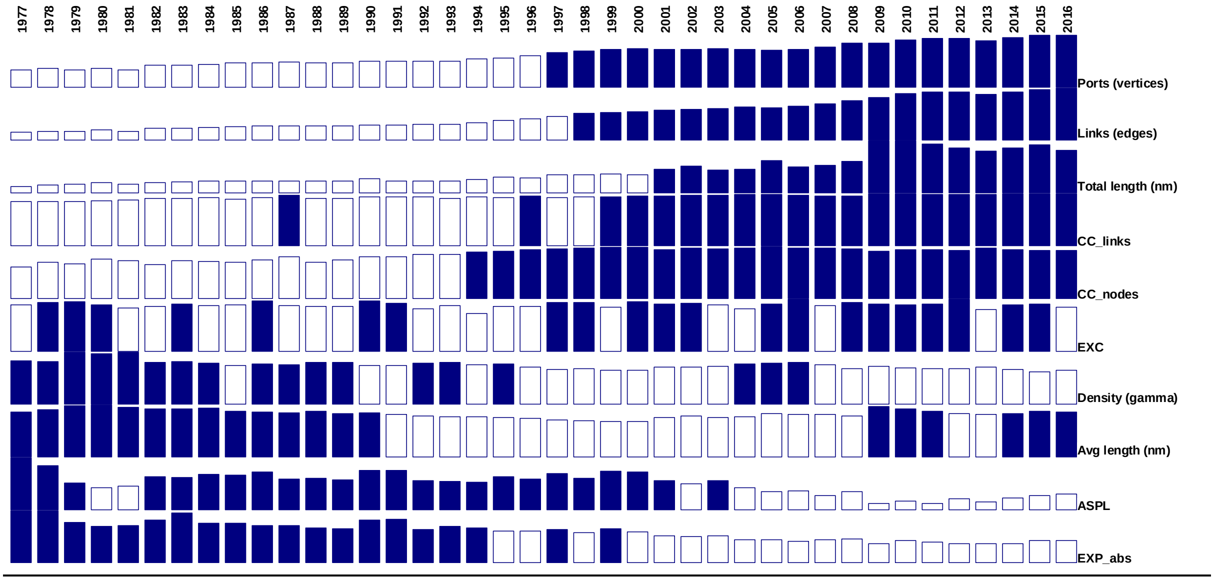
**Figure 8.3: The process of liner service design**




Note: Dark gray/shaded areas are decision variables in liner service design

Source: own elaboration based on insights from Notteboom (2009) and Notteboom and Vernimmen (2009)

**Figure 8.4: Size and topology of the global liner shipping network, 1977-2016**




Source: own elaboration based on LLI data

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