Faculty 7: Business Studies & Economics

STUDYING NETWORK DESIGN IN CONTAINER LINER SHIPPING

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Abstract

Title: Studying network design in container liner shipping

Chapter 1 - Introduction

This thesis studies network design in container liner shipping by concentrating on four research questions:

- How were operational patterns deployed in route design? (Chapter 3)
- How was container shipping network developed? (Chapter 4)
- How efficient were fleet expansion and mega vessel deployment? (Chapter 5)
- How do operational factors influence on route design? (Chapter 7)

Question 1 analyses characteristics of shipping routes, a basis component of shipping operation. Question 2 deals with shipping network, which is a combination of various shipping routes. Question 3 takes account of the deployment of vessel fleet on the shipping system. The first three questions are carried out by conducting empirical researches to investigate strategies of shipping lines in network design. In the final question, we propose a non-linear programming model to optimise the design of a shipping route.

Chapter 2 – An overview of container liner shipping

Chapter 2 concentrates on competition and strategic decisions of operators to survive and grow in the industry. Different market forces have driven competition between them which could be either in favor of or against their rivalry. To seek competitive advantage, shipping lines have made use of various strategies such as capacity expansion, merger and acquisition, dedicated container terminal and logistics involvement. Not only have they fought against other rivals but also cooperated together through long-term commitment of strategic alliances. In addition, liner carriers have enlarged their presence in the global supply chain through handshakes with port and inland operators.

Chapter 3 – Deployment of operational patterns

Chapter 3 studies operational patterns with the emphasis on end-to-end, round-the-world, and pendulum patterns. The first research issue deals with their deployment on designing shipping routes on the East-West corridor. The second one compares their operational characteristics to see more clearly their strength and weakness. An empirical work is carried out using 2,074 route records of the top 20 shipping lines from 1995 to 2011. During the period, end-to-end was the dominant pattern

with 81% to 93% of the surveyed routes operating under the pattern. Pendulum was in favor in the early 2000s, but the use became declined afterwards. Round-the-world had been expected as an innovation in the industry but it was employed limitedly. An important feature of round-the-world and pendulum patterns is to include multiple trades on a single route, which can bring about the advantage of traffic bundling and less fleet requirement. On the other hand, multiple trades result in more complexity of these patterns displayed through long voyage distance and time, a greater number of visited regions and ports of call. The deployment of mega vessels is also restricted due to traffic discrepancy between trade lanes.

Chapter 4 – Development of the shipping network on the East-West corridor

Chapter 4 investigates the topological structure of the East-West shipping network from 1995 to 2011. The theoretical background is based on graph theory, statistical techniques, social network analysis, and transportation network structure. Data is deployed from the service information published in Containerisation International Yearbooks and processed by designated computer programs. The expansion of the shipping network to adapt to the growth of global trade is displayed by the increase of deployed fleet, the number of served ports and weekly calls. Major features of arcs on the network are identified in respect of nautical distance, travelling time and assortativity. Port strength on the network is evaluated on the basis of degree centrality with the majority of the largest degree ports located in East Asia. The power law distribution of port degree indicates the existence of many small degree ports and only a few high degree ones. Highly positive correlation coefficients between port degree and throughput express the causal link between them. The dynamics of regional networks is observed through network indicators. A salient trend is the de-concentration process happening in many regions, in that, secondary ports grew strongly and lowered the centrality of bigger ones.

Chapter 5 – Economics of ship deployment

The world fleet capacity has been continuously enlarged in container liner shipping. In line with the enlargement, new ship generations have been launched, especially since the 1990s. Chapter 5 addresses the two major issues of capacity expansion and growth of ship size in the industry. Multiple regression models are built to measure the effects of fleet capacity and ship size as well as slot utilisation level, market freight rate and oil price on revenue and cost of shipping lines in the period 1997-2012. Investing in new capacity will lead to higher total revenue of operators whereas lower unit revenue. Its positive effect on total and unit cost can be noted. No statistical evidence is found to indicate the relationship between ship size and financial indicators. Additionally, it is

possible to evaluate positive influence of slot utilisation level and market freight rate, and negative influence of oil price on financial results of liner carriers.

Chapter 6 – Literature survey of network optimization in container liner shipping

Container liner shipping is a network-based industry, so network decision contributes much to the success of operators. There are many decisions in respect of network optimization such as route and schedule design, port selection, fleet size and mix, fleet assignment and scheduling, container movement. This chapter conducts a literature survey to realize optimization problems, methodologies as well as research tendencies to deal with network optimization in container liner shipping. Three major categories are focused on: container routing, fleet management and network design. Container routing is related to optimal flow movement of laden and empty containers. Fleet management is involved with decisions of ship assignment and scheduling. Network design is the problem of choosing ports and combining them to create the infrastructure of shipping operation.

Chapter 7 – Optimal route design by incorporating maritime and inland factors

As container shipping network has become a component in the global supply chain, route design should take both maritime and inland factors into consideration. In this article, a model is proposed to optimise container flows between two continents via an end-to-end service. It is concerned with not only an optimal shipping route but also inland connection between hinterlands and ports. The objective is to minimise the total cost consisting of ship cost, port cost, inland/feeder transport cost, inventory cost and CO_2 cost. The model is applied on the real trade between Europe and the USA. It is realised that inland/feeder transport cost contributes the biggest portion to the total cost. The cost is influenced significantly by port choice. Although the deployment of a greater number of port calls on shipping routes results in longer distance and higher shipping cost, it benefits in terms of cheaper distribution cost between hinterlands and loading/unloading ports. Inventory cost is a kind of hidden cost. Nevertheless, it plays a considerable part in the total cost and increases as vessel capacity goes up. In other words, the cost is a barrier for the launch of bigger vessels. Ship cost and port cost only represent less than one third of the total cost. Therefore, maritime network is only a part of the whole game; its optimisation may not guarantee the optimisation in the whole network.

Key words: container liner shipping; shipping network; network design; network structure; ship deployment.

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Abbreviations

CI	: Containerisation International
EU	: European Union
PIERS	: Port Import Export Reporting Service
TEU	: Twenty-foot equivalent unit
UNCTAD	: United Nations Conference on Trade and Development
UN	: United Nations
UK	: United Kingdom
USA	: United States of America
USD	: United States Dollar
WTO	: World Trade Organisation

Chapter 1: INTRODUCTION

1.1 Background

The advent of containers in the 1950s has provided a new mode of sea transportation which is safer, faster, cheaper and easier to transfer between different transportation processes such as sea-rail, sea-road, and sea-sea. Container liner shipping has become a backbone in the world-wide trade and an essential catalyst for globalisation. According to an analysis of Mandrik (2009), only 10% of global seaborne traffic is carried by container shipping, but its cargo accounts for 52% of the global sea transportation value.

Liner operation is different from that of industrial and tramp shipping. Industrial shipping is concerned with in-house traffic. Tramp shipping operates from one port to others with flexible schedule based on the demand of cargo owners. Liner shipping operates in accordance with a published itinerary and schedule like bus or railway activity. It is not only involved with a single route but also a bundle of routes.

Network design is a core interest of container shipping lines because it determines their success or failure. In 2009, Maersk Line made more than 200 network changes to seek cost savings and network efficiency in the face of sharp decline of seaborne trade (Fossey, 2010). On the one hand, shipping routes directly influence on operational cost of carriers; on the other hand, they affect services provided to customers. A sound network design will create competitive advantage for carriers, which is very important in the circumstance of fierce competition in the market.

A route is a basic element of liner network. It is defined as a sequence of visited ports with pre-determined time to call each port. Based on the way to connect markets, a route can be classified into several patterns. In end-to-end pattern, a vessel sails back and forth between two continents, for instance North America – North Europe (Trans-Atlantic) or Far East – West Coast North America (Trans-Pacific). The pattern is most popular in shipping operation. In round-the-world, a ship sails in only one direction, either eastbound or westbound. In pendulum, a ship moves among three markets. The middle one is referred to as a fulcrum. The ship, as a pendulum, swings to either side of the fulcrum to carry cargo among three markets. In triangle, a ship also service three markets, but only in one direction to get rid of imbalance traffic between markets.

Port selection, service frequency, ship schedule and fleet deployment are key elements of route configuration. Port choice is related to market coverage. The more visited ports, the closer a service to customers. Nevertheless, ship voyage can be longer. On the one hand, the sequence of ports on a route determines voyage distance; on the other hand, it impacts on transit time between port pairs. Service frequency regulates how often a port is called. If a service is more frequent, customer service level will be higher, but the operator will suffer from lower traffic per voyage. Ship schedule is determined much by operating speed. Fast speed can benefit customers in terms of less inventory carrying cost; simultaneously it increases profoundly fuel cost, a cubic function of speed, of the operator. Fleet deployment is related to ship size, a number of ships and fleet mix. Bigger vessels bring about shipping cost advantage, but they require more available cargo; or else economies of scale will become diseconomies of scale.

Shipping network is related to a bundle of routes. It means that shipping activities take place in a system consisting of many routes. Increasing co-operation between shipping lines via forms such as strategic alliances, joint operation and slot sharing has promoted shipping operation to be taken place within several operators' network. Furthermore, the integration of shipping network into the global supply chain means that shipping operation could not stand alone, but must be combined with port and inland operation.

Container liner shipping not only involves the movement of ships on the network but also the movement of containers. Whilst a tramp ship or industrial ship provides transportation service for only one or several shipments, a container ship carries a numerous number of shipments. A 5,000 TEU vessel can be related to thousands of containers of several hundred customers. Each container may have different characteristics, for example, dimension (20' or 40'), type (dry, reefer or dangerous), value (high or low), ports of origin and destination. Therefore, it is not simply the carriage of a container from one port to another, but a selection of suitable services and ships in order to satisfy various constraints of time, cost, operating condition and customers' requirements. Challenge is with both laden and empty containers. Imbalance demand force operators to reposition a large number of empty containers between ports without revenue. On the one hand, they must ensure to provide enough empty containers to serve transportation demand; on the other hand, they try to optimize flows of the empty ones in order to reduce repositioning costs.

1.2 Research questions

This thesis concentrates on solving four major research questions:

Research question 1: How were operational patterns deployed in route design?

Operational patterns regulate ship movement between key market regions on a route. End-to-end, round-the-world and pendulum are three principal patterns in shipping operation. Only a few works investigate the application of these patterns in route design. We carry out an empirical research to study the use of these patterns in practice and their major attributes by using route records on the East-West corridor between 1995 and 2011.

Research question 2: How was container shipping network developed?

This question is answered by analysing the topological structure of the East-West network during the period 1995-2011. Structural properties and evolution of the shipping network can be indicated through computing network indicators. The tool of network analysis has been increasingly applied in recent years to study network development. This research is different from others in two aspects. Firstly, the data is deployed from shipping operation in a long time period (16 years), instead of one or two years. Secondly, it is done on a directed network with multiple weighted arcs between ports, not on an undirected network with single arc between ports as other ones.

Research question 3: How efficient were fleet expansion and mega vessel deployment?

New fleet capacity has been substantially invested in the market. In harmony with such tendency, bigger vessels have been growingly launched. The third issue tries to find out their effect on financial results of shipping lines. Multiple linear regression models are established to measure relationships between revenue (and cost) and other operational factors such as fleet capacity, average ship size, market freight rate, utilisation level and oil price. We consider the effect of carrying capacity and ship size not only on total revenue and cost as previous literature but also on unit revenue and cost. Additionally, scale economies of big vessels have been often evaluated based on their potential cost saving, our analysis takes account of their influence on financial performance of CSLs.

Research question 4: How do operational factors influence on route design?

Route design is a classical problem in network optimisation in container liner shipping. Nevertheless the scope is often restricted on maritime side, without interaction with inland side. In this research, a non-linear programming model is proposed to optimise an end-to-end route between two continents determined by both maritime and inland parameters. The application on real trade data provides insight into effects of various costs on route design. The costs consist of not only conventional ship cost and port cost, but also inventory cost and inland/feeder transport cost and environmental cost.

1.3 Thesis structure

The rest of this thesis is organized as follows. Chapter 2 provides a general picture of the industry through reviewing growth trend, market forces as well as vertical integration and horizontal integration strategies of shipping lines. Chapter 3 studies operational patterns in route configuration with the emphasis on end-to-end, round-the-world and pendulum. Chapter 4 find outs characteristics as well as development of the East-West shipping network. Chapter 5 measures economics of ship deployment to investigate the efficiency of fleet expansion and the wave of mega vessels. Chapter 6 carries out a comprehensive review and classification of network optimisation studies in container liner shipping. Chapter 7 proposes a model to optimise container flows between two regions via an end-to-end service. Chapter 8 summaries the whole research outcomes and indicate issues for future research.

Chapter 2: An overview of container liner shipping

Highlights:

- Strong growth of container shipping traffic
- Challenges of the industry
- Horizontal integration strategies of shipping lines
- Vertical integration strategies of shipping lines

2.1 Introduction

Container liner shipping is one of the most important transportation modes of the world-wide trades. Globalization of the world economy has brought about both opportunity and challenge for it. On the one hand, container traffic has undergone profound growth. On the other hand, competition between shipping lines has become fiercer and fiercer. This chapter aims to study (i) competition in the industry by analyzing market forces proposed by Porter (1998) and (ii) strategic decisions of shipping lines by considering two major growth directions – horizontal and vertical integration.

This chapter is structured as follows. The second section describes the growth of liner trade. The third gives some notes about key business partners of the industry. The next two sections demonstrate horizontal and vertical integration strategies of shipping lines. The final section includes some conclusions.

2.2 Growth of liner trade

Globalization, fostered by trade liberalization, international standardization, efficient telecommunication and transportation (Hoffmann & Kumar, 2010), has definitely become an important catalyst for the growth of international trade. Between 1983 and 2012, world export trade increased from \$1,838b to \$17,930b (WTO, 2013). The average annual growth was 8%, which was much higher than that of global GDP, around 3%.

World-wide expansion of production, distribution and consumption has triggered new demand for container transportation. The mode plays an important role in facilitating seamless movement of freight along the global supply chain. It was assessed to be the most dynamically physical component of globalization and exceeded far the increase of the world export value and GDP (Rodrique et al., 2009). Container traffic has been developed in tandem with the rise of manufactured goods. In 2012, the most valuable and dynamic segment of the global freight flow constituted about 64% (\$11,490b) of the world trade (WTO, 2013) and was carried mostly by container shipping. In the last 3 decades, it grew annually on average 9% in terms of value and 6% in terms of volume. The growing demand is not only for finished goods to serve final consumers but also for components, and semi-finished and intermediate products to serve broad production processes of manufacturers.

Container shipping has become a backbone in the global supply chain and progressively captured freight of some traditional shipping modes. Breakbulk liner shipping has definitely suffered most seriously from the surge of the new one. Its major routes were invaded by containerization mainly between 1968 and 1984 (Phillips, 1996). Today, all of the key trades and most of the minor ones are containerized. Of the 2,168m tons of liner volume in 2013, the conventional mode was responsible for only 532m tons (24.5%) (based on Drewry, 2014). Some cargoes of tramp shipping have been transferred into containers as well. For instance, reefer ships transported about two-thirds of seaborne perishable reefer goods in 1985 (OSC, 2000). After 25 years, its share remained less than 35% and was forecasted to drop in the range of 15-25% by 2015 (Dynamar, 2011b; UNCTAD, 2011).

Containerized cargo has been the fastest growing segment among the major groups since 1980. It rose in the world's total seaborne volume from 2.75% in 1980 to 16.49% in 2012. Of 9,568m tons of goods transported by sea, the segment was estimated some 1,578m tons (UNCTAD, 2013). In terms of TEU, world container traffic increased from 13.5m TEUs to 177.4m TEUs, on average 8.5% per year. It was forecasted by IHS Global Insight that the traffic would exceed 200m TEUs in 2020 and 350m TEUs in 2029 (ISL, 2011). The value of world maritime container trade has gone up as well. It was $2 trillion in 2001 and up to $4 trillion in 2008, which accounts for about one in every $14 of global economic output (UNCTAD, 2009a). About 60% of the value of goods shipped by sea is transported by container shipping (Stopford, 2009, p 505).

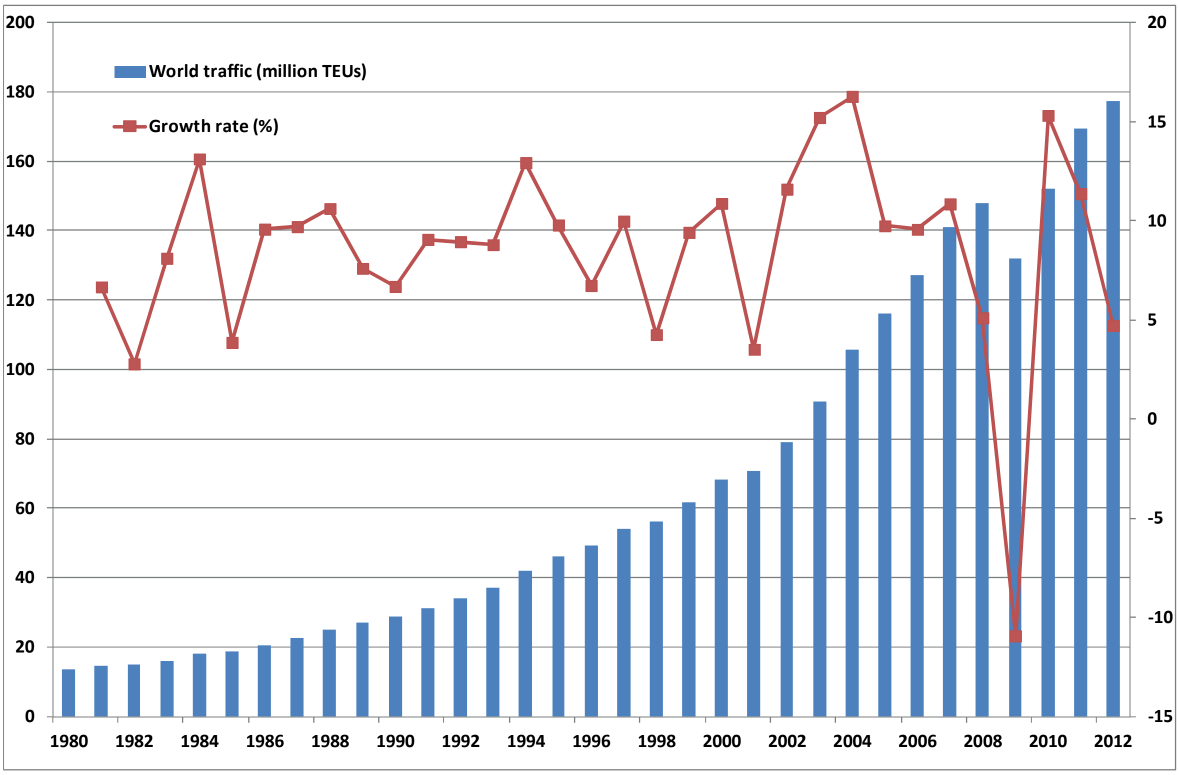


Figure 2-1: Growth of container liner traffic (1980-2012).

Source: Drewry (2000a-2013a).

2.3 Challenge from business partners

Significant market forces influencing on shipping lines come from their business partners, also seen as extended rivals (Porter, 1998). They include shippers who create transportation demand, freight forwarders who play roles of both customers and competitors of carriers, and container terminal operators who provide port services. The section takes into consideration key characteristics of these partners to see their impact on liner competition.

2.3.1 Shippers

In the era of globalization, the world has more and more become a level playing field where all players have the same opportunities. Thus, it is feasible for companies to set up a factory, purchase material, hire labor, and sell products in countries far from their home. They can reach new markets as well as approach cheap and plentiful sources of labor and material. The sourcing of production factors and finished products has become growingly globalized (WB, 2007). Since the 1980s, well-known brands have revised their localized focus which manufacture and marketing products in individual countries (Christopher, 2005). Now they depend on a world-wide basis for their activities. In 2003, 27% of manufacturing activities of American corporations were performed abroad whereas this figure was about 15% for their Japanese counterparts (Rodrique et al., 2009). In 2014, Wal-Mart network embraces 6,100 retail units in 26 countries; or Boeing serves 150 countries and has employees in more than 65 countries.

Whilst benefiting from globalization in terms of new markets and resource supplies, manufacturers have been also faced new challenges. For example, there are more powerful players competing at same target markets. Product life cycle is shorter. Customers require more in respect of service level, lead time, product availability and quality. Especially, their supply, production and market networks become much more complex due to globally geographical expansion.

To remain competitive in the growingly aggressive market, global companies must depend greatly on efficient and effective supply chains to secure their world-wide complicated systems as well as to lower cost. It is argued that “the real competition is not company against company but rather supply chain against supply chain” (Christopher, 2005). Logistics cost could be in the range between 9.5% and 30% of delivered cost (Roberts, 2003), so appropriate logistics strategies will bring considerable cost advantage for products. For instance, thanks to optimal transportation systems, CytoSport, a California-based sport nutrition beverage maker, shaved over $3 million from its 2010 freight budget; LG, a Korean electronic manufacturer, reduced its annual transportation cost by more than 42%, and overall transportation and distributions cost by 8% (Mccrea, 2010). Logistics has certainly become a major attention in the world-wide game and an important source upon which companies can be based to position their competitive advantage. In the USA, the percentage of logistics costs in relation to GDP experienced steady decline from 16.2% in 1981, to 10.6% in 1991, 9.5% in 2001 (MacroSys, 2005) and 8.2% in 2013 (Schulz, 2014).

Container shipping acts as a conveyor belt for manufactured goods around the world, so it contributes greatly to the survival of the global supply chain. Logistics-based competition has inevitably put it under the pressure of cutting cost and improving shipping services. Between 1980 and 2009, maritime freight rates dropped its ratio in import value in all regions. For instance, in developed economies, the ratio was 7.4% in the 1980s, then 7.3% in the 1990s and 6.4% in the 2000s; in developing Asia, the corresponding figures were 8.9%, 8.4% and 7.4% (UNCTAD, 2011). German liner freight indices have also indicated downward trend of liner rate since the middle of the 1980s. Lower freight rates force operators either to cut their expense by network rationalization and mega ship deployment, or to lower their profit.

The operators must enlarge their networks to cover main trades in order to adapt to global market and production of manufacturers. Furthermore extensive port coverage must be taken into consideration to follow market expansion of multi-national companies. Service frequency, on the fortnightly or monthly basis, has been no longer accepted. Weekly service has become a norm in liner industry. In key ports, several calls per week or even daily call is required to serve continuous freight movement of shippers.

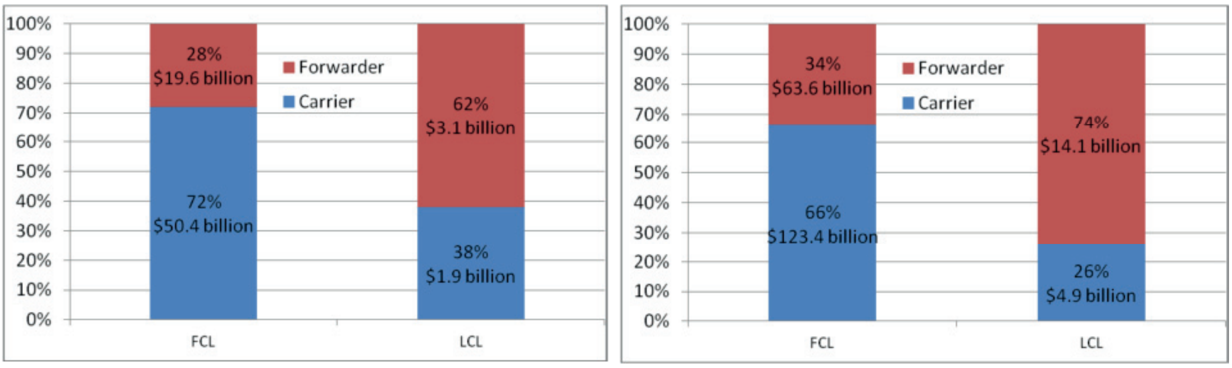
Before some shipping lines, especially Asia-based ones, could have preference in terms of domestic goods as a part of the export-oriented strategy. However, the market is more open now, so they must compete right in their home with other competitors. Liner carriers are doing business with potent shippers who are increasingly dominating the world-wide market and much stronger than local and regional ones. These partners provide a large amount of boxes for them. In 2007, key clients of Maersk Line (about 0.3% of its clients) and direct sale clients (19.6%) represented 47% and 42.1% respectively of its carrying traffic (Maersk Line, 2007). Due to their large volume, global shippers are often in the upper hand when negotiating with shipping lines. If dissatisfied with price or service of an operator, they will be ready to consider other options which could be provided by either other operators or freight forwarders. In 2010, in dispute with Maersk Line over freight increase of its 20,000 TEUs, the British retailer Argos substituted its service provider by the forwarder Kuehne & Nagel.

Shipper power has even been strengthened by their cooperation through influential shipper councils. For example, the GT Nexus Shipper council is a group of large shippers who do business across many industry verticals, earn over $1.2 trillion in collective revenue, and contribute more than 5m ocean TEUs. Such organization certainly owns powerful voice in forcing liner operators to adjust various operating or financial conditions. Moreover, their political lobbies have got rid of some legal frameworks in favor of the operators. In 1998, the Ocean Shipping Reform Act was approved in the USA under the pressure from National Industrial Transportation League, which reduced carriers' US anti-trust immunity (Drewry, 2011d). In 2008, EU liner conference, in operation since the 19th century, was abolished after long struggle of the European Shipper Council. Carriers have been no longer allowed to collaborate in conferences, jointly fix prices and regulate capacity. Consequently, they have been subjected to higher freight rate volatility and competition in liner market.

2.3.2 Freight forwarders

Manufacturers have perceived the need of entire door-to-door services from a single service provider so that they can concentrate on core activities whereas securing their global supply chain scattering in various countries and continents. Global freight forwarders (FFs), capable of providing world-wide coverage and innovative solutions, have captured the opportunity to become bigger and bigger. The gross revenue of the top 50 global companies in 2013 were $260.9b, in that, the top 5 and top 10 made up 40% ($103.8b) and 55% ($142.7b), respectively (A&A, 2013a). They have gradually expanded by taking over other rivals. In the years 1997-2013, 79 acquisition cases over $1m were recorded with total purchase value of $46.6b (based on A&A, 2013b).

Freight forwarders (FFs) are both customers and competitors of liner shipping. On the one hand, they are the most important clients of the industry by purchasing slots to serve their customers' shipments. In 2012, the top 25 FFs were responsible for nearly 31.1m ocean TEUs (A&A, 2013c), some 17.5% of the world container traffic. On the other hand, they fight against liner carriers for catching direct freight from beneficial cargo owners. Several forwarders have reported to capture new business from traditional customers of shipping lines because of slot shortage and high spot rates in 2009 and 2010 (Drewry, 2011d). In 2007, FFs constituted 34% of full-container-load (FCL) shipment revenue and 74% of less-than-container-load (LCL) shipment revenue, while the shares in 1997 were 28% and 62%, respectively. The rise of revenue proportion of FFs indicates clearly their success in attracting more shippers.



Year 1997

Year 2007 (estimated)

Figure 2-2: Rise of freight forwarder revenue share of intercontinental trade.

Source: Based on Merge Global. (2008).

The penetration of FFs into the share of liner operators can be thankful to their structural advantages. Unlike shipping lines which mainly concentrate on maritime legs, FFs can provide a wide range of services to their clients. They are more professional and experienced in inland operation and in organizing optimal flow movement between different partners, transportation modes, and shipments, which can explain their overwhelming share in the LCL segment. They can quickly realize and adapt to any market change due to the closeness to final customers and familiarity with regional marketplaces. Less asset-intensive operation helps them to be more flexible in servicing various customers' demand by choosing different inland or maritime networks.

2.3.3 Terminal operators

Container ports around the world have experienced considerable development. Their throughput grew from 15m TEUs in 1973, to 87.9m TEUs in 1990 and 622.6m TEUs in 2012. On average, it increased 10.1% annually. The growth is clearly in parallel with that of world container traffic (correlation coefficient $R^2 \approx 1$). In line with the upturn of port throughput, it has been observed the acceleration of port liberalization world-wide and growth of global terminal operators.

Privatization has been an important tendency in port development. Since the beginning of the 1990s, private factors have more and more involved port operation, following the dominance of public ones since the 1940s (WB, 1999). From 1990 to 2001, 41 developing countries opened their port markets (WB, 2002). The private sector participated in 220 port projects in developing countries with the cumulative total of over $21.4b in the years 1992-2004 (WB, 2007). Port industry has increasingly adopted the landlord-model and opened to private players to take advantage of their capital, experience in terminal operation and business relationship. According to a survey of Napier University (Baird, 2002c), lower port cost and higher efficiency, trade expansion, less dependence on public funds were main purposes of port privatization.

Following the port liberalization, the public sector has gradually dropped its share and made room for the private sector. The former one handled 41.7% of the throughput pie in 1991, fell to 27% in 2001, and 22.9% in 2012 (Drewry, 2002b, 2013b). Private companies have evolved into container port industry by joint-venture with port authority, renting/investing terminal superstructure or infrastructure, or even in few cases, owning a whole port. According to Peters (2001), the first and second waves of port privatization are related to global expansion of international stevedores such as P&O Ports, HPH, SSA, and PSA whereas the third is the involvement of major carriers. Additionally, there have been participations of financial investors, for instance Macquarie (Australia), RREEF (Deutsche Bank – Germany), Goldman Sachs (USA), and local operators who have concentrated their scope on a single or several ports in a region.

Among these private players, global operators, embracing liner carriers and international stevedores, have been the most dynamic and powerful ones. Global operators have more and more dominated the world-wide container port industry. In 2012, they handled about 78% (466.3m TEUs) of the total throughput, compared with 30% (28.9m TEUs) in 1991 and 53.3% (131.8m TEUs) in 2001 (Drewry, 2002b, 2013b).

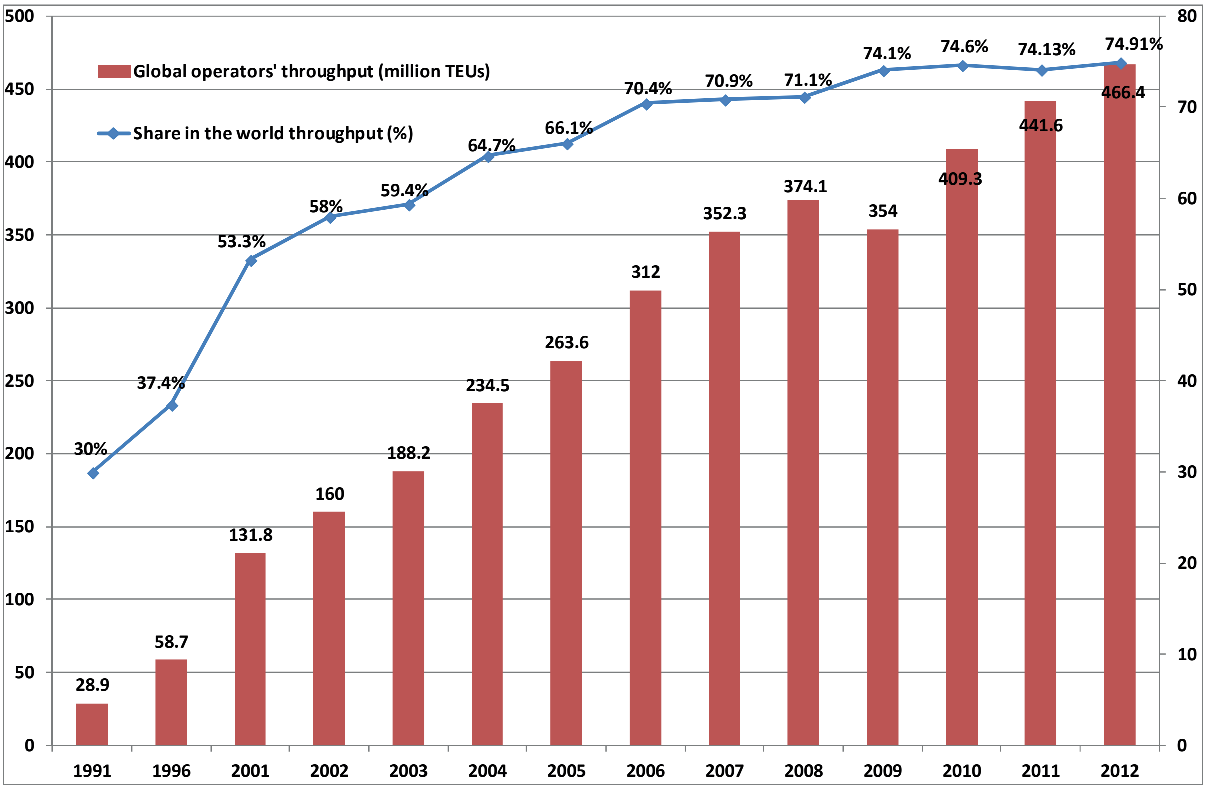


Figure 2-3: Throughput of global terminal operators (1991-2012).

Source: Combined from Drewry (2000b-2013b)

The penetration of liner carriers into the stevedore industry will be analyzed detailedly under the strategy of dedicated container terminal in a later section. On the side of international stevedores, greatly successful in their home ports, they have grasped the wave of port liberalization to enlarge their global coverage. Based in Hong Kong, HPH started going abroad in 1991 by acquiring the port of Felixstowe. In 2014, its network comprises 319 berths in 52 ports, spanning 26 countries in all continents with a combined throughput of 78.3m TEUs. The Singapore-based operator, PSA has approached overseas markets since the second half of the 1990s with the investment in 17 countries across Asia, Europe and the Americas. Since the 2000s, a new player DPW has developed strongly from its home base in Dubai to cover the world-wide market by more than 65 terminals.

International stevedores can diversify their portfolios, increase their throughput and profit by approaching new plentiful markets. They will be less dependent on their home traffic, which can level off in the mature phase and be subjected to aggressive competition from peripheral ports. The dependence of the top international stevedores on home traffic declined significantly during the 2000s, from 53.66% in 2001 to 31.95% in 2012 (based on Drewry, 2002b, 2013b). Among these players, only HHLA still handles most of its traffic in the home base Hamburg (95%), whereas other ones remain a ratio of less than 50%.

2.3.4 Summary

Business partners of liner industry have become more influential and put higher pressure on industry competition. The need of shippers has forced liner carriers to expand market coverage globally, improve service frequency and reliability, and cut cost. Leading freight forwarders have become bigger and bigger. On the one hand, they have been the largest customers of liner carriers; on the other hand, they have posed a threat to liner industry by gaining more direct shipments from beneficial cargo owners. Finally, terminal operation has been no longer carried out by numerous small and local operators, but growingly controlled by global stevedores who certainly possess higher positions in bargaining with shipping lines.

2.4 Horizontal integration

The section aims to introduce key growth strategies of leading carriers to expand their scale in shipping market. The first part mentions capacity concentration in the industry. The second introduces organic growth by acquiring new carrying capacity. Next, it is to describe another growth strategy through merger and acquisition. The final part is an important co-operation mechanism between shipping lines through strategic alliances.

2.4.1 Concentration in liner industry

The game has been progressively in the hands of global carriers, who can service the world-wide market. According to published information of Containerisation International Yearbooks (1991, 2001, 2012), the number of lines dropped from 708 in 1990, to 574 in 2000, and 329 in 2011. At the beginning of the 1980s, the top 20 lines controlled around 40% of the global capacity. The concentration was unclear in the decade; the share of the leading group was often up and down. The process has been accelerated since the end of the decade. In 2013, the top 20 is responsible for more than 76% of the world armada with 14.8m TEUs of 3,398 ships, in comparison with shares of 39% and 57% in 1990 and 2000 respectively. The upward tendency of Herfindahl Hirschman index - HHI (R^2 = 0.92) confirms again the shrink in liner industry. It moved up from 167 points in 1983 to 286 in 2000 and 695 in 2013.

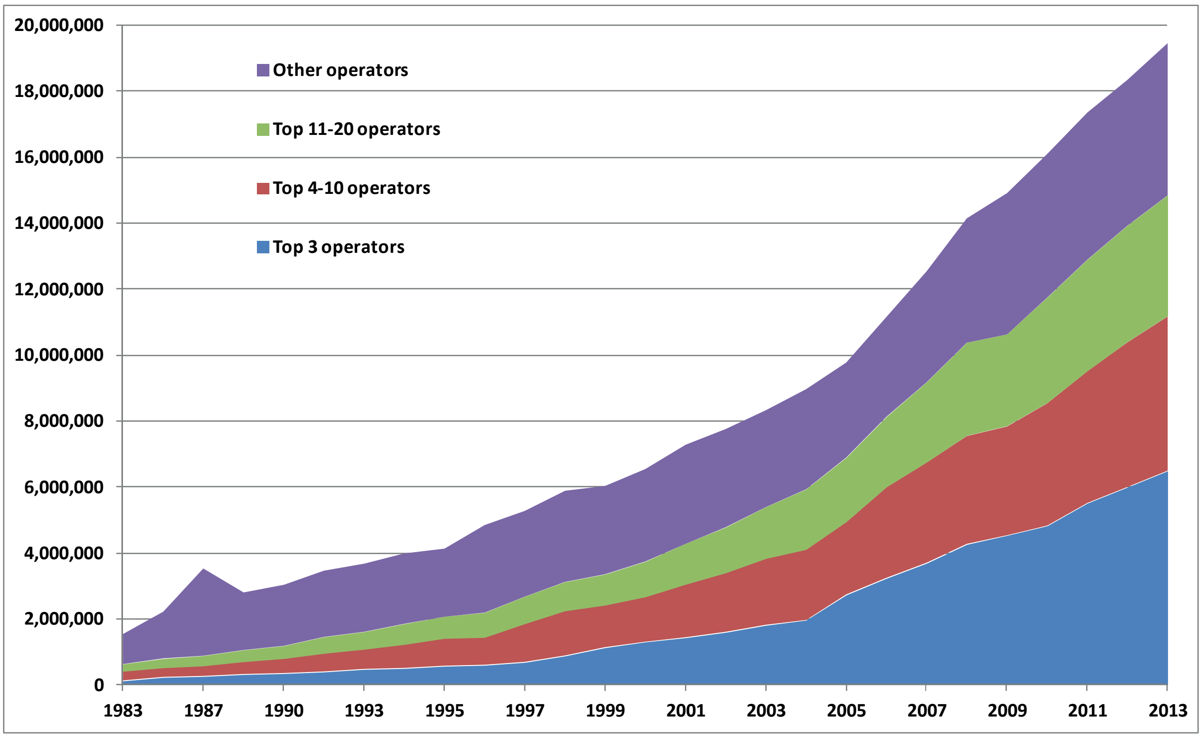


Figure 2-4: Capacity of liner industry segments (unit: 10^6 million TEUs).

Source: Elaborated by the authors based on data published by Containerisation International Yearbook and Monthly (various issues).

Furthermore, some powerful players, especially the top 3, have growingly controlled the market. The gap between the forerunners and others has become wider and wider. In 1990, capacity differences between the largest and the 5th, 10th and 20th largest carriers were 1.9, 2.5 and 4.5 times, correspondingly. These figures were now 3.5, 4.9 and 10 in 2013. The top 3 carriers, Maersk Line (2.6m TEUs), MSC (2.4m TEUs) and CMA-CGM (1.5m TEUs) made up nearly one third of the world capacity, which tripled the top 3 share in 1990. They contributed over 58% of the share growth of the top 20 in the period 1990-2013. In particular, from 2005, almost the growth was thankful to these players.

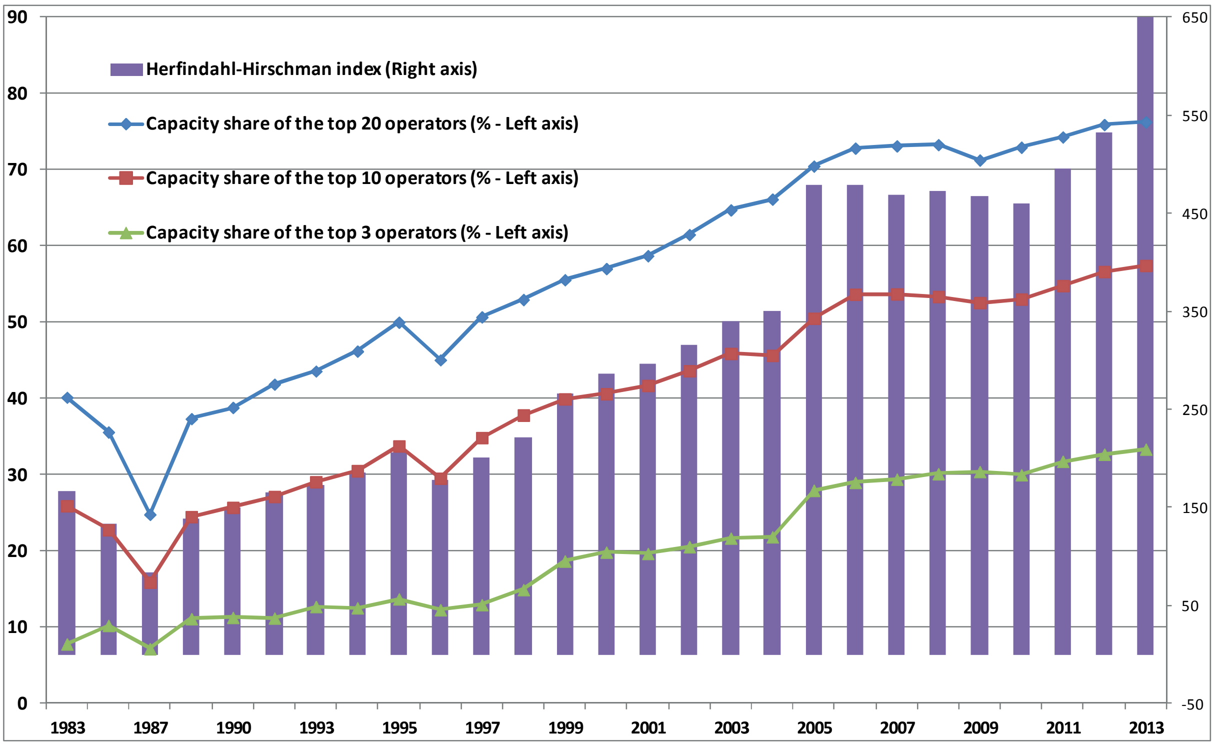


Figure 2-5: Concentration in liner industry (1983-2013).

Source: Calculated by the authors based on data published by Containerisation International Yearbook and Monthly (various issues)

2.4.2 Capacity expansion

Capacity expansion plays a central role in the growth of shipping lines. New building market is a conventional place to increase their scale. According to the containership database of Clarkson (2012), in the years 1990-2011, the top 20 leading carriers occupied more than 6.3m TEUs (1,307 ships), out of 14.7m TEUs (4,635 ships) of the world newbuilding fleet. The three largest companies, Maersk, MSC and CMA-CGM, were also the biggest customers of shipbuilding industry with the new capacities of 1.16m TEUs (215 ships), 0.75m TEUs (127 ships) and 0.55m TEUs (96 ships), correspondingly.

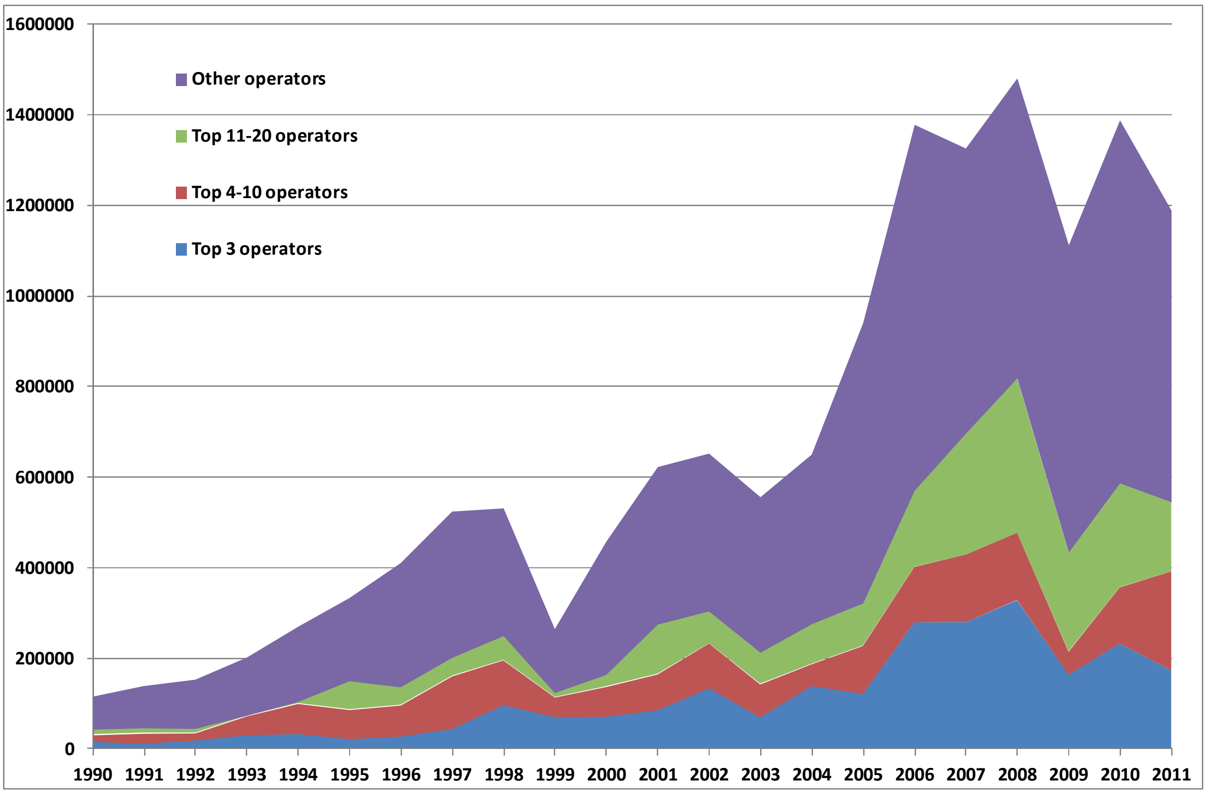


Figure 2-6: New building capacity 1990 -2011 (Unit: TEU).

Source: Compiled based on Clarkson (2012).

A striking feature of fleet development has been the increasing order of mega vessels to create cost leadership position for operators. On the Trans-Pacific route, unit cost of a 1,200 TEU vessel is $648 per TEU, a 4,300 TEU vessel $457 per TEU, and that of an 11,000 TEU one is $360 per TEU (Stopford, 2009). The triple E series of 18,000 TEUs can decrease unit cost 26% lower than current large ships in service. The maximum ship size was 4,300 TEUs in 1988, up to 7,100 TEUs in 1996, 15,500 TEUs in 2006, and then 18,000 TEUs in 2013. By 2011, 390 Post-panamax ships, with the total capacity of nearly 3.8m TEUs, had entered service. Around 62% of the mammoth armada, 2.4m TEUs (246 ships), belongs to the top 20.

Sale and purchase market is another option for carriers to invest in their fleet. Albeit buyers can suffer from higher operating cost, the strategy is beneficial to them in terms of cheaper capital cost and shorter delivery time than the newbuilding one. Whereas the price gap is small in strong market, it becomes significant in crisis time. For example, in 2007, newbuilding price of a 3,500 TEU ship was $58m and price of the same size and 5 years old one was $54.3m, the respective prices were $45.4m and $28.7m in the trough year 2009 (Drewry, 2011a). By 2005, MSC had been well-known for its growth in leaps and bounds based on second-hand purchased tonnage. Its fleet developed from 26,415 TEUs (ranked 19th) in 1990 (Fossey, 1990) to 225,636 TEUs (ranked 4th) in 1999 (CI, 2000), then 618,025 TEUs (ranked 2nd) in 2004 (CI, 2005). Being only an outsider of the top 20 at the end of the 1980s, but the shipping line had moved soon to the top echelon of the industry.

Since the 1990s chartering has become a viable choice for liner operators thanks to the influx of time-charter vessels financed by the German KG system (Drewry, 1999; Stopford, 2009). Similar to plane lessors (see more in Michaels, 2012), container ship lessors are capable of spreading their risks globally, raising debt at lower cost than operators, and taking advantage of preferentially financial regulations. By participating into charter market, shipping lines can avoid capital burden by removing ships from their balance sheet as well as adapt quickly to the surge of cargo demand. Nonetheless they can be confronted with high charter rate or shortage of chartered tonnage in prosperous periods of shipping, as what happened in 2004 (see more in CI, 2005).

In 2013, 50.1% (7.55m TEUs) of the top 20 carriers' capacity were from charter market (Alphaliner, 2013), compared with 46% (2.2m TEUs) in 2001 (Dynamar, 2002). In the last 13 years there has been only slight difference between their owned and chartered capacity. Moreover, various chartering strategies of the top carriers can be realized. For instance, Coscon and Evergreen have extended profoundly the use of outside fleet, whereas CSCL has lowered its leased fraction over 40 percentage points. Some carriers have heavily depended upon chartering, CSAV (80 - 100% of their capacity); CMA-CGM, Hanjin, Huyndai (60-80%); APL (60-70%). In contrast, some have preferred their owned fleet, so chartering has merely played a small part, NYK, Yangming (less than 40%). Between the two extremes, 9 or 10 players, consisting of Maersk, MSC, Hapag Lloyd, MOL, and Zim, have often tended to keep the balance between the two sides, so their share of chartered tonnage has been often in the range of 40-60%.

2.4.3 Merger and Acquisition

Several mega mergers and acquisitions (M&As) have taken place between the biggest carriers in the top 20 since the middle of the 1990s. The privatization of state-owned CGM made opportunity for CMA to join the two French shipping lines in 1996. In the same year, P&O and Nedlloyd merged to overcome their perennial financial underperformance. In 1997, NOL purchased APL; the case was different from others by the use of the latter as the brand name, instead of the buyer or a combination. The strange decision could stem from the better well-known image of APL in the market. Maersk Line has been the most fervent carrier to extend its scale by M&As. Three large players, Sealand and Safmarine in 1999, P&O Nedlloyd in 2005, were purchased by the Danish operator with the total acquired fleet of 700,000 TEUs. After purchasing CP Ships in 2005, Hapag Lloyd carried out another M&A with CSAV at the beginning of 2014.

Table 2-1: Mega mergers and acquisitions in liner shipping

Year	Firm 1			Firm 2		
	Name (Ranking)	Capacity (TEUs)	% world fleet	Name (Ranking)	Capacity (TEUs)	% world fleet
1996	CMA (20)	52,120	1.07%	CGM (n/a)	28,532	0.6%
1996	P&O (11)	94,250	2%	Nedlloyd (8)	106,889	2.2%
1997	NOL (19)	57,379	1.2%	APL (18)	67,072	1.4%
1997	Hanjin (7)	111, 900	2.3%	Senator (17)	75,385	1.6%
1999	Maersk (1)	346,123	5.9%	Sealand (6)	211,358	3.6%
1999	Maersk (1)	346,123	5.9%	Safmarine (20)	55,584	0.95%
2005	Maersk (1)	900,509	15.2%	P&O Nedlloyd (4)	426,996	7.2%
2005	Hapag Lloyd (13)	221,763	2.3%	CP Ships (18)	178,920	1.8%
2014	Hapag Lloyd (6)	649,455	4.1%	CSAV (20)	264,985	1.7%

Source: Combined by the authors from various sources

These mega M&As could be the fastest way for global carriers to broaden their coverage in principal trade routes as well as enhance service quality. It does not take time for them to purchase new ships, design marketing and operational networks; especially they inherit long-standing customers of acquired players. The merger between P&O and Nedlloyd had surmounted the absence of the former from South America and the latter from transpacific trade (Crichton, 1996). Maersk Line had inevitably benefited from traditional cargo bases of Sealand in Northern and Southern America or of P&O Nedlloyd in Australia and New Zealand. Similarly Hapag Lloyd had received strong business between Canada and Europe from CP Ships as well as Latin American business from CSAV.

Cost saving is expected a key outcome of M&As. The combination between P&O and Nedlloyd was expected to save annually at least $200m (Anonymous, 1996a); between NOL and APL was $130m (Fossey, 1997), and between Hapag Lloyd and CP Ships was $200m (Anonymous, 2005a). Cost reduction may stem from scale economies of mega ship and broader network, rationalization of labor, office, IT and sale system, improvement of container logistics, and better vessel and terminal utilization.

In addition to mega M&As, the leading ones have been also interested in taking over small lines in order to strengthen their activities in niche markets, secondary trades or accommodate their feeder and regional distribution. Dynamar (2011) indicated 26 regional subsidiaries of the top 20 liners; Fusilo (2009, p 212) listed various cases of small M&As during 1993-2007. Before belonging to Hapag Lloyd, CP Ships had selected its growth strategy by acquiring small and niche carriers such as ANZDL, Canada Maritime, Cast, Contship, Ivaran Lines and Lykes Lines (see more in Alix et al., 1999; Brooks, 2008). Growth of the third largest carrier CMA-CGM has been in line with several acquisitions of regional lines, for instance, ANL (Oceania routes) in 1998, MacAndrews (intra Europe) in 2003, Delmas (Europe – Africa) in 2005, Comanav (Mediterranean Sea), and CNC Line (intra Asia) in 2007.

The M&A strategy is confronted with some difficulties as well. Firstly, compatibility is a challenge for acquirers when they must combine different operational, management and marketing systems. NOL, CP Ships and Maerks Line had suffered software problems after their acquisitions; Maersk Line had even faced a serious invoice crisis blame for its considerable loss in the first half of 2006 (Porter, 2006).

Secondly, liners must pay extremely high expense to acquire their competitors, for instance the cost to take over APL was $825m (Fossey, 1997), P&O Nedlloyd $2.8b (Beddow, 2005); and CP Ships $2.3b (Drewry, 2009a). Additionally pretty money must be spent to integrate different partners. Roughly $100m was to restructure the combined system of P&O and Nedlloyd (Crichton, 1996); nearly $500m for Maersk Line to absorb P&O Nedlloyd (Anonymous, 2005b). Maersk Line and Hapag Lloyd suffered considerable loss in 2006, -$597m and -$139m, respectively (Drewry, 2008a), because of exceptional costs in their integration processes.

Lastly, market share can be lost, either by anti-trust regulations to limit an operator to dominate a market or by retreat of customers of acquired carriers. It was argued by a president of CP Ships, “one and one did not necessarily make two and that combining market share would usually amount instead to 1.7” (Anonymous, 1997a). Maersk Line had lost approximately 40% of P&O Nedlloyd’s traffic in the US during the first 9 months of 2006 as well as been obliged to give up some traffic in the Europe/South African trade lane (Beddow, 2007).

2.4.4 Strategic alliances

Liner industry underwent pivotal restructuring in the second half of the 1990s with the establishment of global partnerships between top carriers through the so-called strategic alliances. As a result, the top ones have been able to work together in long-term period to serve backbone trade lanes along the east-west axis as well as gain operational synergy. The new consortia were referred to mark a new generation in the development of containerization (Watanabe, 2000). They have been a strategic response of liner shipping to the globalization of world economy (Midoro & Pitto, 2000) and become a predominant form of cooperative agreement in liner shipping (Sheppard & Seidman, 2001). Several empirical and optimization studies have underlined profound impact of global alliances on liner operation, network and service (see for instance Cariou, 2002; Cariou & Haralambides, 1999; Ryo & Thanopolou, 1999; Slack et al., 2002).

Whereas conferences are mainly to stabilize freight rates by controlling pooling capacity and regulating conference tariffs, strategic alliances are more oriented towards technical and operational arrangements to cut costs, extend and enhance shipping services, and utilize assets efficiently.

Therefore, their members are still independent in terms of marketing, sale and price strategies. The new form of co-operation is not only in respect of ocean operation such as vessel deployment and service design but can be in respect of inland operation such as terminal activities, inland transportation and container management as well.

Between 1996 and 2001 was unstable period for strategic alliances. In 1996, Grand Alliance (NYK, Hapag Lloyd, NOL & P&O), Global Alliance (APL, OOCL, MOL & Nedlloyd), and Maersk/Sealand Alliance started their operation whereas CKY Alliance (Coscon, Kline & Yangming) and United Alliance (Hanjin, DSR-Senator, Choyang, UASC) entered the industry two years later. Instability was a noticeable characteristic of the alliances during the first period. It could be caused by their complex activities, inadequate member skills and competencies, fluctuating revenue and cost, and high coordination cost (Midoro & Pitto, 2000; Song & Panayides, 2002; Bergatino & Veenstra, 2002) and especially changes of member ownership. Many variations had taken place as consequences of the reshuffle of members (OOCL from Global Alliance to Grand Alliance), merge and acquisition between shipping lines (P&O & Neddlloyd, NOL & APL), bankruptcy of carriers (Choyang), entry of new ones (Huyndai into Global Alliance). Global Alliance was converted into New World Alliance in 1998; the partnership between Maersk and Sealand resulted in a single liner in 1999; United Alliance came to an end in 2001.

The structure of global alliances has been more or less stable since 2001 with three key consortia: Grand Alliance (NYK, Hapag Lloyd, P&O Nedlloyd, and OOCL), New World Alliance (APL, MOL, HMM) and CKYH or Green Alliance (Coscon, Kline, and Yangming & Hanjin). Only one profound change was the departure of P&O Nedlloyd from Grand Alliance subsequent to its acquisition by Maersk Line.

Strategic alliances have become major actors in liner business. They have often included at least 10 carriers in the top 20 and controlled over 25% of the world capacity. In 2011, total member fleets of Grand Alliance, New World Alliance and Green Alliance were 1.4m TEUs (capacity share 8.1%), 1.33m TEUs (7.7%) and 1.82m TEUs (10.5%) respectively. Obviously their scales are comparable to those of the top 3.

Table 2-2: Structure of global alliances

Year	Alliances	Members	Capacity (TEUs)	% world capacity
1996	Grand Alliance	NYK, Hapag Lloyd, NOL, P&O	354,610	7.3%
	Global Alliance	APL, OOCL, MOL, Nedlloyd	371,560	7.7%
	Maersk/Sealand	Maersk, Sealand	390,554	8.1%
1998	Grand Alliance	NYK, Hapag Lloyd, OOCL, P&O Nedlloyd	595,730	10.1%
	New World Alliance	APL, MOL, HMM	451,400	7.7%
	CKY Alliance	Cosco, Kline, Yangming	371,651	6.3%
	Maersk/Sealand	Maersk, Sealand	557,481	9.5%

	United Alliance	Hanjin, DSR-Senator, UASC, Choyang	330,932	5.6%
2001	Grand Alliance	NYK, Hapag Lloyd, NOL, P&O Nedlloyd	818,600	11.3%
	New World Alliance	APL, MOL, HMM	530,712	6.8%
	CHKY Alliance	Cosco, Hanjin, Kline, Yangming	811,453	11.2%
2006	Grand Alliance	NYK, Hapag Lloyd, NOL	1,035,966	9.3%
	New World Alliance	APL, MOL, HMM	789,134	7.1%
	CHKY Alliance	Cosco, Hanjin, Kline, Yangming	1,137,472	10.2%
2011	Grand Alliance	NYK, Hapag Lloyd, NOL	1,408,958	8.1%
	New World Alliance	APL, MOL, HMM	1,338,166	7.7%
	Green (CHKY) Alliance	Cosco, Hanjin, Kline, Yangming	1,819,953	10.5%

Source: Combined by the authors from various sources.

In recent years, some new co-operations have emerged in the industry. Evergreen has operated closely with Green Alliance. At the beginning of 2012, Grand Alliance and New World Alliance launched G6 Alliance in response to the innovative scheme “Daily Maersk“ of Maersk Line. In 2013, the top 3 players, Maersk Line, MSC and CMA-CGM, planned to establish the so-called P3 alliance. After rejected by the Chinese ministry of commerce, another co-operation has been proposed by the two former ones.

There are several driving factors of liner alliances. Firstly, the role of liner conference, a long-standing mechanism of collaboration in the industry, has been dropped because of its inflexibility and bureaucracy, competition from non-conference operators (Drewry, 1991), growing pressure from influential shippers (Lewis, 1996) and regulations of governmental and international organizations. Alliances are surely a feasible model for shipping lines to coordinate in order to survive and grow in the cut-throat competition market.

Secondly, the dominance of several mammoth carriers has forced smaller ones to work closely if they do not want to leave the business. Fleet capacities of Huyndai (0.33m TEUs) and Yangming (0.38m TEUs) are only around one-seventh of that of Maersk Line (2.6m TEUs), so it will be pretty challenging for them to compete in the global market without joining a specific consortium.

Next, alliance members can combine to provide broader market coverage, higher sailing frequency, better services, highly utilized mega vessels to reap economies of scale, and viably employ dedicated container terminals or inland facilities. These goals can be beyond a single operator’s capability because it is subjected to market and capacity constraint, expensive investment, weak bargaining power, and extremely high risk. Global Alliance mentioned to be able to provide more direct ports of call in Southeast Asia and China, and improve transit time and sailing frequency in many key port-to-port corridors (Anonymous, 1995). CKY alliance had given Kline and Yangming direct services to main Chinese ports; simultaneously Cosco had had opportunity to load/unload its containers via Taiwanese ports (Anonymous, 1996b).

Finally cost saving can be achieved thanks to the rationalization of vessels, port facilities, and containers. Potential cost saving of members in a global alliance had been assessed in the range of $70-100 per TEU (Anonymous, 1997b). Annual savings were anticipated of $100m for Maersk Line and Sealand as a result of their partnership (Boyes, 1995). Participating in a global alliance, MOL alluded to save tens of millions of dollars by not having to invest a new series of big vessels on transpacific route (Boyes, 1996a).

2.4.5 Summary

The leading operators have strongly increased their scale through the horizontal intergration to cover the global market, improve market share and gain scale economies. Consequently, the industry has become more concentrated. Capacity expansion has been a prevailing way for the carriers to develop their business. It can do through new building, second hand and chartering markets. The most marked tendency of this organic growth has been to deploy bigger and bigger vessels to drive down shipping cost. Merger and acquisition has been an option for shipping lines to develop quickly by taking over either a mega operator or a regional one.

Whereas the above strategies are to enhance a single carrier’s competitive advantage to fight against other competitors in the industry, strategic alliances have been a stable and long–term handshake between them to co-exist and develop in the bitter market. In addition to the durable alliances, they have also coordinated in loose forms such as slot exchange or joint operation. Co-operation with other rivals has inevitably played an important role in the growth strategy of shipping lines, even of some ones who have often preferred the “go-in-alone” policy.

2.5 Vertical integration

Vertical integration is pursued in order to expand shipping lines’ participation in the global supply chain and is a shift from cost - based to added value - based competition. Whilst sea leg advantage has become marginal, land side is inevitably a domain where they can seek competitive advantage. The involvement with a huge amount of containers helps them conveniently to coordinate with land side partners or organize their own services. They can engage in stevedoring and logistics industries so that gain competitive advantage by differentiation providing services beyond traditional port-to-port transportation, or focus concentrating on specific value chains of selected shippers. The bundle of closely related stages in the logistics pipeline creates synergy in terms of transaction cost, marketing, information sharing and customer service level. Additionally terminal and inland transportation costs have been estimated some 36% of container shipping unit costs, so securing these stages can be an important source to ensure door-to-door cost advantage.

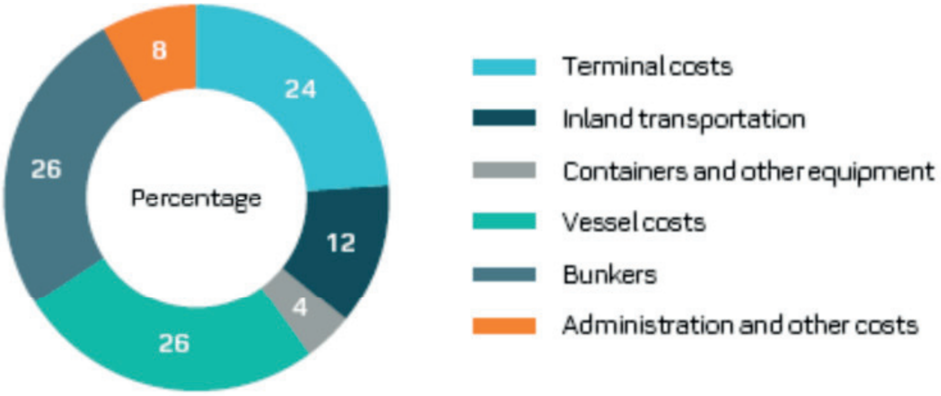


Figure 2-7: **Distribution of container shipping unit costs**

Source: Maersk. (2011).

In terms of finance, terminal and logistics activities seem to be feasible diversification for liner operators. They lighten the dependence on shipping operation which is highly capital intensive and owns unattractive financial indicators, and approach business segments which can be less asset-based and enjoy better profit margins. Container shipping can be very profitable in prosperous market but suffers seriously in crisis time, whereas stevedoring and logistics activities are more stable, they can still bring profit in bad periods.

Table 2-3: Operating income in different business segments

	2009			2010			2011		
	CS	LO	TO	CS	LO	TO	CS	LO	TO
NYK (10^9 Yen)	-55.4	1.5	2.9	30.2	7.7	6.6	-13.6	1.4	1.6
Maersk Line (10^6 USD)	-1,977	22	557	2,820	75	911	-483	97	767
APL (10^6 USD)	-739	54	32	490	67	n/a	-446	69	n/a

(CS: Container Shipping – LO: Logistics activities – TO: Terminal operation). Source: Shipping lines' websites.

2.5.1 Dedicated container terminals

Dedicated container terminals (DCTs) are different from multi-user container terminals (MUTs), which were very popular before. In MUTs, port services are open to many customers, vessels are dynamically allocated. In DCTs, customers are limited and some ships have priority to specific berths. Agreements between one (or several carriers) and a port operator (or port authority) decide participation level of carriers in port operation including both spatial aspect which can vary from berth exclusive use to inland transportation and temporal one which is the period for the use of port facilities (Cariou, 2001; Haralambides, Cariou & Benaccio, 2002). Carriers can control DCTs through their subsidiaries (CMA-CGM & Terminal Link) or sister companies (Maersk Line & APM Terminals), joint-venture with other carriers or stevedoring companies to operate terminals (CMA-CGM & DP World via Portsynergy), outsourcing to pure stevedores (Evergreen at Tacoma) or simply an agreement with terminal operators for the exclusive use of certain part, by which operators still remain their ownership and management system.

DCTs have developed in tandem with the revolutions in liner shipping. At the maiden phase of containerisation, the lack of proper port facilities to handle container traffic made several pioneers decide to invest their own terminals. Sealand was the first one operating its own terminal in Port Elisabeth (the USA) in 1962; then MOL and Kline in Port Osaka (Japan) in 1969, Maersk Line in Port Newark (the USA) in 1975 (Oliver et al., 2007). In the 1980s, the emergence of intermodal transport urged new carriers such as APL, Hanjin, Evergreen to enter terminal operations in the U.S. West Coast to make seamless connection between sea and land. The majority control of state in port industry at that time restricted the scope of DCTs mainly on the USA and some few regions. The wave of DCTs has become strong since the 1990s. On the one hand, port liberalization has promoted ocean carriers to join port industry. On the other hand, the need to secure their networks has promoted liner operators to set up their DCT system.

Table 2-4: The involvement in terminals by ocean carriers

Revolution	Period	Main drivers of terminal investment	Involved carriers
Container	1960-1970s	Need of standardized facilities	Sealand, Matson, K-line,
Intermodality	1980-1990s	Control of the transport chains	NYK, Evergreen, MOL, Hanjin, Maersk
Transhipment	1990-2000s	Defend the assets deployed on the main routes	CMA-CGM, MSC, China Shipping, P&O Nedlloyd

Source: Midoro et al., (2005).

Rationality of DCTs comes from some aspects. First, the use of DCTs is a good solution for shipping lines to limit risks of congestion and delay in ports, face and response with any ad hoc situation. Controlling the weakest points in the global supply chain will help them to secure seamless cargo flow, avoid extra costs for themselves and their customers, and keep schedule reliability and service reputation.

Second, DCTs play a critical role in ensuring the viability of mega ships. Such ships have more requirements in terms of nautical condition, berth length, handling capacity, crane outreach, and hinterland approach - “big ships need big terminals in key locations” (Hill, 2006). Thus, it is impossible for carriers to operate big vessels without efficient and stable terminal operation. At the end of 2001, CP Ships could not employ over 4,000 TEU ships because it did not have any DCTs at that time; MSC could not get appropriate container terminals in Long Beach to handle its mega ships due to its delay in DCT strategy (Midoro et al., 2005).

Third, DCTs is a strategy to make higher entry barriers of potential entrants. DCT users can get ideal locations which are convenient for manoeuvring and easily accessing hinterland markets. They also benefit from favourable terminal operating system and better port service level. In contrast, other players face limited, inconvenient and even no room for berthing, longer time in port, and possibly higher cost for handling and delivering cargo. DCTs can be considered as a form of limit pricing which raises operating cost of other players (Haralambides et al., 2002), so they cannot compete with DCT users or cannot get profit.

On the port side, there are several reasons to cooperate with shipping lines. Firstly, DCTs can be considered as a service differentiation strategy (UNCTAD, 1995), a means to keep carriers for a long time (Heaver et al., 2001). There have been some arguments that a big part of port investment comes from public money, so it is unfair when terminals are dedicated to only a few customers. However, it is the fact that carriers wield more bargaining power than ports. They can move to other ports in case their requirement is not adopted, “take it or leave it” behaviour (Ferarri & Benacchio, 2000).

Secondly, port investment requires a big amount of money. For instance, the project of port 2000 (Le Havre) needed €700m only for infrastructure, dredging and inland access. In the competitive market, port investment takes very high risk, especially when it includes high sunk cost. Delegating DCTs is a feasible option for ports to share the large investment as well as ensures their throughput in the future.

Finally, international stevedores have expanded their activities worldwide after liberalisation process. Although they mainly concern with multi-users, the provision of DCTs will create good cooperation with shipping lines, not only in a port and region but also in the global scope.

DCTs have become an important element in the global strategy of the top liner operators. They have developed their DCT network in most of the leading container ports. In accordance with our survey, there were roughly 223 DCTs around the world in 2012. They were located mostly in East Asia (102 terminals) where concentrated the biggest factories of the world, and then Europe (42) and Northern American (45). In terms of volume, DCTs handled around 184m TEUs in 2012, 3.35 times as many as the throughput in 2001.

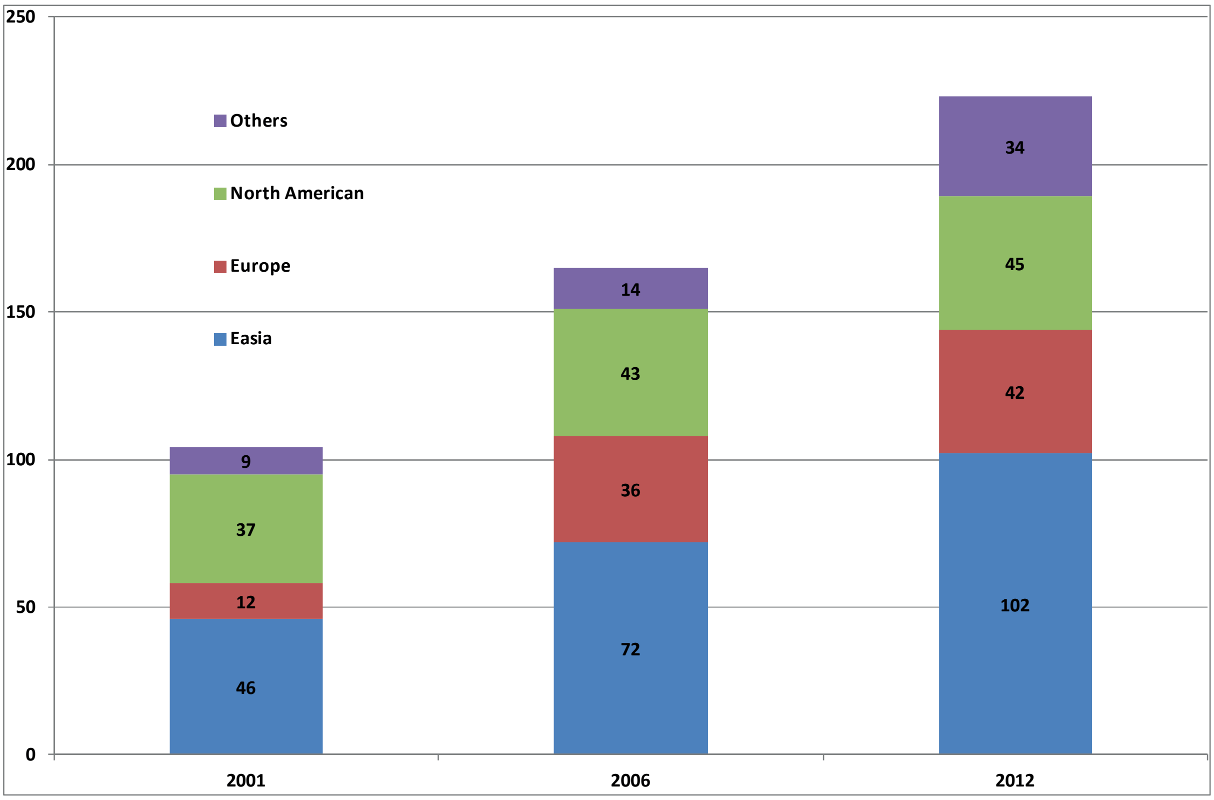


Figure 2-8: The number of dedicated container terminals.

Source: Combined from Drewry (2002b, 2007b, 2013b).

Initially ocean carriers employed DCTs as cost centers to secure their operation. Today, most of them are still in favor of this function. However the use of terminal facilities can be underutilized due to the exclusive service for in-house cargo. Consequently, terminal unit cost will be more expensive. For example, in 2010, the utilization levels at DCTs of Hanjin and Huyndai were only 47.2% and 34.4%, correspondingly (Drewry, 2011b). The open for third party traffic can be a good way to enhance terminal throughput and lessen operators' expense. Additionally, it is a potential area that shipping lines can earn profit in addition to their core shipping service.

Some players have converted DCTs into profit centers and separated them from shipping activity. For example, APM Terminals, a sister company of Maersk Line, was established in 2001 to become an independent stevedore. It has become the second largest terminal operator and has growingly diminished in-house traffic proportion from 90% in 2001 to 44% in 2010 (Drewry, 2002b; Maersk Line, 2011). CMA-CGM and APL set up subsidiaries, Terminal Link and Eagle Marine Services, to be responsible for their stevedoring activities. Under such circumstances, shipping lines can be treated as DCTs' clients, although the relationship is very close and mutual. The tendency in the industry has shifted to favor the profit centre model. While in 2002 the two models were more or less the same in respect of throughput, in 2012 the latter was nearly twice as many as the former.

2.5.2 Logistics activities

Shipping lines have been concerned with logistics activities since the beginning of the containerization revolution. The capability of containers in facilitating the combined transport made them to think beyond shipping operation. Initially they evolved into inland transportation by either their own or hired services for the purpose of extending the use of container transport to wider market (Drewry, 1991) as well as controlling the routine of their boxes on hinterland (Hayut, 1987). Container depots were also established in inland points to consolidate and deconsolidate cargo flows, and serve customers who were located far from loading and unloading ports.

The 1970s witnessed the initial entry of ocean carriers into logistics industry. The upturn of imported cargo from Asia generated the need of shippers for wider services to manage their cargo flows (Heaver, 2010). Some pioneers grabbed the trend and extended their scope to cover also multimodal transport and freight forwarding activities, for instance Sealand and APL (the U.S.), Maersk, Hapag Lloyd (Europe), NYK, OOCL (Asia).

The wave has become stronger since the 1980s, especially in the affair of intermodal transport. In the U.S, the deregulation in transportation industry and the breakthrough of double-stack concept leading to considerable cost saving in carrying containers by train were inevitably important catalysts for players such as APL, Sealand, US Lines to penetrate further into hinterland markets by coordinating with railway operators or organizing their dedicated routes. In 1987, the first merger between a railroad and an ocean carrier took place between CSX and Sealand and created a new company capable of providing transportation services by rail, inland waterway, pipeline, trucking and global shipping (Anonymous, 1987). In Canada, Canadian Pacific Corporation and Canadian National were very active in both shipping and hinterland operation through their railway and road networks (Hayut, 1987). In the UK, a survey of Casson (1986) showed that 9 out of 19 container lines operated in this market had been involved with inland transportation service, mainly by road.

Successes in intermodal transport promoted shipping lines to develop further than transportation affair and provide more value added services. Their ambition was to become a sole logistics provider for shippers, the idea of “one stop shipping” was born by Sealand whereas in Europe Nedlloyd christened the model of “Nedlloyd Flowmasters” (Drewry, 1991).

Liner industry has experienced profoundly changes since the 1990s thanks to the waves of post-panamax container ships, establishment of liner alliances, and global coverage of big carriers. Breakthroughs in the maritime leg have put much pressure on the land one. Today, the success of shipping operation depends greatly upon how ocean carriers secure their hinterland networks. Mega vessels will be only empty floating warehouses without reliable and sufficient traffic bases. Their operation can be collapsed if inland box movement is interrupted. Therefore, involvement in logistics operation is a feasible way for liner operators to ensure competitive advantage of their shipping services.

Additionally, some favorable conditions have supported deeper involvement of shipping lines in logistics industry. The opening of domestic logistics market in many countries, for example South Korea in the first half of the 1990s (Fossey, 1995), has made room for them to enter new domains, seize market share and get profit. Long-term and close relationship with big shippers and the tendency to use one-stop shop in arranging cargo movement facilitated them to become logistics service providers. According to a CI's survey, more than 70% of surveyed shippers wanted liner operators to execute their supply chain on a door-to-door basis (Thorby, 2006). By involving deeper in the value chain, liner operators will tighten their connection with customers as well as enhance their role in the global supply chain.

Nowadays all of the leading ocean carriers are related to logistics activities by different strategies and levels. Some are members of big corporations and logistics functions are carried out by their sister companies: Damco (Maersk Line), Yusen Logistics (NYK), APL Logistics, Yes Logistics (Yangming), OOCL Logistics, Hanjin Logistics, MOL Logistics. Subsidiaries have been established to perform logistics functions for mother companies, for instance, CMA-CGM Logistics, PIL Logistics. Several players (Hapag Lloyd, MSC, HMM, Evergreen) put priority on their inland transport to support their core shipping operation. MSC controls over 300 inland depots worldwide, primarily to perform basic LCL consolidation activities (Baird, 2011). Huyndai offers dedicated trains and trucking services to connect some key ports and hinterland in Europe and North America. Based on their cargo leg, shipping lines can select some specifically geographical focus. CSCL and Cosco strongly connect to their home market in China while Japanese players put more emphasis on Japan, APL on the US market. Some concentrate on particular segments in which they have more advantage or can gain more profit. Key customers of CMA-CGM are in the industries of apparel, footware, sportsware, hypermarket, retail, electronics and automotive.

2.5.3 Summary

Together with horizontal integration to broaden their scale on ocean side, shipping lines have enlarged their scope in the global supply chain by cooperating with other business partners to integrate shipping operation with inland operation. Warlike competition in shipping market has inevitably forced them to pay more attention to terminal operation and logistics activities in order to secure reliable services, seek cost cutting as well as enhance their position in the value chain. Additionally, they can earn profit from the new areas.

2.6 Conclusions

Container liner shipping is still in the growth stage expressing by upward trend of its traffic. The mode plays a backbone position in the global supply chain. There is no potential one which can substitute it as the prevailing workhorse in international trades.

Growing pressure from extended rivals such as global shippers, freight forwarders and terminal operators have made shipping lines compete each other intensely to enlarge geographical coverage, secure strategic positions, enhance service reliability and frequency, and cut expense. They have faced more volatile and competitive market, risk of losing customers not only by other operators but also by freight forwarders.

Rivalry in the industry has resulted in the disappearance of several hundreds of lines, including also some well-known brand names such as P&O Nedlloyd, Sealand, and CP Ships. Simultaneously it has been the emergence of giant operators and global alliances. Therefore the game has been not among numerous shipping lines, but only among a small number of powerful players.

Entry and exit barriers have been raised. Global scale of the incumbents or strategic alliances deters new operators from entering the market. They must spend much capital to invest in fleet capacity to catch up with the forerunners in terms of service coverage. Economies of scale force them to spend enormous investment in expensive mega vessels; otherwise they will suffer from high shipping cost. Vertical integration makes deterrent for them to approach new markets either by having no change to approach a port or hinterland market, or by being unable to compete in terms of service quality and price. On the other hand, by being tied up in intensive capital as well as long term commitment to alliances and port or inland services, it is very difficult for the incumbents to leave the market, even when it is very bad.

Various strategies have been employed by shipping lines to reap competitive advantage in the warlike market. Capacity expansion, with the focus on mega vessels, and takeovers of other competitors are to enlarge their scale and to seek unit cost saving. Involvement into terminal and logistics operation aims to protect their core ocean transportation services, enhance their presence in the global supply chain as well as potentially gain profit.

Harshness of the market also makes challenging for carriers to stand alone. A salient feature in the industry is not only competition between shipping lines but also their cooperation. The strategic alliances have proved their stability since the beginning of the 2000s. Additionally it is the combination of shipping lines with other landside partners to strengthen their presence there.

Chapter 3: Deployment of operational patterns

Highlights:

- Description of operational patterns

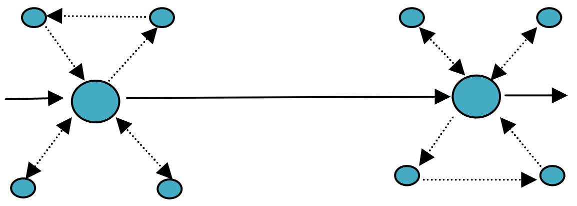
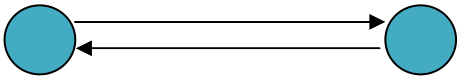
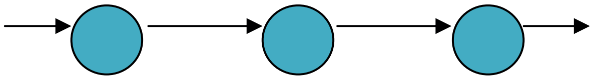
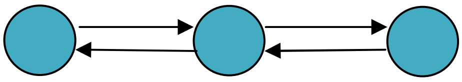
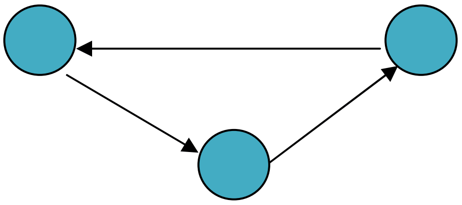
- The deployment of the patterns in route design

- A comparison between the patterns of end-to-end, round-the-world and pendulum

3.1 Introduction

Hub-and-spoke (H&S), end-to-end (ETE), round-the-world (RTW), pendulum and triangle are basic operational patterns of container liner shipping. The H&S is the base for the transportation system whereby different routes are combined through transhipment activities to expand market coverage of shipping services. The other four patterns determine route configuration and depict how ships on a loop travel between markets.

Table 3-1: Models of operational patterns

Pattern	Model	Description
Hub-and-spoke		In each region, a ship calls only at a hub port to receive/distribute containers from/to feeder ports thanks to feeder ships.
End-to-end		A ship travels back and forth between two continents.
Round-the-world		A ship goes through three continents in either eastbound or westbound direction.
Pendulum		Also sailing through three continents, but a ship moves by both directions.
Triangle		A ship connects three imbalances trades by moving only in surpassing traffic directions.

Almost studies involving the operational patterns concentrate on the H&S, for instance: regional H&S system (Gouvernal et al. 2005; Robinson, 1998; Wang & Slack, 2000); viability of transhipment hubs (Baird, 2006; Fleming, 2000; McCalla, 2008); network optimisation (Aversa et al., 2005; Gelareh et al.

2013; Imai et al., 2006); interlining and relay hubs (De Monie, 2001; Notteboom, 2012; Rodrique et al., 2009).

In contrast, not many works deal with other patterns. Different variants of route configurations deployed in the 1980s are clearly described by Pearson and Fossey (1983). Used to be considered as a major innovation in liner shipping, the RTW pattern has attracted significant interest from researchers to evaluate its operational, commercial and economic aspects as well as success and failure of users (Gielessen, 1991; Kim, 1987; Drewry, 1986; Lloyd's List, 1994; Container Insight, 1987; Lim, 1996). Cost comparisons between the ETE, RTW and pendulum patterns are carried out by Lim (1996) and Pearson and Fossey (1983). Fleming (2010) compares the three ones in serving the global market regarding geographical constraint, deployed vessel size, traffic potential and empty container repositioning. Ashar (1999, 2000, 2002) analyse inherent deficiency of the patterns used in practice and propose a new equatorial RTW pattern to restructure the container shipping system. Also dependent upon mega ships and a small number of pure hubs along the equatorial axis to transport the world-wide traffic as Ashar, but Visser and Braam (2001) suggest a backbone transportation system on the basis of the pendulum pattern.

The shortage of researches on route configuration encourages us to approach deeply into the field. The empirical work is based on the service data of the top 20 shipping lines between 1995 and 2011 published in Containerisation International Yearbooks. Two key aspects are dealt with in the research. The first one is the application of operational patterns on designing transcontinental East-West shipping routes. The second one is a comparative analysis between ETE, RTW and pendulum routes regarding number of visited regions, ports of call, transit time, route complexity, and mega ship deployment to see more clearly about the characteristics of each pattern.

This chapter is structured as follows. Section 3.2 provides a description of the operational patterns. Section 3.3 focuses on their deployment in shipping operation. Section 3.4 addresses a comparative analysis between route patterns. Section 3.5 includes some conclusions.

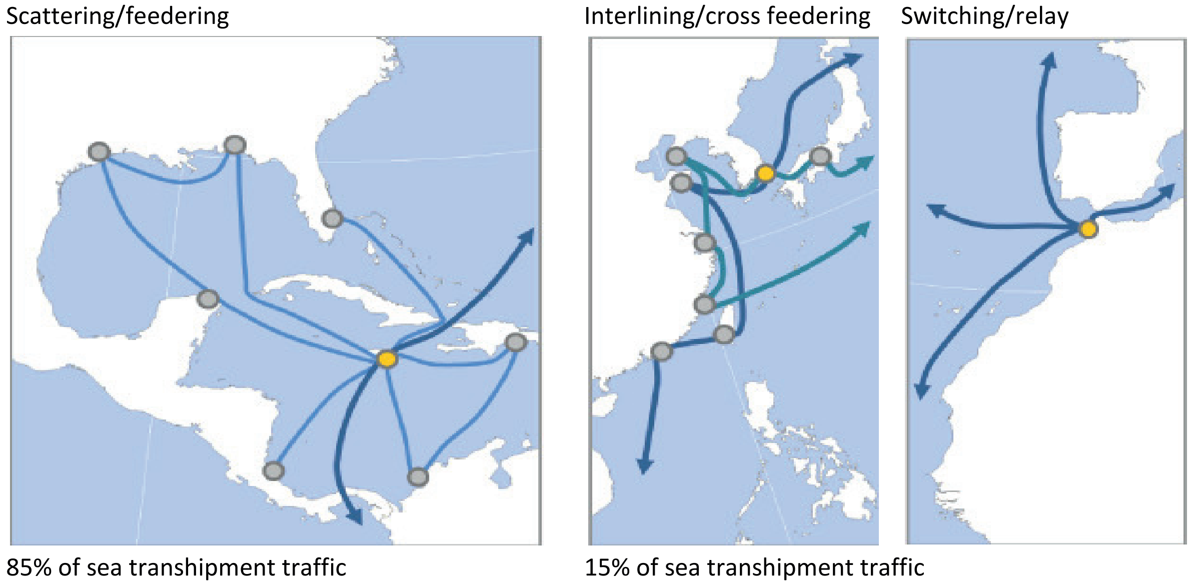
3.2 Review of operational patterns

3.2.1 Hub and spoke (H&S)

The pattern plays a key role not only in container liner shipping but also in other transportation modes. It stems from the model pioneered by Federal Express in the 1970s whereby all packages from different sources are collected through a central hub, then distributed to their destinations (Dynamar, 2007c). The H&S benefits operators in terms of density economies by providing more frequent services, scale economies by deploying larger transport means, and scope economies by joining freight from different routes (Konings, 2003).

It is the fact that a route cannot cover all ports in a specific region. A port may be ignored because it cannot provide adequate traffic to justify a direct call, or it is far from the arterial passage, or lacks of natural and operating conditions to handle big vessels. Moreover, economics of ship size also restricts the number of stops on a string (Gilman, 1999; Tran, 2011). As a consequence, carriers must rely upon the H&S to ensure the efficiency of intercontinental shipping as well as to maintain their market coverage. Several ports are selected as hubs to be directly visited by mother vessels and are transhipment points for boxes to/from their surrounding areas thanks to feeder services. An ideal hub is situated close to the gravity centre of regional demand whereby detour distance and transport time can be minimised (Vrenken et al., 2005).

In addition to be a feedering centre, a hub can also act as an interlining or relay centre. In interlining function, containers to bypassed ports are transhipped at the regional hub, then transported to their destinations by mainline vessels, not by feeder ones as the traditional function. The variant permits two end-to-end services to operate effectively as four ones (Sutcliffe & Ratcliffe, 1995). More ports can be served without lengthening main ships' itinerary. In relay function, operators can extend service coverage and flexibility by linking East-West and North-South loops operating in different directions (OSC, 2007b). Containers are switched between trunk ships and delivered to their destinations which are not in the same region as the transhipment hub. For instance, a box from North East Asia to Australasia could be first shipped by a North East Asia/North Europe route; then transhipped in Singapore and carried to the customer by a South East Asia/Australasia route. The relay system based on some strategic hubs is claimed to successfully facilitate the global coverage of Zim in the 1990s, though the carrier only provides a smaller number of routes (Gardiner, 1997).



Scattering/feedering

Interlining/cross feedering

Switching/relay

85% of sea transhipment traffic

15% of sea transhipment traffic

Figure 3-1: Transshipment functions of a hub.

Source: Rodrigue et al. (2009)

According to UNCTAD's Liner Shipping Connectivity Index (UNCTAD, 2009b), 17.2% of pairs of countries could be linked by direct liner shipping services, 62% by one transhipment, 18.6% by two transhipments; and for the remaining 2.2% by three transhipments. Container shipping must depend substantially on the H&S system to ensure the global coverage. The continual growth of transhipment operation has been noted. The average number of transfers between ship and shore was 2.0 in 1960, up to 2.9 in 1980, 3.2 in 2000 and 3.5 in 2012 (based on Frankel, 2004 & Drewry, 2013a). The worldwide transhipment handling volume increased more than 40-fold between 1980 and 2012, from 4.2m TEUs to 174.6m TEUs (Drewry, 2013a). The transhipment incidence also moved up from 11% to 28% in the same period.

3.2.2 End-to-end (ETE)

ETE is the most common pattern in container shipping. Almost intercontinental routes, whether they serve East-West or North-South trades, follow this pattern (Dynamar, 2007c). Basically, ETE ships sail back and forth between two continents. It is not complicated, relatively easy to organize and does not require high investment.

The simplest form of the pattern is displayed in figure 2 in which containers are only carried between two regions. Routes to serve the Trans-Atlantic and Trans-Pacific trades often fall into the form. Another variant is to link more than two regions on a single loop. For instance, the North Europe/North East Asia (NEA) service in figure 3 goes through the intermediate regions of South East

Asia and the Middle East. Routes between NEA and East Coast North America may also serve the port ranges of West Coast North America, and Central America and the Caribbean.

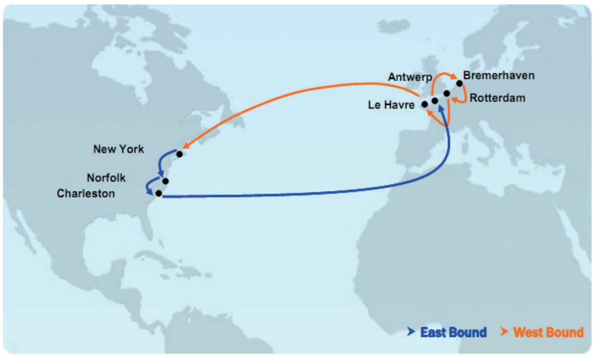


Figure 3-2: Simple end- to-end service.
Source:
http://www.hanjin.com/eservice/en/route/serviceRouteMain.do

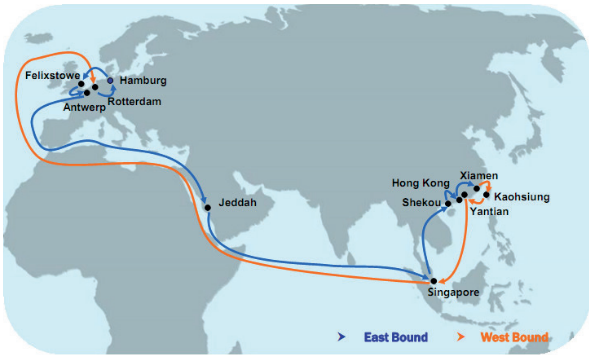


Figure 3-3: End-to-end service with intermediate regions.
Source:
http://www.hanjin.com/eservice/en/route/serviceRouteMain.do

The third variant is a combination of two or three simple ETE routes servicing the same trade lane into a single one. It has been not popular in the industry with only one or two services on the Trans-Atlantic or Trans-Pacific lane in yearly operation. In figure 4, the butterfly service is similar to two ETE ones. They both operate on the Trans-Atlantic corridor with the overlap in North European port range, whereas port ranges in East Coast North America are different: (New York, Norfolk) and (Charleston, Miami, Houston). Instead of operating independently, they are integrated through the joint of the overlapping ports. In practice, such butterfly route has required a smaller number of deployed ships compared to separate ones (Drewry, 2000a; Shipping Online, 2008, 2011), attributable to shorter total time spending in port ranges.

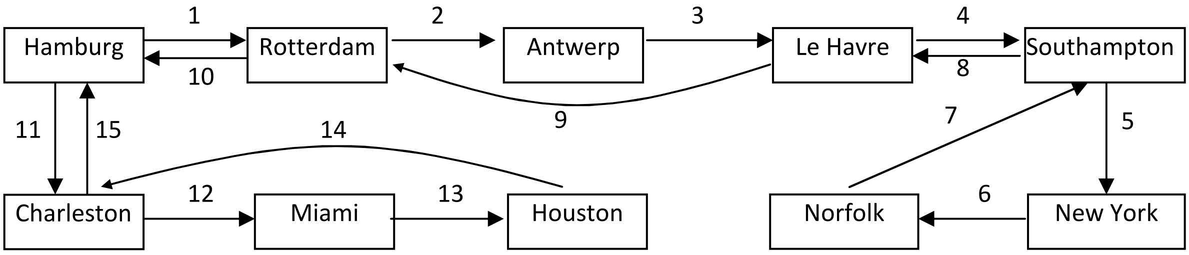


Figure 3-4: Butterfly route.
Source: based on information on ATX/SGX route published by CI (2006).

3.2.3 Round-the-world (RTW)

RTW is the only pattern directing ship movement in one direction, either westbound or eastbound. A ship circumnavigates the world and travels along the East-West axis through major strategic maritime passages. It attempts to serve the three key trade lanes of Trans-Atlantic, Trans-Pacific and Europe/East Asia on a single trip.

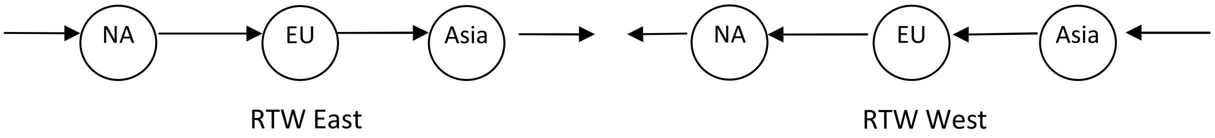


Figure 3-5: RTW models (**NA:** North America; **EU:** Europe)

In 1984, the first RTW services were inaugurated by Evergreen and United States Lines (USL). They expected cost advantage from the breakthrough in order to escape from the cut-throat rate wars of the market (Drewry, 1986). Nevertheless, only the former had succeeded in the new pattern. The demise of the RTW strategy forced the latter to file for bankruptcy at the end of 1986. Some pronounced mistakes include (i) inflexibility in terms of cargo (serves only 40 foot containers), routing (only eastbound) and large ship size; (ii) low speed; (iii) bad service quality; (iv) market miscalculation (Gibney, 1987; Knee, 1987; Lim, 1996; Willmington, 2004).

Besides the traditional RTW services like those of Evergreen and USL, there have been secondary RTW ones passing through Australasia. On the loops, ships travel not only along the East-West axis but also North-South one on some legs. For example, in 2004, a RTW route jointly operated by P&O Nedlloyd, CMA-CGM and CP Ships (ANZ Westabout) made a global tour via Europe, East Coast North America, Australasia and South East Asia. In 2006, CMA-CGM organized a RTW loop (RTW Pan) to call only the three former markets.

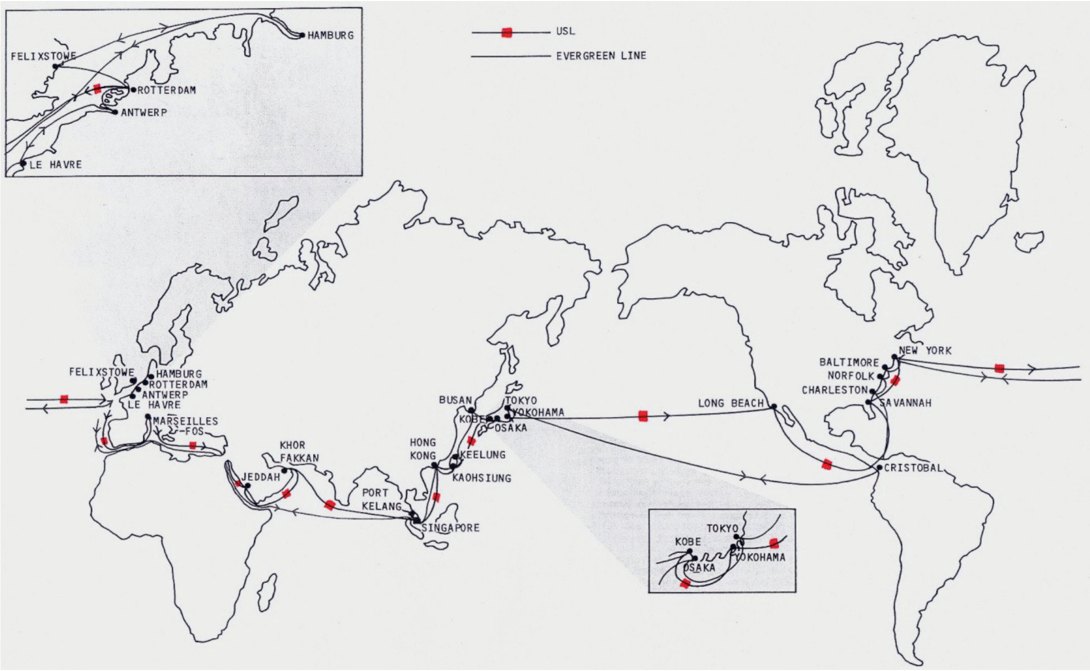


Figure 3-6: The RTW routes of United States Lines and Evergreen.
Source: Drewry (1986).

3.2.4 Pendulum

The pattern is also known as "figure-of-eight" or "double loop" (Gardiner, 1997). It has gone into operation since the 1970s by an Israeli operator Zim. Another pioneer is a Taiwanese carrier Yangming which kicked off a service in the second half of the 1980s. A pendulum route is a combination of two or three ETE ones operating on different trade lanes. It aims to serve the three continents as the RTW route, but the ship travels both eastwards and westwards, not only by one direction. Additionally, one key leg on the East-West axis is often absent from the ships' itinerary.

Following the pattern, a ship moves between the three continents of Asia, Europe and North America, one of which plays a role as a middle market or as a fulcrum of the loop. As a pendulum, the ship swings to either side of the fulcrum to serve the two remaining markets. An operator could be dependent upon strongly captured traffic in the fulcrum to secure the service. This was Yangming' s strategy when it utilised the key cargo base in Taiwan, representing up to 40% of its liftings, to develop its first pendulum service in the 1980s (Boyes, 1985).

In figure 7, the ships assigned to the service cross over the Pacific Ocean from East Asia to West Coast, then East Coast North America. Afterwards they traverse the Atlantic Ocean to the Mediterranean Sea, turn around and return the fulcrum North American, then end up in East Asia to complete a cycle. The ships operate between East Asia and the Mediterranean Sea via the Panama Canal. They merely transport containers on the Trans-Atlantic and Trans-Pacific corridors whereas the Mediterranean Sea/East Asia one is excluded from its voyage. Such service could be not affected by any vulnerability of the Suez Canal (Pearson & Fossey, 1983, p 109), but suffer from the ship size restriction of the Panama Canal.

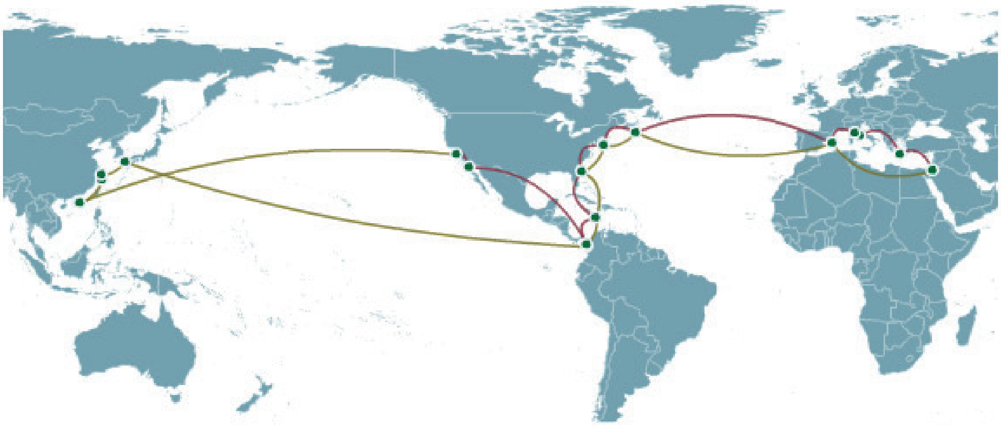
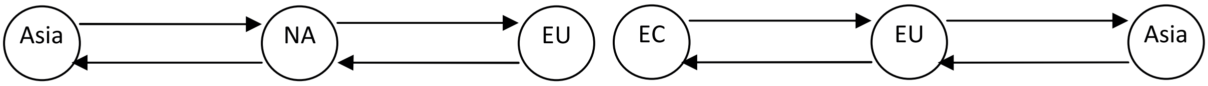
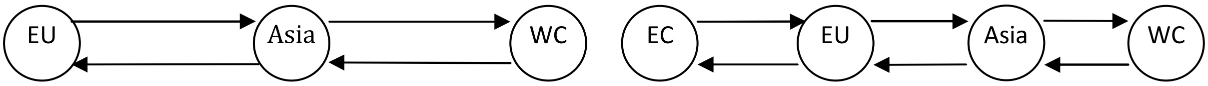


Figure 3-7: Zim's pendulum route in 2011.
Source: http://www.zim.com/LineDetails.aspx?id=485&l=4&LineId=ZCS&ServiceCode=ZCS

Based on the selection of the middle market, three major pendulum models can be classified. An extension of the pendulum, named horse-shoe shaped model (Pearson & Fossey, 1983), comprises all the key legs on a string. The grand pendulum loop swings between East Coast and West Coast North America through the two fulcrums of Europe and Asia. Because the Panama Canal is excluded from the ship journey, the service could avoid the trade restriction between the US West Coast and East Coast as well as nautical limitation of the canal.



Pendulum 1 (North America as the middle market) Pendulum 2 (Europe as the middle market)



Pendulum 3 (Asia as the middle market) Pendulum 4 (Europe & Asia as the middle markets)

Figure 3-8: Major pendulum models (**NA**: North America; **EU**: Europe; **EC**: East Coast North America; **WC**: West Coast North America**)**

The pendulum pattern is employed not only on the East-West corridor, but also on the North-South one. To such an extent, it includes secondary markets in Australasia, Africa and South America. For example, loops are to link Europe, South Africa (fulcrum) and Australasia, or East Asia, South Africa (fulcrum) and South America.

3.2.5 Triangle

The pattern links three markets in one way. It aims to counteract trade imbalance by focusing on denser traffic directions between markets. By that way, ship slot filling factor could be improved. For instance, on a typical triangle route (North Europe -> Australasia -> South East Asia -> North Europe), operators exploit the volume dominance of the southbound leg between Europe and Australasia, and westbound one between South East Asia and Europe. The pattern is almost as old as international shipping (Pearson & Fossey, 1983) and employed a lot in tramp shipping which often suffers seriously from trade imbalance. However, its deployment in liner shipping is not common and only limited in minor trades or applied by carriers combining containers with other bulk cargoes. The selection of three optimal traffic flows can be rather sophisticated.

3.3 Deployment of operational patterns

3.3.1 Data description

The paper aims to study operational patterns of inter-continental routes on the East-West axis linking markets in the three continents of North America, Europe and Asia. Data is retrieved from 2,074 service records of the top 20 shipping lines in the years 1995-2011 published by Containerization International Yearbooks. Basic features of a specific service consist of port rotation, time schedule, ship fleet and operators. From such data, it is possible to determine trade regions as well as their order on the loop, the operational pattern deployed, transit time between ports, route length, fleet capacity and the number of weekly calls (table 2). Data synthesis is carried out by designated computer programs written in the language of Freepascal.

Table 3-2: Information of a shipping service

Service name: APX Operators: APL and MOL Year in operation: 2011

Port rotation: Chiwan (arrival day 0); Hong Kong (1); Kaohsiung (2); Busan (5); Kobe (7); Tokyo (8); Balboa (24); Puerto Manzanillo (25); Miami (29); Jacksonville (30); Savannah (31); Charleston (32); New York (34); Antwerp (43); Felixstowe (44); Bremerhaven (45); Rotterdam (47); Le Havre (49); New York (56); Norfolk (57); Charleston (59); Puerto Manzanillo (63); Balboa (64); San Pedro (72); Oakland (74); Tokyo (86); Kobe (87); Chiwan (91)

Regions of call: North East Asia -> Central America and the Caribbean-> East Coast North America -> North Europe -> East Coast North America -> Central America and the Caribbean -> West Coast North America -> North East Asia

Operational pattern: Pendulum, with the middle market of North America, side markets of North East Asia and North Europe

Number of vessels: 13; Total fleet capacity: 60,889 TEUs; Average vessel size: 4,684 TEUs

Route length: 32,269 miles; Voyage time: 91 days; Number of weekly calls: 27

Source: CI (2012)

3.3.2 Results

The East-West shipping volume climbed significantly from 15.41m TEUs in 1995 to 35.35m in 2003 and 68.61m in 2011 (Drewry 2000a, 2004a, 2012a). It accounted for 42.1% of the global volume in 2011. Being the first international container shipping corridor, but North America/Europe has been left far behind by North America/Asia and Europe/Asia in terms of shipping traffic. From 1995 to 2011, its traffic went up by only 1.8 times (from 3.47m to 6.24m TEUs) in comparison with 3.18 times (7.51m to 23.9m TEUs) of the second and 5.84 times (4.44m to 25.93m TEUs) of the latter corridors. During the period, the Europe/Asia traffic experienced the greatest boom and overcame the North America/Asia one from 2006. Intra-regional trades between East Asia, South Asia, and the Middle East also underwent substantial surge from 1.7m in 1999 to 12.6m TEUs in 2011. They could be served not only by intra-regional but also by trans-continental Europe/Asia routes.

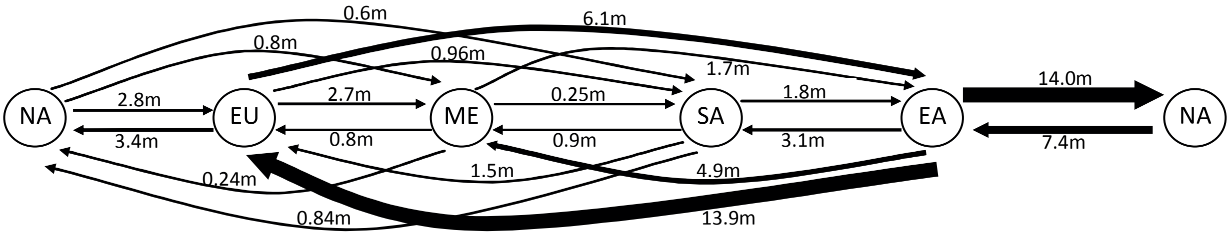


Figure 3-9: The East-West shipping flows (unit: TEUs). (**NA**: North America; **EU**: Europe; **ME**: Middle East; **SA**: South Asia; **EA**: East Asia).
Source: based on data published by Drewry (2012a).

New trans-continental routes and vessel fleet were added to the transportation system in harmony with the growth of the East-West traffic. The system developed from 96 routes (the fleet of 1.48m

TEUs) in 1995 to 123 (3.52m) in 2003 and 132 (6.5m) in 2011. The breakdown of shipping routes, deployed fleet, and the number of weekly calls based on operational patterns bears out the domination of the ETE in route configuration in the years 1995-2011 (table 3). 81% to 93% of transcontinental routes on the East-West axis operated under the pattern. Their portions in the combined fleet capacity and total calls were in the ranges of 68% to 92% and 68% to 89% respectively.

Table 3-3: Breakdown of routes, deployed fleet and weekly calls by operational patterns

	Number of routes					Deployed fleet (1,000 TEUs)					Number of weekly calls				
	ETE	PDL	RTW	TRI	Total	ETE	PDL	RTW	TRI	Total	ETE	PDL	RTW	TRI	Total
1995	83	9	4	0	96	1,138	201	140	0	1,480	867	169	74	0	1,110
1996	93	7	4	0	104	1,219	209	117	0	1,545	924	134	72	0	1,130
1997	78	10	2	0	90	1,330	366	85	0	1,782	812	202	39	0	1,053
1998	71	11	2	0	84	1,415	430	87	0	1,932	768	225	39	0	1,032
1999	80	12	2	0	94	1,497	514	78	0	2,089	835	249	38	0	1,122
2000	90	12	2	1	105	1,814	615	79	12	2,521	939	262	40	6	1,247
2001	90	13	2	1	106	2,100	728	83	6	2,917	928	280	38	7	1,253
2002	82	18	0	1	101	2,111	971	0	12	3,093	855	392	0	7	1,254
2003	109	13	0	1	123	2,815	693	0	16	3,524	1,113	286	0	7	1,406
2004	123	12	1	2	138	3,261	667	35	51	4,014	1,235	248	18	16	1,517
2005	139	10	2	2	153	3,948	541	74	63	4,626	1,348	207	37	16	1,608
2006	143	11	2	3	159	4,313	571	81	98	5,063	1,368	213	41	22	1,644
2007	153	14	0	1	168	4,853	672	0	31	5,556	1,454	253	0	9	1,716
2008	143	15	0	1	159	5,014	806	0	30	5,849	1,415	281	0	9	1,705
2009	110	12	2	0	124	4,513	752	83	0	5,348	1,229	226	21	0	1,476
2010	125	12	1	0	138	5,411	762	42	0	6,216	1,395	231	14	0	1,640
2011	123	8	1	0	132	5,991	457	55	0	6,503	1,328	153	16	0	1,497

ETE: End-to-end; PDL: Pendulum; RTW: Round-the-world; TRI: Triangle

Along the East-West axis, 9 key trade regions can be categorized: West Coast North America, Central America and the Caribbean, East Coast North America, North Europe, the Mediterranean Sea, the Middle East, South Asia, South East Asia, and North East Asia. 132 different configurations linking regions between two continents have been collected. Based on the easternmost and westernmost regions, they can be classified into 19 ETE route segments to serve East-West trans-continental traffic. Their deployment on the shipping system is well illustrated in figure 10.

In the years 1995-2011, North East Asia/West Coast North America, East Coast North America/North Europe and North Europe/North East Asia routes were the most important ETE ones on the Trans-Atlantic, Europe/Asia and Trans-Pacific corridors. Altogether they often accounted for more than 50% of the combined East-West routes and fleet capacity. Furthermore, it could be observed the great upgrading of East Coast North America/Mediterranean routes, Mediterranean/North East Asia and North Europe/South Asia routes, and North East Asia/East Coast North America routes via the Panama Canal in order to adapt to the upswing of shipping demand between these regions.

The North Europe/North East Asia and North East Asia/East Coast North America routes were often the longest ETE ones in the market with the length over 23,000 miles (table 4). From 2009, some longer ones above 27,000 miles were designed to link North East Asia and East Coast North America via the Suez Canal. Compared with the routes via the Panama Canal, they suffer from longer travelling journey but are advantageous in terms of no ship size restriction and high potential for collecting goods from the intermediate markets of South East Asia, South Asia and Middle East.

The pendulum was the second most common pattern. In reality, almost shipping lines in the top 20 involved in the pattern. From 1995 to 2002, pendulum routes were growingly deployed and played an important part in the transportation system. 18 routes contributed to some one third of the total calls (392 weekly calls) and fleet capacity (0.97m TEUs) in 2002. Some carriers reserved a big part of their fleet for pendulum services, which could be comparable with that of ETE ones, for example Maersk Line (0.17m vs. 0.23m TEUs); Hanjin (0.2m vs. 0.1m); CMA-CGM (0.04m vs. 0.1m). Nevertheless many pendulum ones were suspended in favor of the ETE system afterwards. In 2011, the ratios between the two segments of these carriers remained solely 1:10, 1:9 and 1:42 respectively. Overall merely 8 routes fell into the pendulum and constituted around one tenth of the total calls and fleet capacity.

Of the four pendulum models presented in section 2.5, the three former ones were always in use. It could be noted the shrink of second-model routes stretching between North America and Asia through the fulcrum of the Mediterranean Sea (table 5). The phenomenon stemmed from the shift of the easternmost market from North East Asia, to South East Asia, then South Asia. Forth-model pendulum routes were the longest ones in the industry. They were first in operation between 1997 and 2003 and emerged again from 2009. In the latter period, the ships also sailed between the two seaboards of North America via the Suez Canal. Nevertheless in the middle of the voyage, they only visited East Asia but omitted North Europe and the Mediterranean Sea.

The RTW had been expected as a breakthrough in the industry, but its application had been rare. Only Evergreen had successfully employed it for a long time. In the mid-1990s, half of the Taiwanese carrier’s East-West fleet capacity was assigned to its two long-standing RTW services. However they have been abandoned and substituted by pendulum and ETE ones since 2002. Occasionally RTW loops had been designed by operators such as Cho Yang and DSR-Senator (in the 1990s); CSCL, CSAV and Zim (in the mid-2000s); CMA-CGM (from 2009). By 2002, a pair of RTW loops had been often launched simultaneously to serve global trade on both directions. However, carriers only used either an eastbound or a westbound route at a later time.

Between 2000 and 2008, a few triangle routes were designed on the East-West network by Maersk Line, CMA-CGM and CP Ships. The ships often travelled eastwards from East Coast North America (EC) to the Mediterranean Sea (MED), then South Asia. Afterwards they changed the direction to return the starting range. The journey was more or less the same with that of the pendulum ones to link these regions, but bypassed MED ports on the westbound leg. A priority of the loops could be to serve growingly westbound traffic from South Asia to EC.

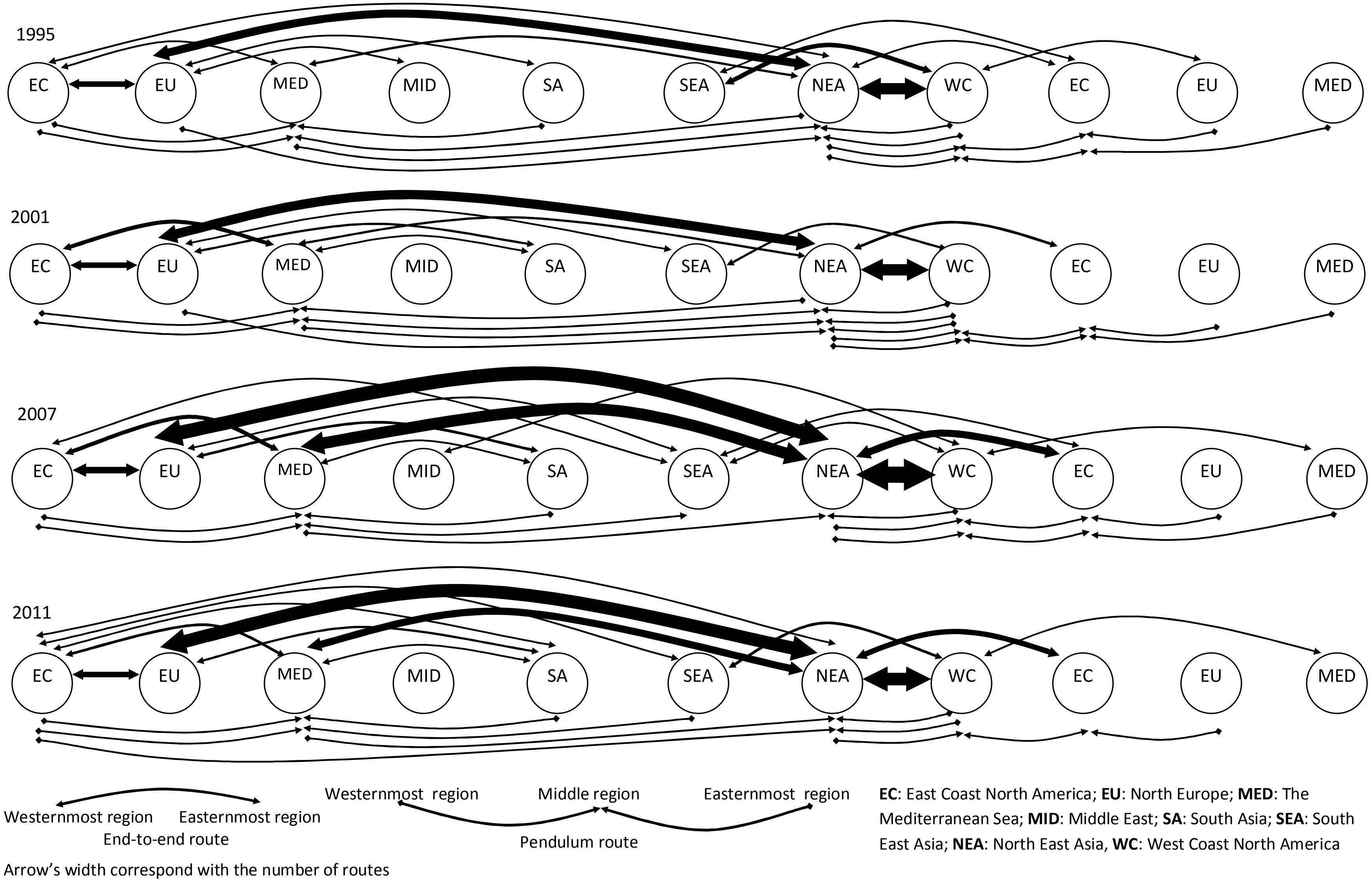


Figure 3-10: End-to-end and pendulum routes on the shipping network

Table 3-4: Operational parameters of major ETE routes

	ECNA/North Europe				North East Asia/WCNA				North Europe/North East Asia			
	Route	Time	Length	Size	Route	Time	Length	Size	Route	Time	Length	Size
1995	12		9,533	2,806	25		12,950	2,905	18		23,598	3,443
1997	12		9,639	2,747	21		13,431	3,409	18		23,453	3,863
1999	15		9,516	2,617	22		13,079	3,417	18		23,404	4,085
2001	12	28	9,405	2,826	25	34	13,047	3,729	21	57	23,459	4,918
2003	11	28	9,229	3,335	33	34	13,010	3,970	20	58	23,606	5,657
2005	12	28	9,205	3,246	42	34	12,708	4,489	30	57	23,123	5,957
2007	15	28	9,374	3,360	40	33	12,672	4,945	31	58	23,059	7,255
2009	10	31	9,403	3,632	28	35	12,877	5,732	26	65	23,708	8,378
2011	12	32	9,706	3,930	28	37	12,520	6,341	29	70	23,371	9,188
	ECNA/MED				North East Asia/ECNA				MED/North East Asia			
	Route	Time	Length	Size	Route	Time	Length	Size	Route	Time	Length	Size
1995	2		9,672	1,662	3		23,577	3,081	5		19,111	2,083
1997	7		11,325	1,225	4		23,602	3,331	4		19,343	2,223
1999	4		10,224	1,600	4		23,886	3,014	5		20,294	3,219
2001	9	32	10,924	2,136	6	61	23,316	3,331	5	55	19,775	2,997
2003	10	32	11,133	2,394	12	60	23,323	3,693	10	54	18,961	3,605
2005	9	32	11,097	2,327	15	57	23,244	4,003	16	52	18,465	3,603
2007	9	35	11,203	2,790	16	56	23,089	4,391	26	54	18,466	4,436
2009	6	36	11,213	3,866	9	56	23,182	4,381	14	61	19,538	6,017
2011	6	36	10,478	3,393	12	61	23,015	4,404	16	64	19,457	6,285

Route: the number of routes operated between two regions; **Time** (day): average voyage time; **Length** (mile): average voyage length; Size (TEU): Average ship size; **ECNA**: East Coast North America; **WCNA**: West Coast North America; **MED**: The Mediterranean Sea.

Table 3-5: Operational parameters of pendulum, RTW and triangle routes

	Pendulum 1				Pendulum 2				Pendulum 3			
	Route	Time	Length	Size	Route	Time	Length	Size	Route	Time	Length	Size
1995	2		34,147	2,896	5		25,018	2,080	2		32,133	2,742
1997	4		32,797	3,125	2		28,126	2,376	3		33,173	3,016
1999	4		32,675	3,440	2		29,065	3,017	4		34,798	4,097
2001	5	90	32,303	3,733	1	91	29,128	2,831	5	88	32,983	4,575
2003	4	90	32,803	4,298	2	73	24,906	3,264	6	87	32,915	4,660
2005	4	91	32,552	4,432	2	70	22,506	3,457	4	84	31,684	5,023
2007	5	88	32,253	4,622	6	59	21,151	4,019	3	86	30,136	5,267
2009	5	89	32,271	4,713	4	61	21,612	4,707	2	91	30,833	7,439
2011	2	91	32,134	4,697	4	64	21,555	4,675	1	98	31,412	5,556
	Pendulum 4				Round-the-world				Triangle			
	Route	Time	Length	Size	Route	Time	Length	Size	Route	Time	Length	Size
1995					4		26,489	3,116				
1997	1		39,545	3,993	2		26,736	3,863				
1999	2		39,242	3,727	2		26,875	4,108				
2001	2	100	38,722	4,087	2	70	26,626	4,138	1	56	19,098	1,521
2003	1	105	39,232	4,253					1	49	19,098	2,646
2005					2	77	27,591	3,506	2	49	18,970	3,961
2007									1	49	19,113	4,366
2009	1	98	37,189	6,059	2	77	25,612	4,857				
2011	1	112	37,189	7,763	1	77	26,796	5,015				

Route: the number of routes in operation; **Time** (day): average voyage time. **Length** (mile): average voyage length. **Size** (TEU): Average ship size.

3.4 Comparative analysis of end-to-end, pendulum and round-the-world routes

3.4.1 Multiple trades

An ETE route is mainly dedicated to the trade between its westernmost and easternmost markets. Additionally more goods flows can be attracted by including intermediate port ranges between the two extreme markets of the route. By 2007, about half of the ETE routes on the East-West corridor only consisted of two regions. Afterwards, operators tended to extend their market coverage and looked for more throughputs by adding more regions on their services. Consequently the share of the simple ETE strings moved down in the range between 41% and 43%.

RTW and pendulum routes covered wider geographical scope than ETE ones. A greater number of markets can be served, which leads to more region-to-region container flows able to be transported by a single loop. A pair of eastbound and westbound RTW strings can serve the global East-West traffic. Nearly all the key flows can be shipped by the forth-model pendulum route, except the one between East Asia and East Coast North America (ECNA). In addition to Trans-Atlantic and Europe/Asia trades, the third-model pendulum service can carry the extra ones between ECNA and the Middle East, and South Asia.

Table 3-6: Captive trades of round-the-world and pendulum routes

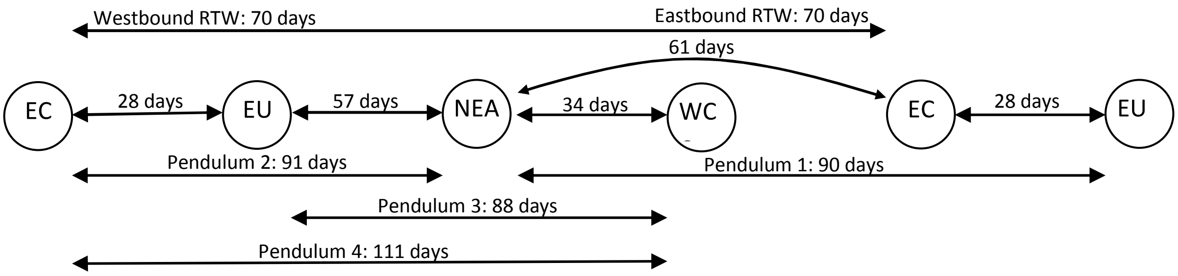
Pattern	Captive trades
Eastbound RTW	Eastbound global
Westbound RTW	Westbound global
Pendulum 1	Trans-Pacific, Trans-Atlantic
Pendulum 2	Trans-Atlantic, Europe/Asia, Intra Asia, North America/Middle East, North America/South Asia
Pendulum 3	Trans-Pacific, Europe/Asia, Intra Asia
Pendulum 4	Global traffic except East Asia/East Coast North America

Between 1995 and 2011, an ETE ship visited 3.48 regions per route on average, the figures were 7.44 for a pendulum one and 6.7 for a RTW one. The former could only serve 5.5 region-to-region cargo flows whereas the second 16.31 and the latter 22.67 flows. Thanks to the multiple trades, it is possible for RTW and pendulum ships to employ their slot several times. Strong legs can subsidise weak ones (Lim, 1996), so the negative effect of any trade variability can be reduced on the whole service. Additionally the combination of various trades on a loop may help carriers to deal better with container imbalance and repositioning as the experience of Evergreen (see more in Lloyd’s List, 1994).

Table 3-7: Multiple trades on shipping routes

	1995	1997	1999	2001	2003	2005	2007	2009	2011
	The average number of visited regions on a loop								
End-to-end	3.49	3.41	3.48	3.46	3.43	3.43	3.33	3.62	3.55
Pendulum	6.89	7.7	8.25	8.08	7.92	7.3	6.71	6.92	6.63
Round-the-world	6.75	7	7.5	6.5		6.5		4	6
	The average region-to-region cargo flows served by a loop								
End-to-end	5.53	5.35	5.55	5.49	5.44	5.31	5.04	5.83	5.65
Pendulum	14.89	17.1	19.42	18.77	17.85	15.6	14.07	14.58	13.63
Round-the-world	23	24.5	28	20.5		22		8	18

The integration of a series of consecutive ETE services possibly allows carriers to run a service with smaller fleet commitment due to the saving on total voyage time. In accordance with our estimation (figure 11), total voyage time of the eastbound and westbound RTW routes were 6 days less than that of separate ETE ones (140 days vs. 146 days), whereas the saving of the fourth-model pendulum one was 8 days (111 days vs. 119 days). The merger of Zim's Trans-Pacific and Asia/Mediterranean loops into a pendulum one in 2001 lowered ship requirement by one unit (Drewry, 2001a). Carriers may have more incentive to exploit pendulum or RTW routes during the period of tonnage shortage. The strongest use of the pendulum pattern in 2002 seemed to coincide with the aggressive growth of East-West shipping demand which was 4 percentage points higher than the growth of the supply.



EC: East Coast North America; **EU**: North Europe; **NEA**: North East Asia; **WC**: West Coast North America

Figure 3-11: Average voyage time of different route patterns in 2001

3.4.2 Multiple calls

Unlike intercontinental airplanes often calling at a single hub per region, trunk line vessels often pass through more than a stop. As a matter of course, the pure hub and spoke or single regional hub seems to be impractical in container shipping. The decrease of mother vessels' daily cost may not pay off extra feeder and handling cost. Gilman (1999) argues that although transhipment hubs have become more important, their use should not be seen as an alternative of multi-port operation. Network strategies of Maersk Line, Evergreen, Huyndai and MOL, presented by Fremon (2007), Sartini (1999) and Tongzon and Chang (2009), confirm the coexistence of the hub and spoke and multi-port systems to permit extensive market coverage.

Shuttle services operating between two ports have been sometimes launched but with very short lifespan (see more in Drewry, 2001a, 2010a; Visser & Braam, 2001). The closest connection makes possible to carry cargo very fast and keep highly reliable service. However the routes must rely much upon the two hubs' traffic as well as suffer from ship size's restriction due to small cargo catchment area. In the early 2000s, the ECS high-speed service between Hong Kong and Trieste (Italy) came to an end soon, chiefly because of poor utilisation levels and lack of customer support (Drewry, 2001a).

In the years 1995-2011, an East-West route visited 2.84 stops per region on average. Recently, carriers have tended to add more regional calls with the upward trend of the figure from 2.76 in 2007 to 2.99 in 2011. ETE routes were often designed with a greater number of calls per region than pendulum and RTW routes between 1995 and 2011. The mean amount of the former segment was 2.95 in comparison with 2.71 and 2.69 of the two latter. Fewer visits per region could be a factor resulting in the saving of voyage time of some RTW and pendulum services as displayed in the previous section. According to the simulation of Ashar (1999), ETE routes suffer from low slot utilisation on some port-to-port links, which could be as small as 36% of the ship capacity, due to the multi-ports of call. On the other hand, they benefit from closer proximity to hinterland than the other two, which brings about lower transhipment/distribution costs as well as higher possibility of regional traffic accumulation.

Table 3-8: Breakdown of average number of calls per region by route patterns

	1995	1997	1999	2001	2003	2005	2007	2009	2011
End-to-end	2.99	3.05	3	2.98	2.98	2.83	2.86	3.09	3.04
Pendulum	2.73	2.62	2.52	2.67	2.78	2.84	2.69	2.72	2.89
Round-the-world	2.74	2.79	2.53	2.92		2.85		2.63	2.67

3.4.3 Complexity

Pendulum and RTW routes are much more complicated than ETE ones. The complication can be demonstrated through the operation in multiple port ranges, the inclusion of a large number of ports of call, the long voyage distance and time (tables 7, 9). As a consequence, high investment and extremely broad service network are prerequisites to phase the pendulum and RTW strings into operation. In 1984, Evergreen spent about $1b to open two RTW services (Transport 2000, 1985), whereas it cost US Lines approximately $570m to build the RTW fleet (Gibney, 1987). In 2011, the longest pendulum route required a fleet of 16 ships. Any mistake in the investment possibly leads to a serious consequence as the case of US Lines.

Table 3-9: Scale comparison between end-to-end (ETE), pendulum and round-the-world (RTW) routes

	1995	1997	1999	2001	2003	2005	2007	2009	2011
The average number of calls per loop									
ETE	10.45	10.41	10.44	10.31	10.21	9.7	9.5	11.17	10.8
Pendulum	18.78	20.2	20.75	21.54	22	20.7	18.07	18.83	19.13
RTW	18.5	19.5	19	19		18.5		10.5	16
The average length per loop (mile)									
ETE	16,634	16,560	16,255	16,332	16,621	16,901	16,908	17,485	17,475
Pendulum	28,628	32,651	33,876	33,308	32,135	30,196	27,042	28,888	27,387
RTW	26,489	26,736	26,876	26,627		27,592		25,613	26,796
The average time per loop (day)									
ETE				43.21	44.62	44.61	44.49	49.62	52.99
Pendulum				91.23	87.54	84	75.5	81.08	81.25
RTW				70		77		56	77

Maintaining service reliability is a real challenge on RTW and pendulum services because their ships travel through many ports, trade lanes, traffic-crowded sea passages, and different weather conditions. The ships confront higher risks of delay and face more difficult than ETE ships to keep schedule. In a survey of American Shipper and the Marine Exchange, out of 8 RTW voyages of Evergreen, only 6 ones arrived at the port of Los Angeles or Long Beach on time whereas all ETE voyages were punctual (Heaney, 2000). Pendulum services was claimed to fall out of favour in 2007 because port congestion made them difficult to follow the schedule (CI, 2010b, p 23).

3.4.4 Transit time

Apart from cost factor, port-to-port transit time is another one influencing on service competitiveness. It is determined not only by operating speed of ships deployed but also by route configuration. Based on the ship schedule, it is possible to estimate transit time from a port to another one by a specific route, then average transit time by each pattern. For example, the 2001 average transit times from Hong Kong to Los Angeles of the ETE, pendulum and RTW routes were 14.1, 17 and 19 days respectively.

Because of a small number of RTW routes in operation between 2001 and 2011, only 554 samples were collected to compare average transit time between ETE and RTW routes. The former was more time-competitive than the latter in 64% of the total samples. Concerning the comparison between ETE and pendulum routes, the latter had faster transit time in 55% of 5,502 port-to-port flows gathered. In particular, pendulum routes had strong advantage on the Trans-Atlantic trade lanes with the ratio of 74% and Trans-Pacific ones with the ratio of 59%. Such advantages could stem from a smaller number of ports of call per region, leading to faster connection between the two adjacent regions on the East-West axis. In contrast, ETE routes provided quicker transportation on North East Asia/East Coast North America (61% of the samples) and had slight time advantage on Europe/North East Asia routes (52%). The fact that the pendulum route often consists of many port ranges leads to the detour of some cargo flows. For instance, the pendulum ship could deviate to the West Coast North America instead of directly linking North East Asia and East Coast North America as the ETE ship. As a result, the transit time could become longer.

Table 3-10: Samples of transit time between ports (Unit: day)

Year	2001		2003		2005		2007		2009		2011	
Direction	E/B	W/B	E/B	W/B	E/B	W/B	E/B	W/B	E/B	W/B	E/B	W/B
Hong Kong – Los Angeles												
ETE	14.1	18	14.4	19.3	14	19.7	14.2	21.2	16.1	18.9	15.6	20.8
Pendulum	17	20		18	12	16.5	15	18.7	15	19.5		20
RTW	19	20										
New York – Rotterdam												
ETE	11	9.5	11.5	10	16.7	10	16.3	11.8	15.5	12.5	17.7	12.7
Pendulum	11	9.75	11.3	9.7	11.7	9.7	12	9.5	11.5	10	13.5	9
RTW		14										
Hong Kong – Rotterdam												
ETE	27.9	22.9	27.4	23.1	29.5	23.7	28.9	25	31.1	27.2	34.7	29.1
Pendulum	25	25	27.3	23.5	27	24.5						
RTW		21										
Hong Kong – New York (via the Panama Canal)												
ETE	29	34	28.1	33	25.4	31.3	25.4	31.3	27.5	33.2	28.3	36.7
Pendulum	32.9	36.8	33.8	37.8	33	33.3	31	33.3	30.8	34.2	31	37.7
RTW	34	36			31	32			26	30	36	

E/B: eastbound; **W/B**: westbound

3.4.5 Mega ship deployment

Deploying big vessels has become an important strategy of liner carriers so as to reap cost saving. The trend happened most substantially on ETE routes between 1995 and 2011. Noticeably, the mean sizes on North Europe/North East Asia, Mediterranean Sea/North East Asia and North East Asia/West Coast North America routes climbed by 2.67 times (from 3,443 to 9,188 TEUs), 3.01 times (from 2,983 to 6,285 TEUs) and 2.61 times (from 2,905 to 6,341 TEUs) correspondingly. The biggest ships in the market have been often launched on the former segment. The growth on the Trans-Atlantic routes was much smaller by merely 1.41 times (from 2,806 to 3,930 TEUs). Though there was no geographical restriction on vessel capacity as North East Asia/East Coast North America routes, the sluggish traffic and short voyage distance have squeezed shipping lines out of investing in large ships on the corridor.

In the mid-1990s, pendulum and RTW loops could be comparable to ETE ones related to ship size. Nevertheless they have become more and more disadvantageous in consequence of the invasion of mega vessels on the key ETE loops. From 1995 to 2011, the average capacity of ETE routes went up by 2.22 times, whilst the respective rates of pendulum and RTW ones were 2.05 and 1.61. The largest ship size on the former sector obtained 15,550 TEUs in 2011, whereas those on the two latter sectors were just 8,533 TEUs and 5,100 TEUs.

Table 3-11: Ship deployment

		1995	1997	1999	2001	2003	2005	2007	2009	2011
End-to-end	Average size (TEU)	3,019	3,325	3,449	3,757	4,146	4,460	5,190	6,156	6,708
	Largest size (TEU)	4,950	6,000	6,690	7,500	8,063	9,200	12,513	13,800	15,550
Pendulum	Average size (TEU)	2,581	3,027	3,723	4,045	4,330	4,506	4,604	5,372	5,312
	Largest size (TEU)	4,072	4,545	6,600	6,600	6,600	6,600	6,611	9,200	8,533
Round-the-world	Average size (TEU)	3,116	3,863	4,108	4,138		3,506		4,857	5,015
	Largest size (TEU)	4,229	4,229	4,211	4,229		4,253		5,624	5,100

The first factor restricting the influx of big ships on pendulum and RTW loops has come from the constraint of the Panama Canal not allowing the use of Post-Panamax ships on RTW and first-model pendulum strings. The second factor has been traffic discrepancy between different trade lanes. As displayed in figure 13, the ratio between the volume on the Trans-Atlantic corridor and that on the Europe/East Asia or Trans-Pacific one was less than one third. Mega vessels could be economical on the two latter corridors, but subjected to serious under-utilisation on the former one. Load factor on the eastbound leg of the Trans-Atlantic trade lane could be merely one fifth of that on the westbound leg of the Europe/East Asia lane or eastbound leg of the Trans-Pacific lane.

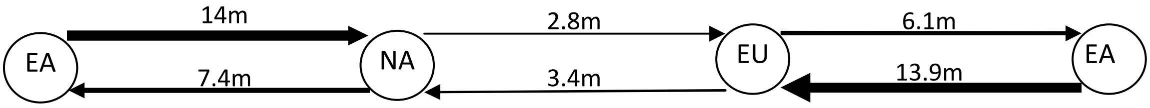


Figure 3-12: Traffic imbalance between the key legs (**EA**: East Asia; **NA**: North America; **EU**: Europe)**.**
Source: based on data published by Drewry (2012a).

Some studies have expected the employment of pendulum and RTW ones as the backbones of the global shipping (Ashar, 1999, 2000, 2002; Visser & Braam, 2001). Nevertheless economics of ship size will be still an obstacle for the ideas. Whereas the Panama Canal's restriction will be solved soon thanks to the expansion project, the trade dissimilarity between the key legs will certainly remain a challenge for operators to place big vessels on RTW and pendulum routes.

3.5 Conclusions

The study takes account of deployed patterns of trans-continental shipping routes on the East-West corridor between 1995 and 2011. The majority of routes operated under the ETE pattern. The pendulum pattern was the second favourite one in the market, but the use became declined in the 2000s. The RTW had been not applied popularly. Evergreen had been the sole one capable of employing the pattern for a long period. The triangle had occasionally appeared in the industry.

Integration of multi-trades is obviously an important advantage of the pendulum and RTW patterns, which facilitates the consolidation of containers from a greater number of markets. Additionally the integration could help operators to reduce the number of ships commitment to the service in comparison with separate ETE ones thanks to shorter voyage time.

ETE routes often consisted of a greater number of ports of call per region than the other two ones, which could be their advantage in terms of hinterland proximity although they could suffer from higher cost of arterial vessels as well as under-utilisation on some regional port-to-port links.

In terms of scale, the pendulum and RTW were evidently much more complex then the ETE regarding the number of regions of call, ports of call, voyage distance and time. Consequently operators were subjected to high investment as well as more challenge to keep service reliability.

In respect of transit time, RTW routes seemed to be less competitive than ETE ones. There were no big difference between pendulum and ETE ones. The advantage of the former often existed on the pairs of ports located in two adjacent regions. On the other hand, the advantage shifted to the side of ETE ones when the flows were subjected to deviation of ship journey because of intermediate calls between the original and final markets.

The deployment of mega vessels was restricted on pendulum and RTW routes. The first reason came from the nautical limitation of the Panama Canal, the second one came from traffic discrepancy between the key trade lanes resulted in low slot usage on some legs.

Chapter 4: Development of the shipping network on the East-West corridor[1]

Highlights:

- Comprehensive review of literature in analyzing container shipping network
- Topological structure of the shipping network (1995-2011)
- Dynamics of regional shipping networks

4.1 Introduction

This chapter concentrates on the topological structure of the East-West shipping network in the years 1995-2011. The corridor connects the three most important economic poles of North America, Europe and East Asia, and can be considered as the backbone of the global shipping. In 2011, some 68.6m TEUs accounting for 42.1% of the global container shipping volume were transported through it (Drewry, 2012a). Research data is combined from 2,329 service records of the top 20 carriers and processed by designated computer programs.

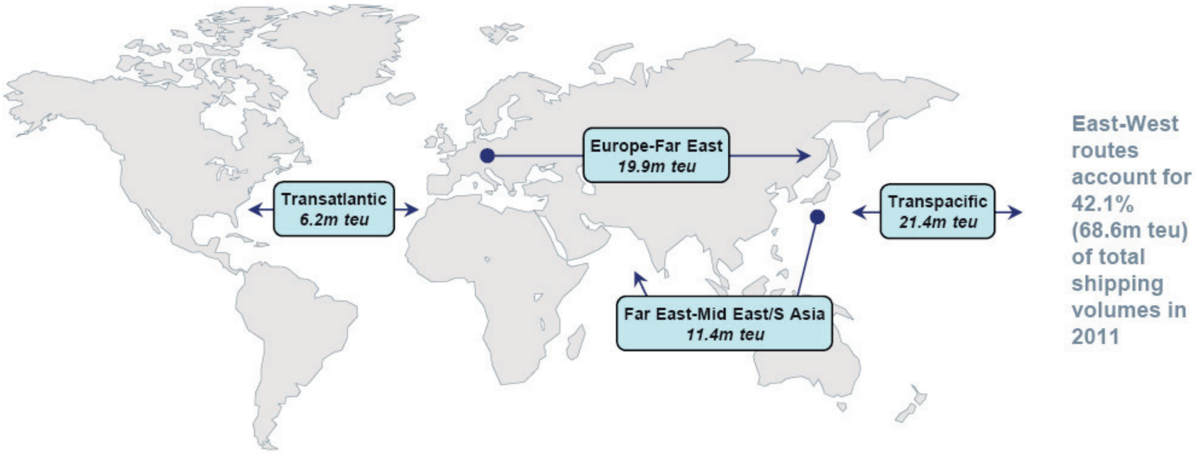


Figure 4-1: Containerised seaborne trade on the East – West corridor.

Source: Drewry (2012a)

Several key issues are presented in the research. The first focuses on network scale through deployed routes and fleet, vertices (ports) and arcs (directed connections between ports). The second addresses arc properties regarding nautical distance, travelling time, geographical distribution and assortativity. Inter-port links which are bundles of arcs on port-to-port corridors are also considered.

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[1] Chapter 4 was published in the journal of Netnomics – Economics Research and Networking (2014, Volume 15, Issue 3, pp 121-153) with the title of "Empirical analysis of the container liner shipping network on the East-West corridor (1995-2011)".

The third evaluates the relative network position of ports on the basis of degree centrality, port degree distribution and concentration, and the relationship between port degree and throughput. The forth considers changes and characteristics of regional networks based on network indicators.

The rest of this chapter is structured as follows. Section 4.2 provides a snapshot of literature in the field of network study. Section 4.3 describes characteristics of the shipping network. Section 4.4 introduces the research methodology. Section 4.5 includes key outcomes of network computation. Section 4.6 goes deeper into dynamics of regional networks. The final section consists of some conclusions.

4.2 Literature review

Networks of shipping lines and regions have been described in abundant studies. UNCTAD (2013) publishes an annual liner shipping connectivity index to describe a country's position on the worldwide container shipping network. The global system of Maersk Line is thoroughly investigated by Fremont (2007). Ferrari et al. (2012) address the role of home markets in the network strategy of carriers. Yap and Notteboom (2011) analyse annualised slot capacity of liner services to unveil dynamics of shipping networks in some key regions. Lam (2011) also deploys slot capacity analysis to study the top liners' connection to Singapore and Hong Kong.

Robinson (1998) sketches Asian hub/feeder nets under the rapid growth of the region in the 1990s. He speculates the transformation of simple mainline/feeder networks into more complex patterns of hierarchical networks reflecting cost/efficiency levels in the market. Parola et al. (2006) address network restructuring in Asia as a consequence of changes in logistics systems. Wang and Ng (2011) classify Chinese ports into three hierarchies based on their foreland coverage. Genco and Pitto (2000) approach the network development of the Mediterranean Sea which creates a hierarchical structure dependent upon the interaction between mega and niche hubs, direct and feeder ports in this area. Wilmsmeier and Notteboom (2009) identify four phases in the evolution of a network connecting two differently developed regions and apply them in the context of the networks of the South American West Coast and Europe.

Quantitative analyses of container shipping network's topological structure have been growingly conducted. Veenstra et al. (2005) introduce a tool stemming from a multi-layer graph structure to visualize and analyze the Caribbean network. Also addressing the network, McCalla et al. (2005) compare its structure between 1994 and 2002 at three geographical scales: intra-basin, regional and global. Integrating services of the 24 leading carriers, Wang and Wang (2011) point out the connectivity between key maritime regions as well as identify a hub and spoke system on the global network. Cullinance and Wang (2012) apply multiple linkage analysis to construct a hierarchical configuration of key ports on the East-West routes. Ducruet et al. (2011) propose five groups of indicators to evaluate the effects of ports' network positions on their throughput.

Hu and Zhu (2009), Deng et al. (2009) and Kaluza et al. (2010) focus deeply on non-trivial attributes of complex liner networks. The two former ones use published data of shipping services whereas the last one uses automatic identification system data. Various structural properties are taken into account to examine the scale-free and small-world features of the shipping network.

Cisic et al. (2007) is among the pioneer papers considering the relative importance of ports on the basis of centrality indices. In the context of the Mediterranean Sea, their role is evaluated by degree centrality, betweenness centrality and closeness centrality. Wang (2013) employs the idea of a turn parameter of Obsahl et al. (2010) to calculate these indices on the weighted shipping network. The concept of proximity foreland is demonstrated by Montes et al. (2012a) and Seoane et al. (2013a, 2013b). A port's proximity foreland is defined as the set of other ports that it can reach through at maximum three links. Appraising degree centrality as a chief indicator of port position on shipping network, Ducruet and Zaidi (2012) propose a topological decomposition method to study sub-groups of isolating ports with comparable sizes.

Wang and Cullinane (2008) consider accessibility as a relevant aspect of the competitiveness of a port. The principal eigenvector method is employed to measure its accessibility. Low et al. (2009) approach the hub status of Asian ports through connectivity and competition indices. The former expresses direct accessibility of a port to other ones whereas the latter reveals its competitiveness in capturing cargo. Low and Tang (2012) study network effects on East Asia ports by improving the two indices and integrating them with the congestion index measuring capacity utilization in a port and the concentration index measuring its throughput share. Using betweenness centrality, Ducruet et al. (2009) bear the position of South Korean ports at the top hierarchy in North East Asia.

Ducruet et al. (2010) use degree centrality, betweenness centrality and vulnerability to investigate North East Asia port hierarchy in 1996 and 2006. The last indicator measures the share of the dominant flow of a port within its traffic. Also based on these indices, Ducruet and Notteboom (2012a, 2012b) and Laxe et al. (2012) describe the world-wide network's evolution in the periods of 1996-2006 and 2008-2010.

Several papers have studied the network structure not only of container shipping but other transportation modes as well. To such an extent, it is possible to compare features of the container shipping network with others. Some works can be mentioned: Kaluza et al. (2010) (bulk dry ships, oil tanker and container ships); Montes et al. (2012b) (general cargo and container shipping); Ducruet et al (2011) (air transportation and container shipping); Ducruet et al. (2013) (solid bulk, liquid bulk, container, general cargo, and passenger/vehicles).

The topological structure of networks has become an important issue of the shipping network research since the mid-2000s. The emergence of dedicated softwares, such as Tulip and Ucinet, has greatly facilitated the analysis and visualization of very large scale networks. The literature on the group often deals with three principal issues: measurement of basic network properties (node, link, network density, length, diameter), complex network features (scale free, small-world, assortative mixing), and position of ports in the network (centrality indices such as degree, betweenness and closeness centrality). Data is mainly obtained from two major sources: the automatic identification system (AIS) information recorded by Lloyd's Maritime Intelligence Unit about actual ship movements from port to port, and the route information published in Containerisation International Yearbooks or shipping lines' website.

Table 4-1: A summary of researches on the topological structure of the container shipping network

Author (year)	Research issue	Key indicators	Data source
Cisic et al. (2007)	Importance of Mediterranean sea ports	Degree, betweenness, closeness centrality	Service information
Cullinane and Wang (2012)	Hierarchical configuration of key container ports	Basic network properties	CI
Deng et al. (2009)	Measurement of complex shipping network	Complex network properties	Service information
Ducruet (2013)	Comparison between container shipping network and other shipping networks	Complex network properties, degree and betweenness centrality	AIS
Ducruet and Notteboom (2012a,b)	Evolution of world-wide shipping network between 1996 and 2006	Degree and betweenness centrality, vulnerability	AIS
Ducruet and Zaidi (2012)	Application of topological decomposition method to analyze world-wide maritime network	Complex network properties, degree centrality	AIS
Ducruet et al. (2011)	Comparison between air transportation network and container shipping network	Complex network properties	AIS
Ducruet et al. (2010)	Evolution of North East Asia shipping network between 1996 and 2006	Degree and betweenness centrality, vulnerability	AIS
Ducruet et al. (2011)	Position of Korean ports on Asian shipping network	Betweenness centrality	AIS
Ducruet et al. (2011)	Effect of ports' network position on throughput	Complex network properties, degree and betweenness centrality	AIS
Hu and Zhu (2009)	Measurement of complex network	Complex network properties	CI
Kaluza et al. (2010)	Measurement of complex shipping network	Complex network properties	AIS
Laxe et al. (2012)	Evolution of world-wide shipping network between 2008 and 2010	Complex network properties, degree and betweenness centrality	AIS
Low et al. (2009)	Hub status of Asian ports	Cooperation and connectivity index	Service information

Low and Tang (2012)	Importance of East Asia ports	Centrality, competition, congestion and concentration indices	Lloyd's List port of the world
Mc Calla et al. (2005)	Comparison of the Caribean network between 1994 and 2002	Basic network properties	CI
Montes et al. (2012)	Evolution of the global shipping network from 2007 to 2011	Proximity foreland	AIS
Montes et al. (2012)	Comparison between container shipping network and general shipping network	Complex network properties, betweenness centrality	AIS
Seoane et al. (2013a)	Evolution of the South Atlantic network from 2007 to 2011	Degree and betweenness centrality	AIS
Seoane et al. (2013b)	Comparison between container shipping network and general shipping network	Foreland proximity	AIS
Veenstra et al. (2005)	Container network in the Caribbean	Basic network properties	AIS
Wang and Cullinane (2008)	Importance of ports on the shipping network	Port accessibility	CI
Wang and Wang (2011)	Hub and spoke system on the global network	Basic network properties	Service information
Wang (2013)	Calculation of centrality indices on weighted shipping network	Degree, betweenness, closeness centrality	CI

AIS: Automated identification system. CI: Containerisation International

4.3 Network description

A route is a basic component of the container shipping system. It is characterized by a predetermined sequence of visited ports, arrival schedule, frequency and deployed ships. It operates in accordance with the circular principle: after the last port in the sequence, the ships will visit the first port again and start a new cycle. Routes are designed to serve shipping demand between regions. In each region, several ports are chosen to call by a route's ships. Nine different regions along the East-West corridor are categorized in this research: East Coast North America, North Europe, the Mediterranean Sea, the Middle East, South Asia, South East Asia, North East Asia, the West Coast of North America, and Central America and the Caribbean.

The combination of numerous routes forms a directed network. Figure 2 illustrates the Trans-Pacific network of K-Line including three routes to serve the trade between North East Asia and the West Coast of North America. It consists of 14 vertices (ports) and 28 arcs with a total length of 37,230 miles.

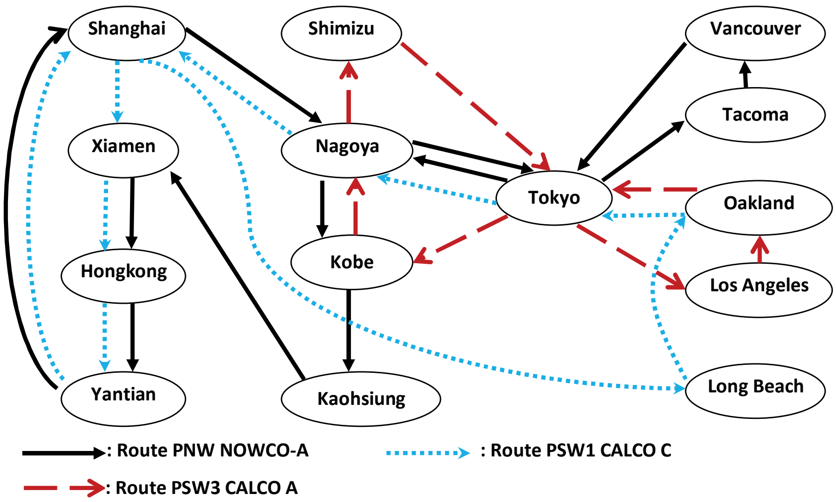

Figure 4-2: K-Line's Trans-Pacific network in 2011.

Source: visualized by the authors based on route information published in Containerisation International Yearbook (2012).

There are several characteristics of a shipping network:

- Each vertex represents a port passed through by at least one route.

- Each arc represents a ship movement between two consecutive ports on a specific route. Between two ports, two arcs or more can coexist with the same or different directions (for instance Xiamen-Hong Kong; Nagoya-Tokyo).

- An arc's weight corresponds to the average ship size of the route it belongs to. Arc Tokyo-Los Angeles on route PSW3-CALCO A has the weight of 4,768 TEUs; arc Kobe-Kaohsiung on PNW NOWCO-A: 5,836 TEUs; arc Nagoya-Shanghai on PSW1 CALCO C: 4,475 TEUs. Furthermore, each arc could possess two other attributes: nautical distance and transit time from its tail to head. The length and transit time of the former arc are 4,874 miles and 15 days, respectively.

- Because East-West routes are circular and weekly in frequency, the numbers of in-arcs (in-degree) and out-arcs (out-degree) are similar and equal to total weekly calls at a port. For the sake of simplicity, they are called port degree. Minimum degree is 1, or each port must have at least one in-arc and one out-arc. Maximum degree can be larger than the total number of routes because a port can be visited more than one time on a loop. Weighted degree is equivalent to total capacity of vessels visiting the port per week. The degree and weighted degree of Hong Kong are 2 and 10,311 TEUs. Those of Tokyo are 5 and 25,683 TEUs, respectively.

- The number of arcs on the network is equal to total weekly calls at all ports.

- The network length is equal to the total length of all routes and corresponds to the total travelling distance of all ships per week.

- An inter-port link represents a pair of ports connected by at least one arc, irrespective of arc direction. The link degree corresponds to the total number of ship movements whereas the weighted link degree corresponds to total fleet capacity travelling between them per week. The degree and weighted degree of link Shanghai-Nagoya are 2 and 10,311 TEUs, of link Nagoya-Tokyo are 3 and 16,147 TEUs.

4.4 Research methodology

The purpose of this paper is to analyze the structural properties of the container shipping network on the East-West trade lane of the top 20 shipping lines in the period 1995-2011. Controlling over 70% of the global fleet capacity, they are dominant operators on the East-West axis. The theoretical background stems from graph theory, statistical techniques, social network analysis, and transportation network structure proposed in various works (see for example Kanski, 1963; Newman, 2011; Rodrique et al., 2009; Wasserman & Faust, 1995). It is the basis for developing network indicators which are applied for in-depth analyses (for additional descriptions see Appendix 1).

Data is recruited from the service information of the leading carriers published by Containerization International Yearbooks (CIYs) from 1996 to 2012. Basic information of a specific route consists of ports of call, time schedule, ship fleet and operators. To avoid replication, a route jointly operated by several operators is only deployed once in the study. Additional data includes port throughput also published in CIYs and nautical distance between ports collected from Dataloy Distance Table[2].

Data synthesis and calculation of network indicators are carried out by specially tailored computer programs written in the language of Freepascal. There are three major program packages dedicated to the research. The first creates a route database from the retrieved input information. Based on the database, the second calculates the network indicators. The third exports programming results for further visualization and analyses.

The methodology is different from others in two main aspects. Firstly, network data lasts for a long period of 17 years, instead of one or two years, so it is possible to describe more clearly dynamics of the shipping network. Secondly, the research is done on directed networks with multiple valued arcs between ports. It takes into account not only connectivity but also different connections between them created by different shipping routes.

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[2] http://www.dataloy.com/

4.5 Computational results

This section aims to show the characteristics of the shipping network through the indicators. The outcomes of network computation will be presented in several parts: the growth of the shipping network (sub section 4.5.1), the properties of the arcs (4.5.2) and the inter-port links (4.5.3), the degree of ports on the shipping system (4.5.4), the scale-free attribute of the shipping network (4.5.5), the concentration trend of port degree (4.5.6) and the relationship between port degree and throughput (4.5.7).

4.5.1 Network development

Global container traffic grew more than 3.5 times from 46m to 164m TEUs over 1995-2011 (2012). New East-West routes were launched to meet such growth. The transportation system consisted of 100 routes (R) (total network length L of 1.78m miles) in 1995 and peaked with 199 (3.35m miles) in 2007. Afterwards, consequences of the global financial crisis reduced its scale to 163 routes (2.77m miles) in 2011. Vessel fleet (F) on the corridor moved up from 1.51m in 1995 to 7.12m TEUs in 2011. The trend to deploy big vessels is expressed through the upswing in the average ship size (Avg) from 2,914 to 6,304 TEUs.

New end-to-end routes were a key driver of network expansion. From 1995 to 2011, inter-continental routes on the Europe-Far East corridor nearly doubled the length whereas their fleet capacity went up almost 6 times. In 2011, 45 loops operated on the corridor and accounted for 36% of the total network length (989,099 miles) and 51% of the fleet capacity (3.61m TEUs). The connection between East Asia and East Coast North America also developed markedly from 5 strings (125,991 miles; 36,982 TEUs) to 12 (276,184 miles; 466,905 TEUs). The Trans-Pacific network more or less concentrated on raising fleet capacity (3.14 times); there was insubstantial change in respect of the number of services and network length. The Trans-Atlantic lane slightly grew from 14 routes (133,750 miles; 64,545 TEUs) to 18 (179,349 miles; 196,516 TEUs). Only a minor group on the East-West axis with 4 services (39,914 miles; 26,561 TEUs) in 1995, the Far East-Middle East/South Asia link experienced remarkable growth to reach 31 services (377,664 miles; 620,990 TEUs) in 2011.

The emergence of new routes evidently resulted in network enlargement. More vertices and arcs were added to the shipping network, which meant the involvement of more ports on the transportation system as well as the larger number of port calls. The network was broadened from 93 vertices (Ver) and 1,139 arcs (Arc) in 1995 to 142 vertices and 1,843 arcs in 2011. The number of inter-port links (IPL) climbed from 341 to 646, corresponding with connectivity coefficients (γ) of

7.5% and 6.0%. Altogether the ports served the weekly fleet capacity (Cap) of 5.03m TEUs in 2001. It went up to 11.05m TEUs in 2011.

In recent years, slow steaming has been widely applied in the industry in response to expensive bunker cost and over-capacity (Cariou, 2011; Ferrari et al., 2012; Maloni et al., 2013). Additionally more stops have been inserted on shipping routes. For instance, the average stops per loop were 10.21 in 2006 and up to 11.25 in 2011. The average ones in North Europe increased from 3.66 to 3.73, while in North East Asia from 4.90 to 5.63. Slow steaming and more port calls have surely affected the average transit speed (v). The indicator determined by time at sea and time in port measures how fast a container is transported on the network. It was rather stable between 366 and 370 miles per day from 2001 to 2007, but fell afterwards and was merely 325 miles in 2011.

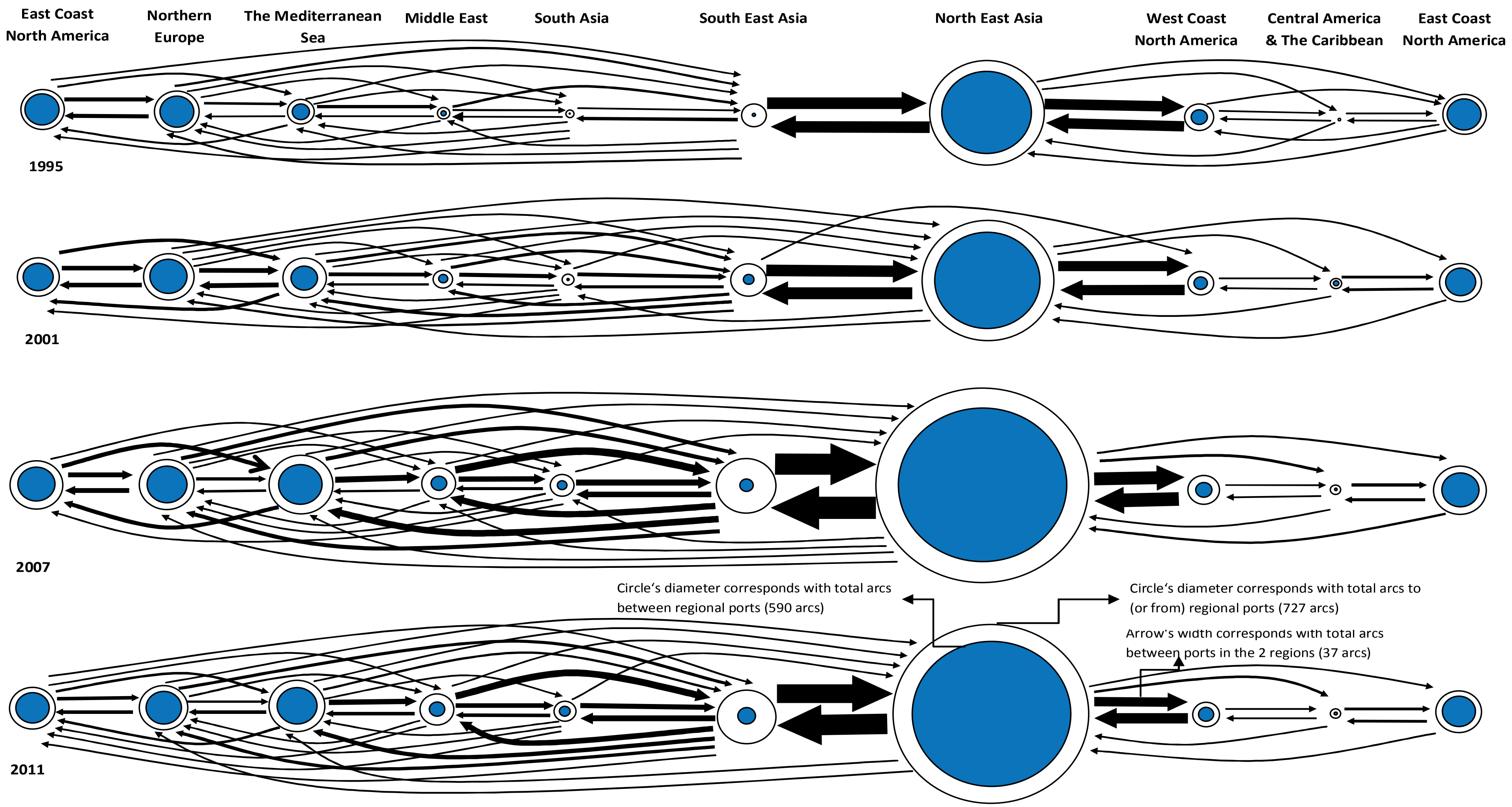

Figure 4-3: Development of the East – West shipping network.
Source: Visualized by the authors based on the input data

The shipping network is visualized on the basis of trade region. The order of the regions from left to right matches with their positions on the East-West corridor. The involvement of each region on the network is represented by two concentric circles. The diameter of the outer circle is corresponding to the total number of arcs connected to (or from) the regional ports (including both intra-regional and inter-regional arcs), whereas the diameter of the inner circle is corresponding to the total number of arcs between two regional ports (including only intra-regional arcs). The width of the arrow expressed the total number of arcs connecting ports located in the two regions (inter-regional arcs).

Table 4-2: Network indicators

Year	*R*	*L*	*F*	*Avg*	v	*Ver*	*Arc*	*Cap*	*IPL*	μ_1	μ_2	μ_3	μ_4	γ	η_1	η_2	HHI	ρ	λ
1995	100	1.78	1.51	2,914	-	96	1,139	-	450	11.86	-	3.34	-	4.93	1,566	-	305	0.37	0.69
1996	110	1.86	1.58	3,134	-	98	1,170	-	510	11.94	-	3.12	-	5.37	1,592	-	274	0.29	0.66
1997	97	1.74	1.81	3,226	-	106	1,110	-	535	10.47	-	2.84	-	4.81	1,566	-	257	0.31	0.71
1998	92	1.69	1.98	3,389	-	107	1,094	-	517	10.22	-	2.83	-	4.56	1,544	-	275	0.3	0.72
1999	104	1.85	2.16	3,478	-	111	1,201	-	559	10.82	-	2.82	-	4.58	1,544	-	257	0.28	0.71
2000	114	2.05	2.61	3,430	-	116	1,343	-	654	11.58	-	2.74	-	4.90	1,526	-	248	0.29	0.76
2001	118	2.12	3.05	3,690	369	115	1,379	5.03	672	11.99	43,723	2.65	9,651	5.13	1,540	4.17	234	0.26	0.75
2002	116	2.13	3.28	3,978	366	121	1,435	5.70	690	11.86	47,095	2.71	10,772	4.75	1,488	4.06	233	0.33	0.70
2003	140	2.46	3.71	4,011	367	132	1,606	6.34	766	12.17	48,040	2.69	10,622	4.43	1,534	4.2	233	0.41	0.71
2004	158	2.74	4.22	4,080	370	139	1,725	6.92	802	12.41	49,807	2.75	11,024	4.18	1,590	4.3	247	0.43	0.72
2005	176	3.02	4.88	4,244	369	145	1,838	7.68	862	12.68	52,938	2.71	11,321	4.13	1,644	4.47	252	0.44	0.69
2006	188	3.18	5.37	4,576	369	148	1,924	8.56	899	13.00	57,865	2.68	11,944	4.13	1,652	4.52	246	0.45	0.71
2007	199	3.35	5.92	4,830	366	151	2,020	9.57	926	13.38	63,367	2.74	12,983	4.09	1,660	4.51	256	0.46	0.72
2008	192	3.33	6.26	5,149	355	149	2,032	10.14	931	13.64	68,021	2.75	13,715	4.22	1,640	4.66	258	0.44	0.69
2009	150	2.64	5.84	5,784	349	135	1,744	10.02	819	12.92	74,241	2.73	15,685	4.53	1,513	4.35	247	0.43	0.73
2010	164	2.87	6.75	5,959	334	147	1,921	11.14	848	13.07	75,801	2.88	16,681	3.95	1,495	4.48	260	0.46	0.71
2011	163	2.77	7.12	6,304	325	148	1,843	11.05	818	12.45	74,670	2.85	17,107	3.76	1,505	4.63	263	0.43	0.73

Source: Calculated by the authors based on the input data

R: the number of shipping routes; ***L***: total network length or total travelling distances of all ships per week (10^6 miles); ***F***: fleet capacity to serve shipping routes (10^6 TEUs); ***Avg***: average ship size (TEU); v: average transit speed per day (mile); ***Ver***: the number of vertices; ***Arc***: the number of arcs; ***Cap***: total fleet capacity all ports served per week (10^6 TEUs); ***IPL***: the number of inter-port links; ***γ***: connectivity coefficient, a quotient of the number of inter-port links to the maximum number of inter-port links; μ_1: average port degree or average weekly call per port; μ_2: average port weighted degree (TEU) or average weekly calling capacity per port; μ_3: average inter-port link degree or average number of ship movements between two ports per week; μ_4: average inter-port link weighted degree or average fleet capacity travelling between two ports per week; **γ**: connectivity coefficient (%), a quotient of the number of inter-port links and the maximum number of inter-port link; η_1: average arc length (mile); η_2: average travelling time per arc (day); ***HHI***: concentration index of port degree; ρ: assortative mixing coefficient; λ: Scale free coefficient

* From 1995 to 2000: the information of deployed ships and voyage time per route is not available, so there are some missing indicators of average transit speed per day (v), total fleet capacity all ports served per week (***Cap***), average port weighted degree (μ_2), average inter-port link weighted degree (μ_4) and average travelling time per arc (η_2).

4.5.2 Arcs on the network

Assortative mixing coefficient (ρ) fell into the region between 0.26 and 0.37 over 1995-2002. After that it moved upwards between 0.41 and 0.46. The positive values state that arcs tended to connect ports with similar degree characteristics. Moreover, the trend was stronger from 2003. In reality, the network was dominated by connections between high degree ports. In 1995, arcs between the top 10 largest degree ports contributed to 23% of the total arcs, top 30: 68%, and top 50: 86%. The respective percentages were 22%, 51% and 72% in 2003 and 25%, 53% and 71% in 2011.

There was substantially negative correlation between the average number of calls per string and mean arc length (η_1) with Pearson correlation coefficient (PCC) of -0.91. The more stops made η_1 diminish from 1,660 miles in 2007 to 1,513 in 2009 and 1,505 in 2011. The mean travelling time per arc (η_2) moved up from 4.17 days in 2001 to 4.52 in 2006 and 4.63 in 2011. It seemingly varied in the same direction with η_1 (PCC of 0.5) and opposite one with the transit speed (PCC of -0.5).

In 1995, 742 arcs were intra-regional whereas 397 ones were inter-regional. The corresponding amounts were 1,045 and 561 in 2003, and 1,222 and 621 in 2011. The two segments were often in the rough proportion of 2:1. In 2011, the largest number of the former segment came from North East Asia (590 arcs), then the Mediterranean Sea (148), North Europe (131) and East Coast North America (124). Connections between North East Asia and South East Asia contributed most to the latter segment (155 arcs), then between North East Asia and West Coast North America (78).

Intra-regional arcs were often less than 2,000 miles. Below 1,000 mile ones played over 90% of the segment from 2004, some higher percentage points than the previous years. The trend of shorter intra-regional arcs could be witnessed through strongly negative correlation between their average lengths and values of time (PCC of -0.97). The average length was 523 miles in 1995, down to 503 in 2001, then 466 in 2007 and 444 in 2011.

The largest group of the inter-regional segment was arcs between 1,000 and 2,000 miles with about a third portion. More than 75% of arcs in the segment were shorter than 5,000 miles. There were few ones longer than 10,000 miles. Nevertheless, the further appearance of such very long arcs on the network could be recognized from only 1 or 2 arcs in the latter half of the 1990s to above 10 from 2005. They often tied North East Asia and East Coast North America, sometimes North East Asia and North Europe, East Coast North America and South East Asia, for example Hong Kong-New York (11,277 miles); Boston-Qingdao (10,821 miles); Antwerp-Xiamen (10,825 miles); Felixstowe-Shanghai (10,558 miles); and Savannah-Singapore (10,722 miles).

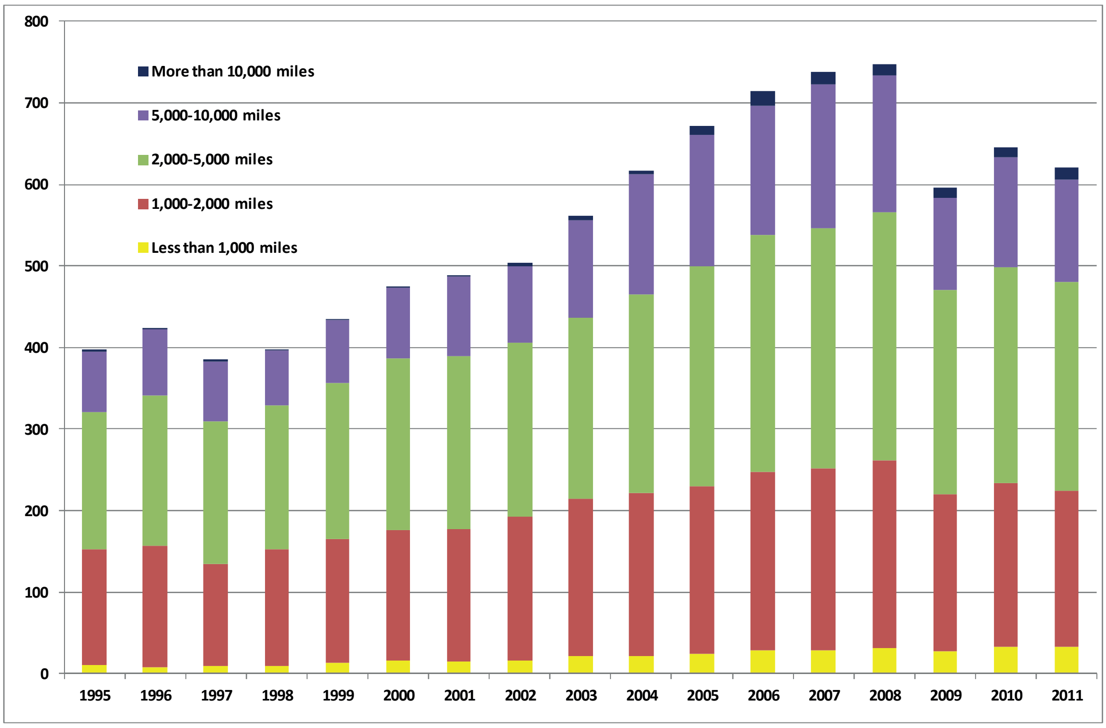

Figure 4-4: Nautical distance distribution of inter-regional arcs.
Source: visualized by the authors based on the input data

4.5.3 Inter-port links

Inter-port link degree measures the number of ship movements between two ports per week whilst weighted link degree corresponds to the total fleet capacity travelling on the corridor. Over 2001-2011, there were nearly perfect correlations between the two indicators ($PCCs \approx 1$). Furthermore, the mean link degree (μ_3) only underwent minor growth (2.65 in 2001; 2.68 in 2006; 2.85 in 2011) but the mean weighted degree (μ_4) experienced significant upturn (respective values of 9,651; 11,944; 17,107 TEUs). Such substantial growth was obviously attributable to the influx of mega vessels, which led to higher value of weight of arcs, and in turn, weight of links.

From 1995 to 2011, the proportions of the top 10 and top 20 largest degree links were rather unchanged. The former accounted for 20% of the total ship movement, whereas the latter some 28%. The busiest links were dominated by intra-regional ones. In the top 20, merely Hong Kong-Singapore, Shenzhen-Singapore, and sometimes Colombo-Singapore were inter-regional links.

Hong Kong-Singapore, Hong Kong-Kaohsiung, Virginia-New York, Shenzhen-Hong Kong and Port Klang- Singapore were regular members of the top 10 links from 1995. Shenzhen-Singapore, Ningbo-Shanghai, Busan-Shanghai and Shenzhen-Ningbo strongly rose to the top ones in the 2000s. Los Angeles-Oakland and Hamburg- Rotterdam occasionally belonged to the group. Kobe-Nagoya, Bremerhaven-Rotterdam, Busan-Kaohsiung, Colombo-Singapore and Nagoya-Tokyo were among the most deployed links over 1995-1999. Nevertheless, their importance on the network decreased and was no longer in the list. Before 2000, the leading links were Hong Kong-Singapore and Hong Kong-Kaohsiung. However, Shenzhen-Hong Kong took first place from 2001 whereas Ningbo-Shanghai took second one from 2006.

Table 4-3: The top 10 largest degree links

	1995					2001			
	Deg	W_deg	Rou	Dis		Deg	W_deg	Rou	Dis
Hong Kong-Singapore	70	-	44	1,434	Shenzhen- Hong Kong	46	201,966	36	33
Hong Kong-Kaohsiung	53	-	43	353	Hong Kong-Kaohsiung	45	191,092	39	353
Kobe-Nagoya	23	-	21	245	Hong Kong-Singapore	44	162,817	30	1,434
Colombo-Singapore	19	-	15	1,596	Port Klang-Singapore	27	89,636	22	211
Los Angeles-Oakland	19	-	17	384	Virginia-New York	22	70,305	19	309
Virginia-New York	18	-	16	309	Hamburg-Rotterdam	19	83,085	18	316
Hamburg-Rotterdam	18	-	16	316	Kobe-Nagoya	18	73,254	15	245
Long Beach-Oakland	16	-	13	386	Hong Kong-Shanghai	17	62,885	16	872
Kaohsiung-Kobe	15	-	14	1,146	Shenzhen-Singapore	17	67,217	13	1,436
Bremerhaven-Rotterdam	14	-	14	262	Nagoya-Tokyo	15	57,638	11	225
	2007					2011			
	Deg	W_deg	Rou	Dis		Deg	W_deg	Rou	Dis
Shenzhen- Hong Kong	95	527,987	84	33	Shenzhen-Hong Kong	88	604,703	71	33
Ningbo-Shanghai	68	331,821	68	163	Ningbo-Shanghai	70	460,881	69	163
Hong Kong-Singapore	45	196,085	36	1,434	Shenzhen-Singapore	40	241,320	35	1,436
Shenzhen-Singapore	45	212,534	41	1,436	Busan-Shanghai	31	182,195	31	501
Port Klang-Singapore	29	106,244	20	211	Hong Kong-Singapore	29	173,854	23	1,434
Busan-Shanghai	27	117,706	25	501	Port Klang-Singapore	26	131,859	23	211
Virginia-New York	24	92,159	22	309	Hong Kong-Kaohsiung	20	123,131	16	353
Shenzhen-Shanghai	22	129,421	22	890	Shenzhen-Ningbo	20	134,648	20	778
Hamburg-Rotterdam	21	132,855	21	316	Virginia-New York	19	92,516	18	309
Hong Kong-Kaohsiung	21	106,560	20	353	Los Angeles-Oakland	19	102,048	18	384

Deg: link degree; **W_deg**: weighted link degree (TEU); **Rou**: the number of routes operating between two ports; **Dis**: nautical distance (mile). Source: retrieved by the authors based on the input data.

4.5.4 Port degree

From the network perspective, the degree of a port is the number of arcs connected to (or from) it. From a transport perspective, the degree represents total calls at the port per week. Higher degree means more centrality of the port on the network. It is connected to a greater number of shipping routes, is visited by more ships as well as has more options to carry cargo. Similar to the relationship between the link degree and the weighted link degree, the port degree was also highly correlated with the weighted port degree ($PCCs \approx 1$). The average port degree $\left(\mu_1\right)$ slightly varied from 11.99 in 2001 to 13.00 in 2006 and 12.45 in 2011, whilst the average weighted degree $\left(\mu_2\right)$ substantially climbed with corresponding figures of 43,723; 57,865; and 74,670 TEUs.

From 2003, the top 10 largest degree ports were more or less fixed with Hong Kong, Singapore, Busan, Kaohsiung, Rotterdam, New York/New Jersey (NY/NJ), Shenzhen, Shanghai, Ningbo and Port Klang; except NY/NJ which was substituted by Jeddah in 2011. Actually the 6 former ports were in the top ranking from 1995 whereas the 4 latter ones participated from the early 2000s. Two or three Japanese ports (Kobe, Tokyo, Yokohama) often belonged to the top 10 while there was no Chinese port in the second half of the 1990s. Nevertheless, Japanese ports were out of the top echelon after that and replaced by Chinese ones. Hong Kong and Singapore were the busiest ones until 2004. However, Shenzhen took over second place from Singapore from 2005 and first place from Hong Kong from 2007.

Table 4-4: The top 10 largest degree ports

1995						2001					
Port	Region	Deg	W_deg	Route	Thrput	Port	Region	Deg	W_deg	Route	Thrput
Hong Kong	NEA	98	-	69	12.55	Hong Kong	NEA	113	0.45	76	17.90
Singapore	SEA	81	-	49	10.80	Singapore	SEA	78	0.30	45	15.52
Kaohsiung	NEA	59	-	49	5.23	Shenzhen	NEA	48	0.20	39	5.08
Kobe	NEA	48	-	34	1.46	Kaohsiung	NEA	47	0.20	41	7.54
Rotterdam	EU	40	-	34	4.79	Busan	NEA	46	0.17	36	8.07
NY/NJ	EC	38	-	26	2.31	Port Klang	SEA	35	0.12	30	3.76
Tokyo	NEA	38	-	27	2.18	Rotterdam	EU	35	0.15	33	6.10
Busan	NEA	36	-	33	4.50	NY/NJ	EC	34	0.11	25	3.32
Oakland	WC	33	-	30	1.55	Shanghai	NEA	33	0.11	32	6.34
Yokohama	NEA	32	-	25	2.76	Le Havre	EU	30	0.13	29	1.53
2007						2011					
Port	Region	Deg	W_deg	Route	Thrput	Port	Region	Deg	W_deg	Route	Thrput
Shenzhen	NEA	140	0.77	111	21.10	Shenzhen	NEA	141	0.97	103	22.57
Hongkong	NEA	133	0.66	102	24.00	Singapore	SEA	111	0.64	66	29.94
Singapore	SEA	128	0.58	72	27.94	Hong Kong	NEA	109	0.73	82	24.38
Shanghai	NEA	101	0.48	100	26.15	Shanghai	NEA	97	0.62	92	31.70
Ningbo	NEA	78	0.39	78	9.36	Ningbo	NEA	78	0.51	76	14.69
Busan	NEA	62	0.31	53	13.26	Busan	NEA	66	0.40	56	16.18
Port Klang	SEA	54	0.23	37	7.12	Port Klang	SEA	56	0.33	37	9.60
Kaohsiung	NEA	51	0.28	42	10.26	Jeddah	MID	40	0.24	31	4.01
NY/NJ	EC	42	0.17	36	5.30	Kaohsiung	NEA	40	0.24	31	9.64
Rotterdam	EU	40	0.24	39	10.79	Rotterdam	EU	36	0.29	35	11.88

Deg: port degree or number of weekly calls; ***W_deg***: weighted degree or weekly calling capacity (10^6 TEUs); ***Route***: Number of routes to visit the port; ***Thrput***: yearly throughput (10^6 TEUs); ***EC***: East Coast North America; ***EU***: North Europe; ***MID***: Middle East; ***SEA***: South East Asia; ***NEA***: North East Asia. Source: retrieved by the authors based on the input data.

The top 10 most connected ports received the combined weekly calls of 503 in 1995, 599 in 2003 and 774 in 2011, accounting for respective calling shares of 44%, 36% and 42%. Their total degrees evidently became greater. Nevertheless their combined shares just fluctuated in a small range with negative trend from 1995 to 2003, and then a positive one. The same situation happened with the top 20. In these years, their weekly calls were 742 (share of 65%), 864 (54%) and 1,069 (58%), correspondingly.

4.5.5 Scale free network

Scale free is a non-trivial characteristic of a network, in that its degree distribution function follows the power law: $P(x = k) = \omega * x^{-\lambda}$. In other words, the majority of vertices have small degree whereas only a few ones possess very high degree. In 2011, there were 23 ports with degree of 1; 20 with degree of 2; and 85 with degree no more than 10. On the opposite side, only 5 ports owned degree of 50 and more; 11 ports with degree of 30 and more. Power regression results reveal the scale free characteristics of the shipping network with high coefficients of determination ($0.65 \leq \mathrm{R}^2 \leq 0.80$) in the years 1995-2011. Additionally, there were only marginal differences between the functions, with ω in the range of [0.11; 0.15] and power law coefficient λ in the range of [0.66; 0.76].

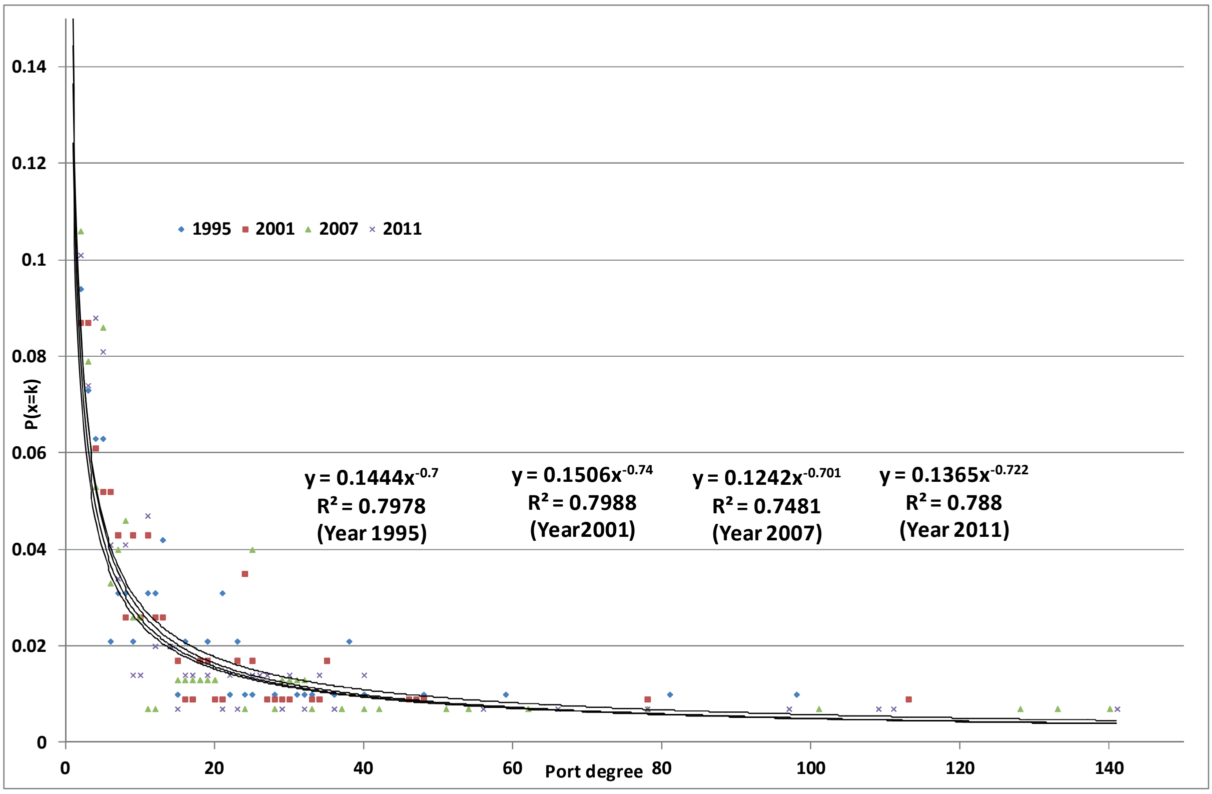

Figure 4-5: Distribution functions of port degree.
Source: visualized by the authors based on the input data.

4.5.6 Port degree concentration

Herfindahl Hirschman Index (HHI) is used by U.S Department of Justice to measure market concentration and divided in three categories: unconcentrated (HHI below 1,500); moderately concentrated (HHI between 1,500 and 2,500); and highly concentrated (HHI above 2,500). In some researches on container liner shipping, HHI has been adopted to quantify the level of market concentration (see for example Lam et al., 2007; Luo et al., 2014; Sys, 2009). In this research, the index is applied to realize the concentration or de-concentration on the shipping network.

The network tended to be more decentralized over 1995-2011. In other words, liner routes dispersed to a greater number of ports instead of focusing on some key hubs. Such tendency could be seen through negative Pearson coefficient correlations (PCCs) between HHIs and values of time, for instance PCC of -0.38 at the global network; -0.83 at South East Asia, North Europe and the Mediterranean Sea; and -0.5 at North East Asia.

At the world level, the index varied in the unconcentrated range between 233 and 305. The small change was seemingly in tandem with that of calling share of the top most visited ports. At regional level, the Mediterranean Sea (MED) was always the most decentralized one. North East Asia and East Coast North America were also situated in the unconcentrated level as MED. West Coast North America belonged to the moderately concentrated range. Sharp decline of HHIs took place in South East Asia, South Asia, the Middle East and Central American. The former was still highly concentrated while the three latter shifted to the moderately concentrated range.

Table 4-5: Concentration index at the world level and regional levels

	1995	1997	1999	2001	2003	2005	2007	2009	2011
South East Asia	7,850	5,943	5,264	4,268	3,523	3,783	4,059	3,874	3,432
South Asia	5,529	5,123	4,558	3,835	3,517	2,412	2,379	2,272	2,190
The Middle East	3,507	2,479	2,170	1,856	1,653	1,701	1,738	1,685	1,777
Central America	3,400	4,222	4,375	1,565	1,682	1,544	1,537	1,309	1,759
West Coast North America	2,016	1,795	1,779	1,834	1,722	1,772	1,842	1,898	1,885
North Europe	1,454	1,396	1,431	1,325	1,327	1,323	1,246	1,272	1,307
East Coast North America	1,282	1,139	1,252	1,263	1,227	1,195	1,222	1,190	1,134
North East Asia	1,170	1,054	1,052	1,002	998	1,044	1,028	980	1,077
The Mediterranean Sea	786	703	772	664	549	570	512	615	553
The world	305	257	257	234	233	252	256	247	263

Source: Calculated by the authors based on the input data

4.5.7 Port degree and throughput

There is a reasonably close relationship between port degree and throughput. The former representing the number of weekly calls at a port reveals its service availability as well attractiveness to shipping lines. The latter is a popular indicator to measure port performance and shows port strength in capturing hinterland and transshipment goods.

Port degree obviously hangs on network decision of operators. Several empirical studies indicate that potential traffic is among their most priorities to choose a port on their loop (Chang et al., 2008; Lirn et al., 2004). It is estimated that in the early 1990s, a carrier on the Asian-Europe lane could use direct call as long as the volume at its disposal was no less than 580 TEUs per week (Alderton, 2008). From industrial interviews, Fremont and Parola (2011) state that at least 10% of vessel capacity must be handled to justify a call. On the other hand, better shipping service availability will upgrade a port's network position. Consequently, it can become an ideal gateway for inland traffic or transshipment hub for cargo to/from other ports. Some surveys exhibit that high service frequency is a factor to attract goods to a port (Ugboma et al. 2006; Veldmand & Buckman, 2003).

Linear regressions are carried out to quantify the relationship between port degree and yearly throughput in the years 1995-2011. High coefficients of determination $(0.79 \leq R^2 \leq 0.90)$ mean a strongly positive link between them. A high degree port on the East-West network is able to gain high throughput. Another striking result is slopes of regression functions moved up from year to year: 100,832 in 1995; 150,421 in 2001; 183,294 in 2007; and 211,648 in 2011. Such phenomenon could stem from the upward trend of ship size. Thanks to bigger vessels, an additional call could bring about a greater number of boxes for a selected port; on the other hand, shipping lines required more captive traffic to choose a port on their service.

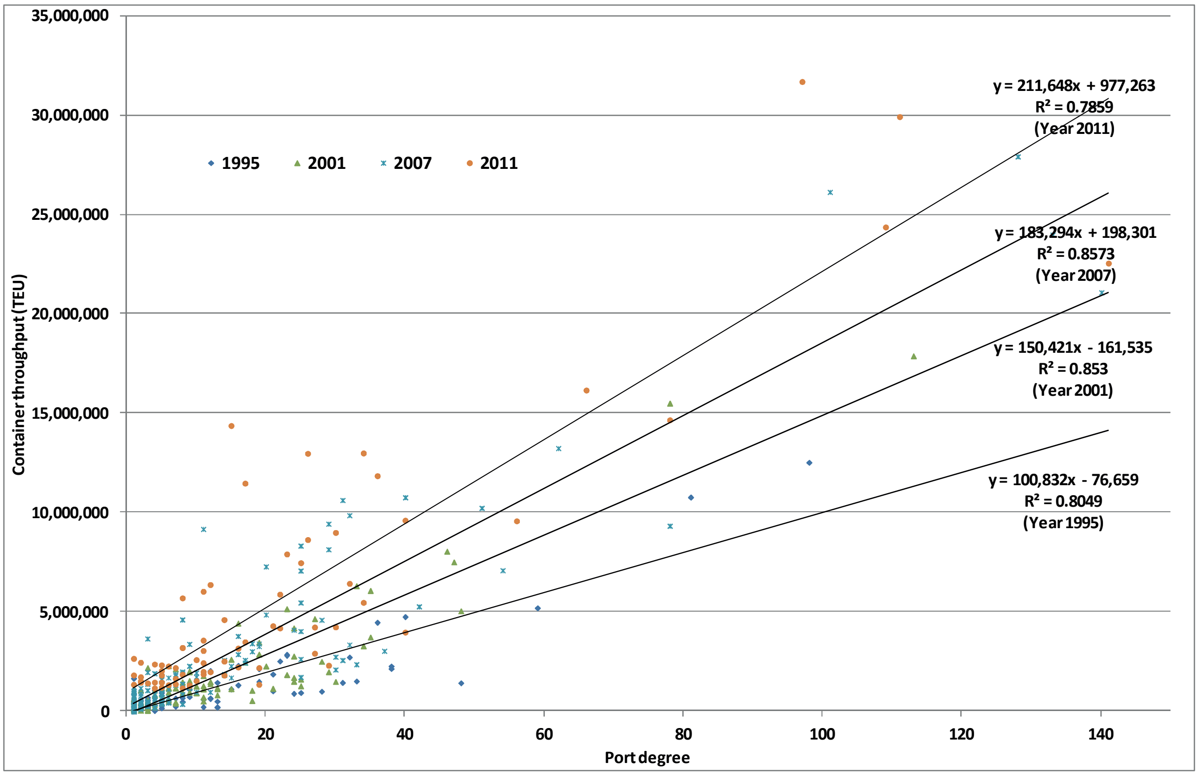

Figure 4-6: Relationship between port degree and port throughput.
Source: visualized by the authors based on the input data.

The error of the regression models may come from several reasons. First, the study is limited to East-West traffic (around 42% of the world traffic), whereas port throughput also consists of additional cargo of North-South and Intra-region trades. Second, the number of loading/unloading containers per visit is different from port to port. Third, some ports located in inconvenient positions can be unfavorable to call regularly, though their local traffic can be more abundant than other ones.

4.6 Dynamics of regional networks

4.6.1 West Coast North America (WCNA), East Coast North America (ECNA) and North Europe (EU)

WCNA, ECNA and EU are the first markets of international container shipping. Nevertheless, their centralities on the East – West axis became narrower. In contrast to the strong enlargement of other ones, their networks were fairly static with insignificant rise of service, visited port and weekly call. Between 1995 and 2011, the number of weekly calls at these regions grew only by 0.2%, 0.5% and 0.7% per year, which was much smaller than the global rate of 3.3%. The calling share of WCNA slipped from 9.5% in 1995 to 7.2% in 2003 and 5.4% in 2011. The corresponding figures were 14.2%, 10.1% and 9.2% for ECNA and 14.6%, 10.9% and 9.7% for EU.

Table 4-6: Development of regional networks

Region	1995				2003				2011			
	Call	Cap	Rou	Port	Call	Cap	Rou	Port	Call	Cap	Rou	Port
ECNA	162	-	33	18	163	0.57	41	16	169	0.79	43	19
North Europe	166	-	40	11	175	0.83	45	13	179	1.34	48	15
Mediterranean Sea	100	-	24	21	184	0.62	47	31	207	1.11	48	42
Middle East	46	-	21	8	97	0.33	38	14	125	0.69	52	13
South Asia	29	-	20	4	62	0.19	34	6	81	0.36	37	8
South East Asia	92	-	49	4	168	0.65	62	8	218	1.29	87	8
North East Asia	425	-	77	18	595	2.50	107	24	727	4.74	129	25
WCNA	108	-	46	8	115	0.49	51	9	99	0.57	43	9
Central America	10	-	7	3	46	0.17	14	10	38	0.16	15	9

Call: total number of weekly calls at regional ports; ***Cap***: total weekly fleet capacity served by regional ports (10^6 TEUs); ***Rou***: number of routes to serve a region; ***Port***: number of ports called by at least one route. Source: calculated by the authors based on the input data.

The majority of services to WCNA involved the Trans-Pacific lane with 34 ones in 2011. 93% to 97% of regional calls concentrated on Oakland, Los Angeles, Long Beach, Vancouver, Seattle and Tacoma. The rest was for other ports such as Dutch Harbor, Prince Rupert and Anchorage. A small number of visited points resulted in moderately concentrated level in WCNA $(1{,}689 \leq HHI \leq 2{,}016)$. Oakland and Los Angeles were the busiest ports in the region with the respective calling shares of 29% and 22% in 2011. Substantial enhancement came from Vancouver BC, which posted its share growth from 5.5% to 14.1%. It replaced Seattle for the 4th position from 2004 and Long Beach for the 3rd in 2011. Los Angeles and Long Beach were always the two biggest ports in WCNA in terms of throughput. However, the close distance between them (10 miles) prevented carriers from choosing both on a string, which explains their lower degrees in comparison with Oakland.

In 1995, 36% of total routes to ECNA were to transport containers between the region and EU. In 2011, the percentage remained only 27%, chiefly because of the booms on the East Asia-ECNA lane from 3 to 12 routes and the ECNA-the Mediterranean Sea lane from 2 to 6 routes. Different from WCNA network limited in a few ports, ECNA network stretched in a long coastline and included from 15 to 21 ports. Major gateways in ECNA consisted of New York/New Jersey, Savannah, Virginia and Charleston whose combined portion on regional degrees was between 57% and 65%.

Two major route groups passing through the EU operated on the EU-East Asia and Trans-Atlantic corridors. Whereas the former saw an upswing from 18 loops in 1995 to 22 in 2003 and 29 in 2011, the latter remained rather stable with the respective amounts of 12, 11 and 12 loops. Rotterdam, Hamburg, Antwerp, Bremerhaven, Le Havre and Felixstowe were the most connected ports in EU. In 2011 they were responsible for 83.8% of total calls at EU, a small decrease compared with 87% in 1995 and 84% in 2003. Such downgrading could be a factor influencing on negative trend of the regional concentration index with HHI of 1,454 in 1995; 1,327 in 2003 and 1,307 in 2011.

4.6.2 North East Asia (NEA)

NEA is where the world's leading manufacturing centers are situated: Japan - a long-standing industrialized country; Hong Kong, South Korea and Taiwan - three tiger economies, and especially China - the emerging dragon. According to the report of Deloitte (2013), except Hong Kong, the other four were among the 10 largest manufacturing export nations in 2011: China ($1,768.5b, ranked 1st); Japan ($724.8b, 4th); South Korea ($473.5b, 5th) and Taiwan ($270.7b, 7th). They also fell into the top 10 global manufacturing competitiveness index nations.

Benefiting from very strong export cargo base, NEA was the most central region on the East-West axis. Over 1995-2011, 6 out of the 10 largest degree ports were located there. It contributed from 16% to 23% of total ports and from 32% to 40% of total calls on the network. About 70% to 80% of the East-West loops went through NEA. In 2011, 25 ports were situated there and received 727 weekly calls of 129 routes with total calling capacity of 4.7m TEUs. The region had the highest average port degree (29.1) and weighted degree (189,492 TEUs), which were 2.34 times and 2.53 times higher than the world average ones.

The evolving role of Chinese ports was one of the most noticeable features of NEA network. In 1995, they were visited by only 12 routes (out of 77 routes to NEA) with 20 weekly calls (4.7% of regional calls). In 2011, the corresponding amount was 127 routes (out of 129) with 429 calls (59.2%). According to some descriptions (Robinson, 1998; Wang, 2004), Chinese ports only stood in secondary tiers of the shipping network and mainly fulfilled feeder functions for other hubs in the mid-1990s.

However, in 2011, they were the leaders on the ranking: Shenzhen (141 weekly calls, ranked 1st), Shanghai (97, 4th), Ningbo (78, ranked 5th); Qingdao (34, 11th); and Xiamen (32, 13th).

The rocket-fuelled growth of Chinese ports was obviously in parallel with erosion of other ones. From 2007, Hong Kong lost its top centrality in the hands of its neighbor Shenzhen. Its portion in total degrees at NEA gradually went down from 24.2% (98 weekly calls) in 1995, to 21% (125 calls) in 2003, then 15% (109 calls) in 2011. Kaohsiung, the second busiest port in NEA in the 1990s, saw downward trends of both calling share and degree with the respective figures of 13.9% (59 weekly calls); 8% (47 calls) and 5.5% (40 calls). Busan was one of the exceptional cases with a small variation of the calling share between 7% and 10%.

In contrast to the affluent situation of Chinese ports, the leading roles of Japanese ones greatly diminished. The number of loops to Japan dropped from 53 in 1995 to 20 in 2011. Consequently its calling portion sunk dramatically from 45.4% (193 weekly calls) to 7.3% (53 calls). Japanese ports were only in favor of Trans-Pacific loops. Often belonging to the top 10 busiest ones in the 1990s, Kobe, Tokyo and Yokohama were even not in the top 30 in 2011.

There are several reasons for such great fall. Firstly, tariff at Japanese ports were most expensive in the region, demonstrated by comparative analyses of ESCAP (2002) and Marine Department (2006). Secondly, South Korean ports, especially Busan, succeeded in capturing transshipment flows from Japanese rivals. As a consequence, transshipment volume moved down by nearly threefold, from 835,600 TEUs in 1995 to 292,600 in 2011 (OSC, 2013). Thirdly, many operations of Japanese firms were shifted to low cost countries from 1993 (Dicken, 2011), which affected container volume growth, and in turn, lower attractiveness of the domestic ports.

Being the largest throughput port in the world, but Shanghai was merely ranked 4th in terms of degree centrality in 2011. Its throughput was 31.7m TEUs in comparison with 22.6m of Shenzhen and 24.4m of Hong Kong. The paradox may stem from the geographical advantage of the two latter ports at the entrance of the region, which is suitable for more regular visits. It is viable to apply the double-dipping pattern in these ports whereby the first call is to unload import boxes whereas the second one is to load export ones. In 2011, the average calls per route were only 1.05 in Shanghai, but 1.37 in Shenzhen and 1.33 in Hong Kong.

4.6.3 South East Asia (SEA)

SEA consists of large exporting economies with the advantages of low labor cost and plentiful raw material. The separation between the countries by sea has resulted in strong transshipment demand to transport containers between hubs and spokes. Additionally as an intersection between East-West and North-South routes, SEA ports could act as relay and interline transshipment hubs to exchange containers between long haul routes. Transshipment made up a big part in regional port operation. In 2011, nearly 45% of SEA throughput (38.84m TEUs) was transshipment liftings, compared with 15% (36.23m TEUs) of North East Asia (NEA) and 26% (15.12m TEUs) of North Europe (EU) (OSC, 2012b; OSC; 2013).

The pattern of double dipping has been often applied in SEA because of its position as a midway point between NEA and South Asia, Middle East, the Mediterranean Sea and EU. A port can be visited by both eastward and westward legs. In 2011, an SEA port was called 1.46 times per trip on average, whereas the figures were just 1.12 in NEA, 1.02 in EU and 1.2 in the Mediterranean Sea.

SEA was the second most connected region from 2005. 87 routes chose its ports in their itineraries with 218 weekly calls in 2011. Its average port degree (27.3) and weighted degree (161,680 TEUs) were also ranked second after those of NEA. The routes passing through SEA often operated on the Europe-Far East axis. Only a few ones served the Trans-Pacific trade (4 in 2007; 6 in 2011).

The concentration index HHI at SEA substantially contracted from 7,850 in 1995 to 3,432 in 2011, which means that network de-consolidation happened there. Singapore accounted for 88% of total regional degrees in 1995, but just 51% in 2011. Other ports, especially their neighbors Port Klang and Tanjung Pelepas, took largely from its share. The portion of Port Klang jumped from 10% to 26%. Tanjung Pelepas has been just in operation since 1999, but gained a share of 11% in 2011. It has been well-known for successfully drawing two influential operators Maersk Sealand and Evergreen from the leader Singapore at the beginning of the 2000s. The surges of the two followers surely made SEA become less concentrated. Nevertheless, the huge dominance of the three hubs (some 90% of regional degrees) thanks to their close proximity to the Strait of Malacca, one of the most important maritime passages in the world, still kept SEA the most centralized in the world.

4.6.4 The Mediterranean Sea (MED)

Being a crossroads on the network as SEA, MED also provided ideal relay and interlining transshipment hubs in addition to traditional ones. The transshipment incidence in the total throughput moved up from 23.9% (13.54m TEUs) in 1995, to 32.3% (24.71m) in 2000, 38.7% (39.31m) in 2005 and 40.1% (51.59m) in 2010 (2012b).

The number of MED ports often accounted for some one fourth of total ports, the largest portion on the shipping network. The amount doubled from 21 ports in 1995 to 42 in 2011. During the period, half of the increase of port quantity stemmed from MED. Some remote ones in the Black Sea such as

Constanza, Odessa, Illiichivsk and Novorossiysk were admitted to main services, instead of only being served by feeder ones.

On the East-West axis, the role of MED was improved substantially. 24 routes connected to the region in 1995, the amount was up to 48 in 2011. The number of routes between MED and East Asia increased from 5 to 16, and between MED and East Coast North America (ECNA) from 2 to 6. Consequently, total port degrees advanced from 100 to 207. MED overcame North Europe, West Coast and ECNA to become the third busiest region from 2005. Although it received a large number of calls, having many ports located there caused low value of its average port degree (4.92 in 2011) and weighted degree (26,532 TEUs). The indicators were merely higher than those of Central America and around two fifths of the average degrees on the network.

The most crowded port in MED was Algeciras in the mid-1990s, then Gioia Tauro from 1997 to 2004, and Port Said from 2005. Besides the three ports, the top 10 ones often comprised Valencia, Damietta, Marsaxlokk, Marseille-Fos, Barcelona, Genoa and La Spezia. The leading ports significantly relied upon transshipment operation as well as a small number of key carriers.

Table 4-7: Operating information of major ports in the Mediterranean Sea in 2011

	Weekly call	Transshipment Volume (10^6 TEUs)	Incidence (%)	Key carriers (weekly call)
Port Said	30	2,789	92.5%	Maersk (8); CMA-CGM (6); Hanjin (6)
Valencia	21	2,237	51.7%	MSC (7); Hapag Lloyd (5); Hanjin (4)
Genoa	14	0.100	5.7%	Hapag Lloyd (4); Hanjin (3)
Barcelona	12	0.637*	33%*	MSC (3); Hapag Lloyd (3)
Algeciras	11	3,437	92.7%	Hanjin (6); Maersk (4)
La Spezia	9	0.190*	14.5%*	MSC (5)
Damietta	8	0.870*	82%*	CMA-CGM (4); APL (3)
Marseille-Fos	7	-		Hapag Lloyd (3)
Piraeus	7	1,243	74%	Coscon (2); Evergreen (2)
Gioia Tauro	6	2,167	94%	MSC (5)
Marsaxlokk	5	2,186	95.6%	CMA-CGM (5)

Source: Weekly call based on the calculation from the input data; Transhipment data based on Drewry (2012a); *: data in 2010 based on (OSC, 2012b).

In accordance with Section 5.6, MED was always the least consolidated region. In 2011, the top 10 largest degree ports played only 60.4% of total regional calls, in comparison with 97% in North Europe, 87% in North East Asia and 85% in West Coast North America. Unlike in SEA where nearly all transshipment volume focused on the three key hubs of Singapore, Port Kelang and Tanjung Pelepas (99% in 2011); in MED, various ports could act as a transshipment hub, stretching from the Strait of Gibraltar to the Suez Canal. The lack of strong local traffic caused high volatility for the ports. Their centrality can quickly disappear subsequent to network restructuring of shipping lines. Algeciras and Gioia Tauro were typical victims of Maersk Lines' revamp. The former saw the carrier's visit decline from 11 times per week in 2006 to only 4 in 2011, whereas the latter from 9 to 1.

Noticeably, the calling portion of the top 10 ports went down from 80% (80 weekly calls) in 1995, to 66% (122 calls) and 60.4% (125 calls) in 2011. They faced intense competition from smaller and new ports. The growing part of the other ones possibly pulled down the concentration index at MED with HHI of 786 in 1995 and 553 in 2011, bearing network de-centralization here.

4.6.5 The Middle East (MID)

MID has been well-known for its abundant oil resource. High oil price has not only boosted import containers for consumer goods but also export ones from manufacturing zones and containerized petrochemical cargo (OSC, 2007). The region saw great dynamics of its network between 1995 and 2011. The number of loops to MID grew from 21 to 52, in that, intra Asia ones between MID and Far East from 4 to 18. As a result, total regional calls leapt 2.7 times from 46 to 125 per week.

Jeddah and Dubai were always the most employed ports in MID whereas Salalah gained third place from 2002. The three leaders received 82 weekly calls in total with the combined share of 66% in 2011. The two former ones served as both gateway and transshipment hubs whereas the latter only a pure transshipment hub. Their respective transshipment incidences were 41.6% (1.7m TEUs), 49.5% (6.4m) and 97% (3.0m) in 2011 (OSC, 2007).

The combined share of Jeddah and Dubai was gradually downward from 78% in 1995 to 50% in 2003. Such deterioration made the MID network shift from the highly concentrated range (HHI of 3,507) to moderately concentrated range (HHI of 1,634). After that their share fluctuated between 51% and 60%. In parallel, the concentration index also varied between 1,653 and 2,033.

Dubai was the largest throughput port in MID. However, its location in the Arabian Gulf results in the long deviation distance (1,357 miles)[3] from the arterial maritime passage. As a consequence, it could be disadvantageous over Jeddah (23 miles) in the Red Sea and Salalah (102 miles) in the Arabian Sea in attracting loops between North Europe and Far East. In contrast, the closeness to big markets in MID benefitted it from capturing Intra Asia ones connecting the region and Far East.

Table 4-8: Characteristics of the key ports in MID

	2010			2011		
	Jeddah	Dubai	Salalah	Jeddah	Dubai	Salalah
Throughput (million TEUs)	3.8	11.6	3.5	4.0	13.0	3.2
Transshipment (million TEUs)	1.7	5.5	3.4	1.7	6.4	3.0
Total weekly calls	35 (31)	28 (27)	20 (15)	40 (31)	26 (25)	16 (13)
Total weekly calls of Intra Asia routes	6 (6)	12 (12)	2 (1)	7 (6)	12 (12)	2 (1)
Total weekly calls of Europe-Far East routes	16 (14)	6 (6)	6 (5)	18 (14)	4 (4)	4 (4)

In bracket (): the number of services. Transshipment volume: based on OSC (2007); Other indicators calculated by the authors based on the input data

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[3] Deviation distance of a port is calculated by difference between the itinerary from Singapore to the port, then to Suez Canal and the direct itinerary from Singapore to Suez Canal.

4.6.6 South Asia (SA)

Similar to MID, SA also experienced great network expansion. The number of routes serving it increased from 20 (25 weekly calls) in 1995 to 37 (85 calls) in 2011. Most of the growth was attributable to routes between SA and East Asia (from 0 to 13 routes) and between North Europe and SA (from 1 to 5 routes).

Colombo always retained the position as the most visited port in SA. The close proximity to the trunk shipping lane (deviation distance of 51 miles) supported its role as a regional transshipment hub with transshipment incidence of 73% (3,124m TEUs) in 2011. However, its regional centrality was downgraded. The calling portion slid from 72% (21 weekly calls) in 1995, to 52% (32 calls) in 2003, and 33% (27 calls) in 2011.

On the other hand, a remarkable growth of the port of Jawaharlal Nehru (JNP) was observed with the corresponding shares of 14% (4 weekly calls), 23% (14 calls) and 27% (22 calls). Not as convenient as Colombo to be a transshipment hub (deviation distance of 443 miles), but JNP functioned effectively as a key gateway for India, the largest economy in SA and the 8th largest manufacturing export nation in the world (Deloitte, 2013). Its throughput was even higher than that of Colombo from 2001. Other gateways in India and Pakistan such as Mundra, Karachi and Port Qasim enhanced their centralities at the expense of the leader as well. Such improvements obviously created de-consolidation of the SA network with HHI of 5,529 in 1995, then 3,517 in 2003, and 2,190 in 2011.

Because of the geographical advantage, Colombo was in favor of the routes on which SA acted as an intermediate market in order to save sailing time, for instance routes between North Europe/the Mediterranean Sea and East Asia. Nevertheless, the far distance from the mainland markets prevented it from economically serving the routes choosing the region as an extreme (either Eastern or Western) market such as routes between SA and East Asia or between Europe and SA. The comparison in Table 9 provides clear advantage of Colombo over JNP in the former route group, but disadvantage in the latter. The fact that the SA network was chiefly expanded thanks to the latter one lightened Colombo's centrality.

Table 4-9: Breakdown of weekly calls by routes in South Asia in 2011

	Region	Colombo	Jawaharlal Nehru
Group 1: South Asia acts as an intermediate market			
Intra Asia: Middle East – East Asia	9 (5)	4 (3)	
End to end: Europe – East Asia	4 (3)	3 (2)	1 (1)
End to end: East Coast North America – East Asia	2 (2)	2 (2)	
End to end: The Mediterranean Sea (MED) – East Asia	3 (1)	2 (1)	
Pendulum: East Coast North America – MED – East Asia	2 (1)	2 (1)	
Pendulum: MED – East Asia – West Coast North America	2 (1)	2 (1)	
Total	22 (13)	15 (10)	1 (1)

Group 2: South Asia acts as an extreme market			
Intra Asia: South Asia – East Asia	32 (13)	9 (8)	11 (11)
End to end: East Coast North America – South Asia	2 (1)		1 (1)
End to end: Europe – South Asia	14 (5)	1 (1)	5 (5)
End to end: MED – South Asia	5 (2)	1 (1)	2 (2)
Pendulum: East Coast North America – MED – South Asia	6 (3)	1 (1)	2 (2)
Total	59 (24)	12 (11)	21 (21)

In bracket (): the number of services. Source: calculated by the authors based on the input data

4.6.7 Central America and Caribbean (CAM)

There was significant growth of services to CAM, from only 7 (with 10 weekly calls) in 1995 to 17 (40 calls) in 2011. However, it still played the smallest role on the East-West corridor. CAM merely served less than 15% of total loops and constituted smaller than 3% of total degrees on the corridor. The majority of loops passing through CAM carried containers between North East Asia and East Coast North America with a number of 9 in 2011. Additionally, CAM was also a strategic way-stop for round-the-world and pendulum strings operating between East Asia, North America and North Europe/the Mediterranean Sea, especially in the early 2000s.

The Panama Canal is a critical bridge between the Pacific and Atlantic Oceans. For this reason, Panama ports such as Manzanillo, Balboa and Cristobal were a top priority of shipping lines to call. In total, they received 13 routes with 26 weekly calls in 2011. In addition, Kingston (Jamaica) and Freeport (the Bahamas) were also frequent selections of carriers. The geographical condition in CAM facilitated these ports to become transshipment hubs with very high level of transshipment incidence: Freeport – 99% in 2011 (1.1m TEUs); Kingston – 86.4% (1.5m TEUs); Manzanillo – 80% (1.52m TEUs); and Balboa – 92.8% (3m TEUs) (Drewry, 2012a).

4.7 Conclusions

Using quantitative tools of network analysis, together with a large amount of route data processed by specially tailored computer programs, the research approaches the evolution of the East-West container shipping network between 1995 and 2011. In harmony with world trade growth, the network became bigger with the surge of shipping routes (from 100 to 163), network length (1.78m to 2.77m miles), deployed fleet (1.51m to 7.12m TEUs) as well as the number of ports (96 to 148) and arcs to connect them (1,139 to 1,843).

Assortativity was an attribute of the shipping network whereby arcs tended to connect ports with similar degree characteristics. Nearly two thirds of arcs were intra-regional ones whose lengths were often less than 1,000 miles. The largest group of the inter-regional segment was the ones in the range between 1,000 and 2,000 miles. The longest arcs could be longer than 10,000 miles. The most crowded port-to-port corridors were recognized as well. Most of them were intra-regional in nature with short nautical distance.

The largest degree ports were often located in East Asia where the largest manufacturing economies were located in. The scale free characteristic appeared on the network with many small degree ports and only a few high degree ones. De-concentration of port degrees could be realized based on Herfindahl Hirschman index and implied that shipping routes did not concentrate on a small number of hubs, but tended to spread to more ports. The close relationship between port degree and throughput was also quantified. A high degree port possibly gained high container throughput.

Regional networks experienced different developments due to dissimilarities of their geographical location, traffic situation, and roles of regional ports as well as their competitions. North Europe, West Coast and East Coast North American, the first markets of international container shipping, saw the stability of their networks with insignificant increase of routes, visited ports and weekly calls. In contrast, strong expansion was observed in other ranges. The influence of geographical factors on port centrality is illustrated in some specific cases. An important trend of regional networks was the centrality downgrading of leading ports under the penetration of their neighbors, which was suitable to the phase of "challenge of the periphery" in the well-known port development model of Hayut (1981).

The deployed indicators possibly reflect various issues in the industry such as the growth of global shipping volume, deployment of mega vessels, strategy of slow-steaming, choice of ports of call and network decentralization. They are proved to be a feasible tool for network analyses. As the network is the backbone in shipping operation, the research may be useful for both shipping lines and ports with a comprehensive report about characteristics and dynamics of the shipping network over a long period.

Appendix 1: Notation and network indicators

PORTS: set of ports

$sd_{\alpha,\beta}$: nautical distance between port α and port β (mile)

n: the number of routes

Route

Sequence of ports of call: $p_{i,1}; p_{i,2}; \dots p_{i,j}; \dots p_{i,n_i};\ p_{i,n_i+1}; p_{i,n_i+2}; \dots p_{i,n_i+j}; \dots\ p_{i,2*n_i}$

n_i: the number of stops on route i

$p_{i,j}$: the jth visited port on route i $j = 1...n_i$ $p_{i,j} \in PORTS$

$p_{i,j} = p_{i,j+n_i}$ $j = 1 \dots n_i$ The first n_i elements display port sequence on route i. The use of additional n_i elements is to show the circular characteristic of liner routes.

Arrival schedule: $d_{i,1}; d_{i,2}; \dots d_{i,j}; \dots d_i;\ d_{i,n_i+1}; d_{i,n_i+2}; \dots d_{i,n_i+j}; \dots\ d_{i,2*n_i}$

$d_{i,j}$: arrival day of port j on route i $j = 1...n_i$

$d_{i,1} = 0;\ d_{i,j+n_i} = d_{i,j} + voy_i$ $j = 1...n_i$

$d_{i,j+1} - d_{i,j}$: transit time from port $p_{i,j}$ to port $p_{i,j+1}$ (day) $j = 1...n_i$

voy_i: round voyage time of route i (day)

s_i: the number of ships on route i

$cap_{i,j}$: capacity of ship j on route i (TEU) $j = 1...s_i$

$size_i$: average ship size on route i (TEU), or weight of arcs on route i $size_i = \frac{\sum_{j=1}^{s_i} cap_{i,j}}{s_i}$

$ME_{\alpha,\beta,i,j}$: a binary matrix to represent arcs between port α and port β on route i

$(\alpha, \beta \epsilon PORTS, i = 1..n, j = 1..n_i)$ $ME_{\alpha,\beta,i,j} = \begin{cases} 1: if\ (p_{i,j} = \alpha) \cap (p_{i,j+1} = \beta) \\ 0: otherwise \end{cases}$

Centrality indicators

$arc_{\alpha,\beta}$: the number of arcs from port α to port β $arc_{\alpha,\beta} = \sum_{i=1}^{n} \sum_{j=1}^{n_i} ME_{\alpha,\beta,i,j}$

$w\_arc_{\alpha,\beta}$: total fleet capacity travelling from port α to port β per week (TEU)
$w\_arc_{\alpha,\beta} = \sum_{i=1}^{n} \sum_{j=1}^{n_i} size_i * ME_{\alpha,\beta,i,j}$

deg_α: degree of port α $deg_\alpha = \sum_{\beta \epsilon PORTS} arc_{\alpha,\beta}$

w_deg_α: weighted degree of port α $w\_deg_\alpha = \sum_{\beta \epsilon PORTS} w\_arc_{\alpha,\beta}$

$link_{\alpha,\beta}$: degree of inter-port link (α, β) $link_{\alpha,\beta} = link_{\beta,\alpha} = arc_{\alpha,\beta} + arc_{\beta,\alpha}$

$w\_link_{\alpha,\beta}$: weighted degree of inter-port link (α, β) $w\_link_{\alpha,\beta} = w\_link_{\beta,\alpha} = w\_arc_{\alpha,\beta} + w\_arc_{\beta,\alpha}$

General network indicators

arc: the number of arcs $arc = \sum_{i=1}^{n} n_i$

ver: the number of vertices (ports) $ver = |SV|$ $SV = \{\alpha | \alpha \in PORTS; deg_\alpha > 0\}$

IPL: the number of inter-port links $IPL = \frac{|SP|}{2}$ $SP = \{(\alpha,\beta)|\alpha,\beta \in PORTS; link_{\alpha,\beta} > 0\}$

avg: average ship size on the whole network (TEU) $avg = \frac{\sum_{i=1}^{n}\sum_{j=1}^{s_i} cap_{i,j}}{\sum_{i=1}^{n} s_i}$

μ_1: average port degree $\mu_1 = \frac{arc}{ver}$

μ_2: average weighted port degree $\mu_2 = \frac{\sum_{\alpha \in PORTs} w\_deg_{\alpha}}{ver}$

μ_3: average link degree $\mu_1 = \frac{\sum_{\alpha \epsilon PORTs}\sum_{\beta \epsilon PORTs} link_{\alpha,\beta}}{2*IPL}$

μ_3: average weighted link degree $\mu_1 = \frac{\sum_{\alpha \epsilon PORTs}\sum_{\beta \epsilon PORTs} w\_link_{\alpha,\beta}}{2*IPL}$

nl: network length (mile) $nl = \sum_{i=1}^{n}\sum_{j=1}^{n_i} sd_{p_{i,j},p_{i,j+1}}$

η_1: average arc length (mile) $\eta_1 = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n_i} sd_{p_{i,j},p_{i,j+1}}}{\sum_{i=1}^{n} n_i}$

η_2: average travelling time per arc (day) $\eta_2 = \frac{\sum_{i=1}^{n} voy_i}{\sum_{i=1}^{n} n_i}$

v: average transit speed per day (mile) $v = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n_i} sd_{p_{i,j},p_{i,j+1}}}{\sum_{i=1}^{n} voy_i}$

γ: connectivity coefficient (%), a quotient of the number of inter-port links and the maximum number of inter-port links $\gamma = \frac{IPL*100}{ver*(ver-1)/2}$

Complex network indicators

HHI: Herfindahl Hirschman index to measure degree concentration ($0 < HHI \leq 10{,}000$), the higher the value is, the higher level of concentration is. $HHI = \sum_{\alpha \in PORTs}(\frac{deg_{\alpha}*100}{\sum_{\alpha \in PORTs} deg_{\alpha}})^2$

ρ: Assortative mixing coefficient ($-1 \leq \rho \leq 1$), it is measured by Pearson correlation coefficient of degree between heads and tails of all arcs. $\rho = \frac{\sum_{\alpha,\beta \in PORTs} arc_{\alpha,\beta}*(deg_{\alpha}-\mu_1)*(deg_{\beta}-\mu_1)}{\sum_{\alpha \in PORTs} deg_{\alpha}*(deg_{\alpha}-\mu_1)^2}$

λ: Scale free coefficient, or the power coefficient of the distribution function of port degree: $P(x = k) = \omega * x^{-\lambda}$ where $P(x = k)$: probability a vertex has degree of k; ω: positive scale factor.

Chapter 5: Economics of fleet expansion and growth of ship size[4]

Highlights:

- A comprehensive review of ship fleet and ship generations in container liner shipping
- Models to measure the relationship between operational factors and shipping lines' financial results
- The efficiency of fleet expansion and mega ship deployment in the shipping industry
- The critical role of slot utilisation in shipping lines' performance

5.1 Introduction

The world container ship fleet has experienced profound development since the 1990s. The carrying capacity increased by a factor of 6, from 3.17m TEUs (4,772 ships) in 1990 to 18.9m TEUs (8,337 ships) in 2014. A substantial portion of the growth was thanks to the container shipping lines (CSLs) in the top 20. Their capacity share in the global fleet was from 39% to around 75%. The fleet capacity of Maersk Line advanced nearly 28 times whereas that of MSC went up about 90 times. In tandem with such strong growth of the world fleet, it has been the trend of ever-increasing vessel capacity. As stated by Ashar (2002), the evolution in liner shipping refers to the growth of ship size. The maximum size was 4,300 TEUs in 1988, up to 7,100 TEUs in 1996, then 15,500 TEUs in 2006, and is 18,000 TEUs now. The influx of mega ships has been obviously among the major breakthroughs in the shipping industry.

The research concentrates on the two major issues of ship deployment, capacity expansion and growth of ship size. The central research question is how these factors influence on financial results of CSLs. To answer it, multiple regression models are built to measure the relationships between variations of their revenue and cost (total and unit) and those of their carrying capacity, average ship size and other such factors as slot utilisation level, oil price and market freight rate during the period 1997- 2012. Results from the regression models, together with in-depth analysis based on practices from the industry, provide some insights into scale economies of firm capacity and ship size.

This chapter is structured as follows. Section 5.2 reviews literature regarding economy of ship deployment in container liner shipping. Section 5.3 summarizes the expansion of global fleet as well as major eras in the development of container ships. Section 5.4 presents models to evaluate

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influence of capacity expansion and ship size growth on CSLs' financial results. Section 5.5 provides in-depth analysis regarding the two issues. Section 5.6 includes some conclusions.

5.2 Literature review

Ship deployment has been attracted much attention in the domain of maritime logistics. Basic understanding of ship operation can be found in some textbooks (Alderton, 2008; Jansson & Shneerson, 1987; Stopford, 2009; Wijnolst & Wergeland, 2009; Talley, 2009). Different strategies of CSLs to develop their ship fleet are completely analysed by Notteboom (2004) and Cariou (2008). Drewry (2009) and Notteboom (2012) pay attention to operational strategies of CSLs to tackle over-capacity in the market. Many papers concentrate on tackling optimization problems concerning ship deployment (Qi & Song, 2012; Verni & Grigentin, 2009). They are comprehensively reviewed and classified by Christiansen el al. (2013), Meng et al. (2013) and Tran and Haasis (2013).

The relationship between carrying capacity and firm performance has been studied in several researches. Lam et al. (2007) use the structure-conduct-performance paradigm to evaluate the situation of liner shipping on the Trans-Pacific, Far East – Europe and Trans-Atlantic trades between 1998 and 2002. The analysis indicates that there is no conclusive evidence that the increased concentration of fleet capacity leads to better financial results. Lun et al. (2010) examine the positive correlation between firm scale and profit. Lun and Marlow (2011) apply a data envelopment analysis (DEA) to evaluate the impact of CSLs' fleet capacity on their profit and revenue. DEA is also employed by Bang et al. (2012) to point out positive contribution of firm size and ship size to firm performance. Yip et al. (2012) build an S-curve to formulate the association between firm capacity and revenue. The curve can describe well both scale economy and diseconomy of carrying capacity.

Cost saving is an important driving force to deploy bigger and bigger ships. Scale economies of ship size have been quantified so as to assess the viability of large ships. Gilman (1980, 1983) provide cost estimation of several ship sizes in correspondence with different operating speeds and handling rates. The model takes account of capital cost, operating cost and fuel cost. Veldman (1993) incorporate shippers' cost into shipping cost to evaluate optimum ship size. Lim (1994) investigates efficiency of large ships not only in terms of cost but also in terms of income. Drewry (1996) compares total cost of a Super post panamax ship (6,000 TEUs) and that of an optimised Panamax one (4,000 TEUs) with 21% saving of the former over the latter. Tozer (2003) and Tozer and Penfold (2002) present cost difference between ultra large container ships and smaller ones under various operating speeds. Sys et al. (2008) quantify cost advantage of ship size up to 18,000 TEUs by using the liner service cash flow model of Stopford (2004) and taking into account cost distinction between single and twin propeller systems on ships. Stopford (2009) considers the variation of container ship costs with various carrying capacities on the transpacific round voyage.

Some studies have established regression functions to explain the relationship between cost component per unit (DWT or TEU) and ship size by employing data of ship operation from industry consultants and CSLs. In the models of Jansson and Shneerson (1978, 1987), capital cost is estimated to conform with the two-third power rule whereas the size elasticities of operating cost and fuel cost are 0.43 and 0.72 respectively. Talley (1990) deploys regression functions to calculate operating and port cost. The outcome implies the upward trend of optimal size in case of fewer numbers of port calls, shorter port time and longer ship distance. Cullinane and Khanna (1999, 2000) exclude port cost in their estimation as the argument that it has little variation in carrying capacity. The model confirms again benefit of ship size at sea as well as advantage of large ships on long routes. Veldman (2009) takes into consideration economies of ships from 6,000 to 20,000 TEUs.

Our paper contributes to literature regarding ship deployment in container liner shipping by several facets. Firstly the development of the fleet will be summarized in detail. Secondly we do empirical analyses to see effects of carrying capacity and ship size on firms' financial indicators, not only total revenue and cost but also unit revenue and cost. Thirdly economies of ship size have been often studied to evaluate their potential cost saving, our analysis takes account of their influence on financial performance of CSLs.

5.3 Development of container ship fleet

5.3.1 An overview

At the beginning of the 1970s, the world fleet included 166 ships totalling 126,267 TEUs (Gibney, 1981). After a decade, it numbered 2,565 ships with the combined capacity of 1.53m TEUs. It developed into 4,772 ships (3.17m TEUs) in 1990 and 7,093 ships (6.54m TEUs) in 2000. In April 2014, the armada consisted of 8,337 ships (18.9m TEUs). In the last 32 years, the fleet capacity increased on average by 8.3% per year, it nearly doubled every decade.

Table 5-1: Fleet deployment

	Number of vessels			Fleet capacity (mTEUs)			Average ship size (TEU)		
	FCC	NFCC	Total	FCC	NFCC	Total	FCC	NFCC	Fleet
1982	675	1,890	2,565	0.67	0.85	1.53	997	452	596
1985	965	3,010	3,975	1.01	1.36	2.37	1,055	453	599
1990	1,299	3,473	4,772	1.65	1.52	3.17	1,267	438	664
1995	1,723	4,255	5,978	2.67	1.74	4.41	1,548	409	737
2000	2,723	4,370	7,093	4.72	1.82	6.54	1,732	417	922
2005	3,506	4,444	7,950	7.85	1.91	9.76	2,239	430	1,228
2010	4,855	3,092	7,895	13.97	2.14	16.11	2,878	687	2,026

2014	5,102	3,235	8,337	17.32	1.49	18.9	3, 394	462	2,256

Combined from Containerisation International yearbooks and monthly magazines, and Clarkson (2014b)

Contributing the most to the fleet development is fully cellular container (FCC) vessels. From 1982 to 2014, their capacity grew nearly 26 times in comparison with only 1.8 times of non-fully cellular container (NFCC) vessels. In 2014, FCC ships play some 92% of the total capacity; the rest includes NFCC ones such as roros, semi container and break-bulk ships. Before 1990, the world fleet had been dominated by the NFCC ships, but the FCC ones have become overwhelming since then. In the last three decades, the NFCC capacity increased on average by only 3.2% annually whilst the figure was 11% for the FCC capacity. Moreover, NFCC fleet's growth has become smaller and smaller. The average annual growth rate was 8.73% in the 1980s, down to 2.28% in the 1990s and 1.64% in the 2000s. On the contrary, FCC fleet has kept steady development with these indicators of more than 10% in each period.

In harmony with the fleet scale's expansion, it has been the upturn in ship size. Average size was from 596 TEUs in 1982 to 2,256 TEUs in 2014. NFCC ships have been limited in respect of size growth. The largest ships have been often under 3,000 TEUs whereas the mean size has been often less than 500 TEUs. In contrast, there has been no restriction for FCC ships. Between 1980 and 2014, average FCC ship size increased from 997 TEUs to 3,394 TEUs with the average growing ratio of 3.89% per year. In the 2000s, the figure was 5.23% in comparison with 3.21% in the 1980s and 2.92% in the 1990s.

The development of containerisation has witnessed the emergence of new FCC ship generations. The Handy ships (1,000 – 1,999 TEUs) had developed strongly since the end of the 1960s. The Sub-Panamax ships (2,000 – 2,999 TEUs) and Panamax (3,000 – 4,500 TEUs) ships emerged at the beginning of the 1970s. The Post-Panamax generation started at the end of the 1980s and has accelerated since the mid-1990s. Since the 2000s, the fleet over 8,000 TEUs has experienced substantial growth. Today, the Post-Panamax armada represents 55% of the FCC capacity, in which, less than 8,000 TEU ships play 21% whereas the bigger ones 34%. Panamax ships account for 21.2% of the global carrying capacity and take the second place. The portions of sub-Panamax and Handy are more or less the same, 9.9% and 9.7% correspondingly. Feeder ships (less than 1,000 TEUs) are the smallest group with the share of 4.2%.

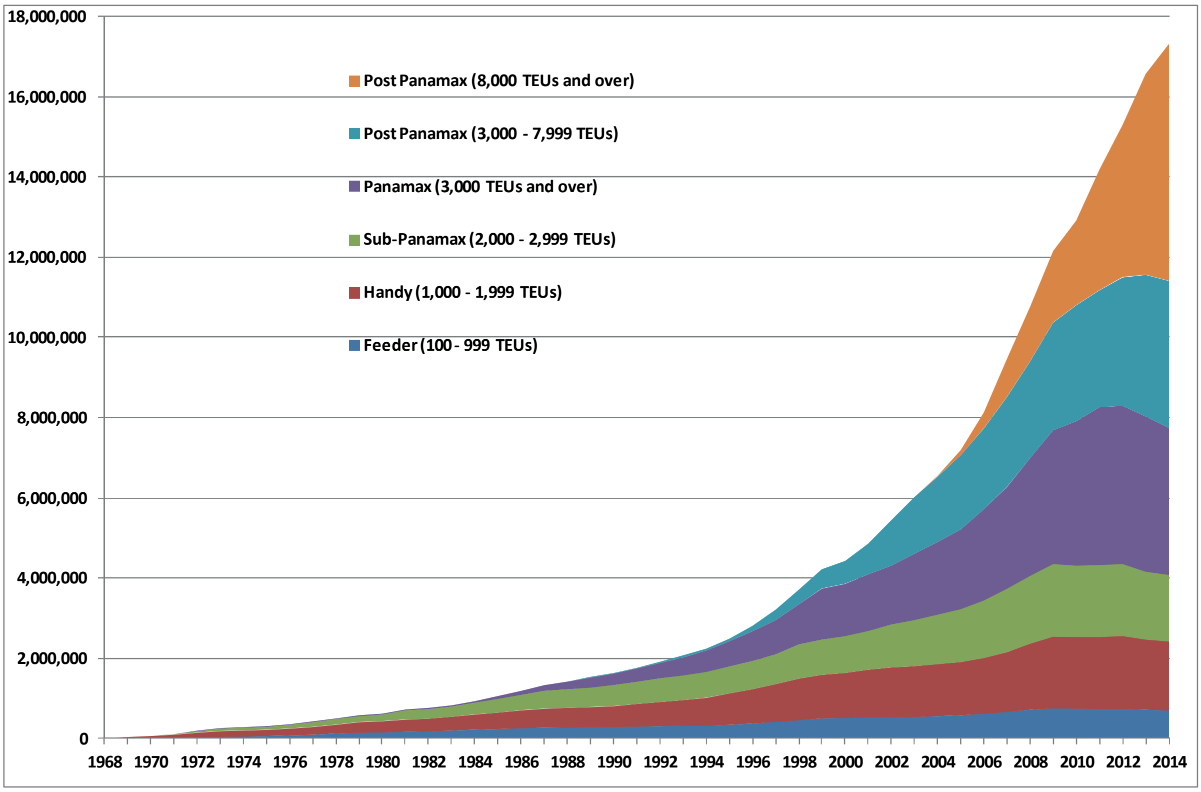

Figure 5-1: Development of fully cellular container ship segments 1968-2014 (Unit TEU).

Data source: Estimated based on Clarkson (1995, 1999, 2010, 2013, 2014b)

5.3.2 Generations of fully cellular container ships

5.3.2.1 Trial era

The converted T2 tanker Ideal X opened up the era of container transportation by carrying 58 containers on its flat spar deck from Port Newark to Houston on April 26, 1956. Following the pioneer ship, three other converted T2 tankers entered the Pan Atlantic container service in the same year. One year later, the basic design of modern container ships was introduced by a rebuilt World War II cargo ship, Gateway City. She was rebuilt to carry containers only and used cell guides to facilitate the stack of containers both in hold and on deck. Her capacity is fourfold as many as that of the previous ships. The way to design Gateway City had never done before and created fundamentally operational styles of container shipping.

The period 1956-1966 could be regarded as the trial and error time of containerisation (Watanabe, 1985, 2000). Shipping industry was still doubtful about success of the new system. The adoption of containerisation meant to face with operational and investment risk. The modal was limited in the US domestic market with various box sizes, for instance 35’ of Sealand, 24’ of Matson, and 17‘ of Grace Line (Levinson, 2005). About 42 ships (19,950 TEUs) entered the service during the period (Gibney, 1981). The first container ships were mostly less than 1000 TEUs, often sailed with the speed of 18 to

20 knots (Rodrique et al., 2009) and were facilitated with gears due to the lack of proper handling equipment in ports. There was no purpose built container ships; deployed ships were mostly converted from other types such as tankers, general cargo ships and troop ships. Obviously, it was too risky to build totally new ships with the transport concept still in inception time. By using converted ships, pioneer operators could take advantages of cheaper capital cost and faster delivery time than new building orders.

5.3.2.2 Sub-panamax era

The new modal had been gradually proved to be time, labour and cost saving, and really successful in terms of commerce. It had been more and more accepted. Successes in the domestic market had encouraged CSLs to broaden their geographical scope. In 1966, Sealand inaugurated a Trans-Atlantic container route; one year later Matson set up a Trans-Pacific route. Following the US pioneers, other players from Asia and Europe also attended the global container game. Around 1971, long distance voyages sailing through several oceans such as Far East – Europe and Europe – US West Coast were containerised (Watanabe, 1985, 2000). The standards of container transportation, published by the International Standard Organisation in 1970 (Levinson, 2005, p 149), has inevitably fostered the global development of containerisation.

The ship fleet took a big step at the end of the 1960s and the beginning of the 1970s. Purpose-built cellular ships became the priority of CSLs instead of converted ships as the previous time. Cranes was removed from ships so that more boxes could be loaded on board. Ships sailed with the faster speed of 20-24 knots which would become the reference speed in container shipping (Rodrique et al., 2009). American Lancer (1,210 TEUs) and Encounter Bay (1,530 TEUs) were among the first purpose-built cellular ships in operation in 1968 and 1969. Between 1967 and 1972, nearly $10b, equivalent to $40b in 2005, was spent for the new fleet (Levinson, 2005, p 214). 337 ships of 338,627 TEUs were delivered between 1968 and 1973 (Gibney, 1981). In the six years, the fleet was enlarged by 9.02 times regarding ship amount and 17.97 times regarding carrying capacity. Vessels beyond 1,000 TEUs were increasingly built; the 1,000 – 1,999 TEU (Handy generation) ships became the largest group with about 95 new ships totalling 132,172 TEUs (Clarkson, 1995) during these years.

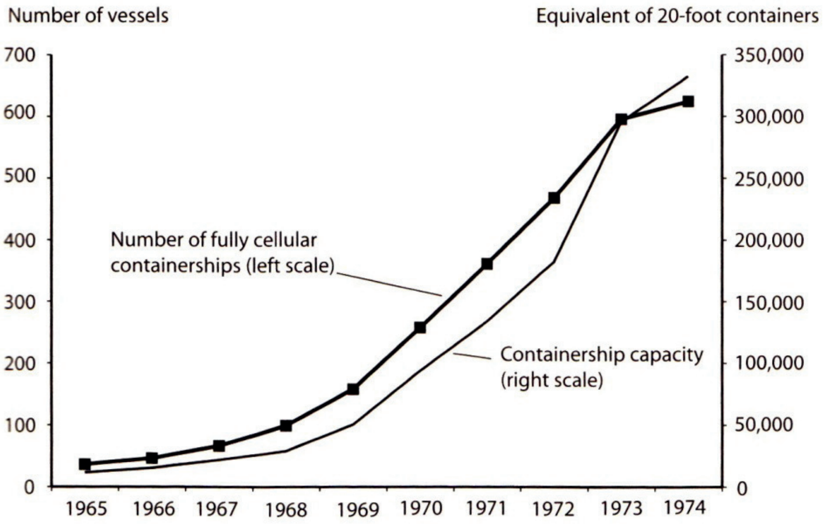

Figure 5-2: The container ship boom.

Source: Levinson (2005)

The container ship fleet continued expanding in the 1970s. Except in 1974 and 1975 when it edged up less than 10% per year, the remaining years witnessed its strongly growing level by over 16% per year. Approximately 176 Handy ships (219,072 TEUs) entered the service in the decade. Together with such strong growth, the sub-Panamax (2,000 – 2,999 TEUs) generation also emerged and grew quickly with the entrance of roughly 61 ships (152,167 TEUs).

The development of container ships in the 1970s was affected by the oil shocks in 1974 and 1979. In order to save fuel consumption in exchange of speed reduction, the diesel engines began taking over from large powered steam turbines suitable for high speed ships (Watanabe, 1985, 2000). The ambition to deploy express services of some carriers, for instance Sealand with 33 knot SL-7 fleet, had been end up.

5.3.2.3 Panamax era

Reaping scale economies has been a catalyst for CSLs to invest in larger and larger ships. Nevertheless, it had been a rule of thumb for a long time that container ships should not exceed the Panama Canal's limitation, 294 metres in length, 32.3 metres in width and 12 metres in depth. The canal is the most important connection between West Coast North America and Europe, Far East and East Coast North America. The Panamax limitation naturally makes vessels flexible; they can easily change from one route to another without route constraints.

Generally, the Panamax generation refers to ships which can travel through the canal and carry more than 3,000 TEUs. Furthermore, it was widely agreed by most shipyards and carrier executives that the maximum capacity of Panamax-configured ships lies between 4,300 and 4,500 TEUs (Fossey, 1994). The first Panamax ships were deployed in 1972 and 1973. Nevertheless, it was not until 1981 that the next ones entered the service. The Panamax fleet experienced a fast growing phase during the 1980s. It expanded more than 13 times within the decade with the annual rate of 35%. Afterwards, the expansion became slower in the 1990s and 2000s, with the growing figures of 18% and 10% respectively.

In the mid-1980s, the Econ ships of US Lines became the first ones to reach the maximal Panamax size. They were the largest ships at that time, capable of transporting 4,354 TEUs, and employed to operate the round-the-world service. Although advantageous regarding carrying capacity, these ships were argued not to be efficient regarding hydro-dynamic point of view (Drewry, 2001). Large amount of water ballast needed carrying to maintain their stability, which resulted in lower DWT carrying capacity and higher fuel consumption.

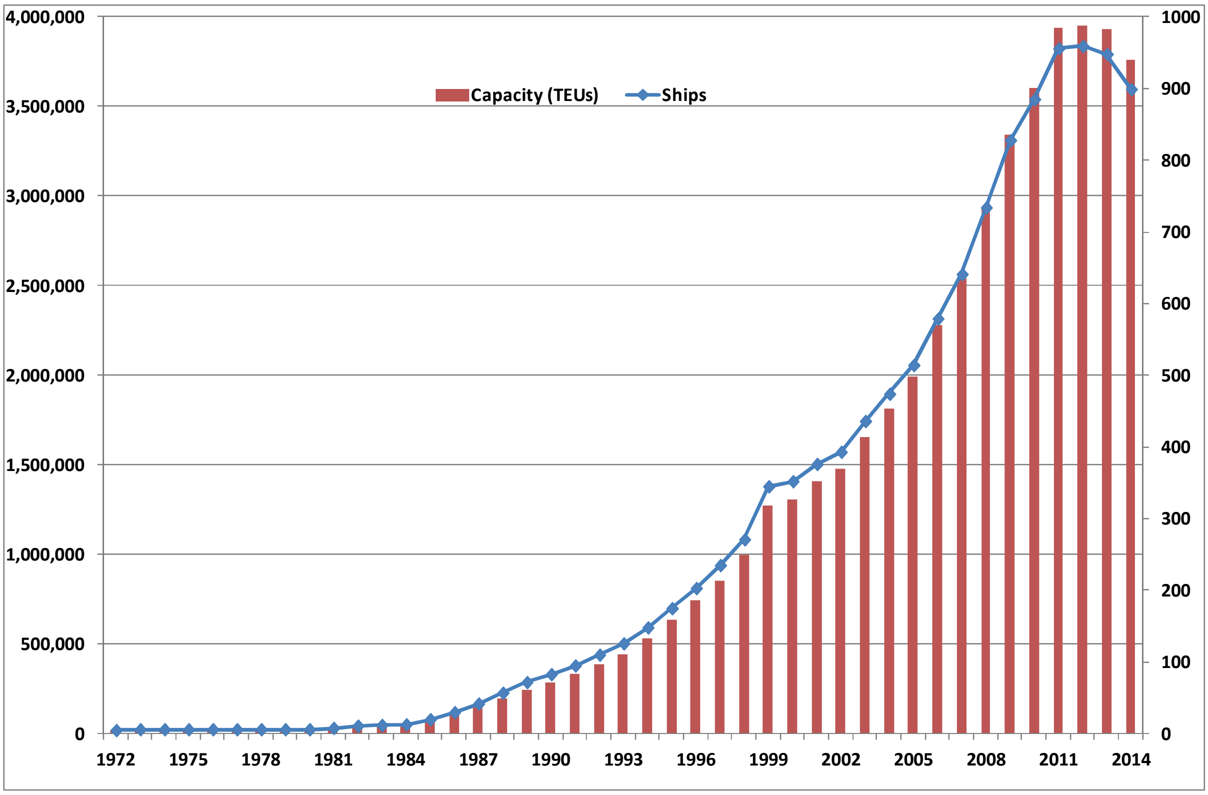

Figure 5-3: Evolution of the Panamax fleet (1972-2014).

Data source: estimated based on Clarkson (1995, 2001, 2010, 2013, 2014b)

5.3.2.4 Post-panamax era

The panamax barrier was broken up in 1988 by a post-panamax fleet of APL. The new generation was designed with a wide beam of 39.40 metres and capable of carrying 4,340 TEUs. The new ships' capacity was not superior to that of Panamax ones, even it was smaller than that of US Lines' Econ ships and optimised Panamax ships (Table 2). However, the wide beam benefits them in terms of better stability, less requirement of ballast capacity, more flexible, easier, faster stowage of containers, and smaller heeling motion associated with loading and discharging (Fossey, 1994; Kai &Dan, 1997; Lloyd's Shipping Economist, 1996; Ryle, 1993; The Motor Ship, 1988; Tozer, 2003). Furthermore, a Post-Panamax vessel could have advantage over a Panamax one with the same capacity concerning cheaper investment cost (about 5%) and less fuel consumption due to less or no ballast (Ham 2005, p 92). Following APL, other CSLs have joined the post-panamax game, especially since the latter half of the 1990s. 1,188 new ships (9.3 m TEUs) were delivered between 1991 and 2014. It was forecasted that some 348 ships (3.5m TEUs) will enter the service within the next 3 years (Clarksons, 2014b).

Table 5-2: Comparison of the first Post-panamax and panamax designs

	First Post Panamax ship	US Lines's Econ ships	Optimised Panamax
Length (metres)	275.2	289	294.0
Beam (metres)	39.4	32.2	32.3
Moulded depth (metres)	23.6	21.5	21.4
Draft (metres)	12.5	11.7	13.5
DWT	54,665	58,900	67,680
Speed (knots)	24.2	18	23.8
Power (bhp)	56,960	-	49,636
Capacity (TEUs)	4,340	4.354	4,422

Source: Drewry (1996, 2001).

5.3.2.5 Ultra large container ship era

The appearance of APL's new fleet has virtually changed the mindset of the industry about ship development and heralded the post-panamax era, in that, ship capacity has continuously increased. The terms "Ultra large container ship" and "mega container ship" have been widely used to imply new ships with giant capacity, often more than 10,000 TEUs.

Technical aspects of mega vessels have been conducted in various studies. Man Diesel & Turbo (2008) discusses their main engine and propeller trends. Shi et al. (2006) review of the technology of American Bureau of Shipping applied in support of giant ships in service. The design of ultra large ships have been suggested elsewhere, for example 12,500 TEU ship of Lloyd's Register (Tozer & Penfold, 2003); 13,400 TEU ship of Germanisher Lloyd (Jefferies & Probst, 2007); 20,250 TEU ship of Alphaliner (2011); 22,000 TEU ship of STX (The Motor Ship, 2010).

The expansion of the Panama Canal will allow the passage of New Panamax (NPX) ships up to 366 metres long, 49 metres wide and 18.3 metres deep (Tozer & Penfold, 2007). Ashar (1999) studies the employment of NPX ships, up to 15,000 TEUs, in configuring the new backbone container route on the East-West axis. World Cargo News (2005) discusses possible sizes of NPX ships. Tozer and Penfold

(2007) present the prospect of NPX ships by taking account of operational conditions, world supply and demand, and cost saving.

The concept of Malacca-max generation is proposed sophisticatedly by Wijnolst et al. (1999). A Malacca-max ship could carry 18,000 TEUs with cost saving of 16% over an 8,000 TEU one. It has the length of 400 metres, beam of 60 metres and draught of 21 metres. These dimensions are restricted by operational conditions of Malacca Strait and Suez Canal, which are the two key strategic positions on the East-West route. The former restriction only allows ships with maximum draught of 21 metres to travel whereas the latter one merely facilitates ships with maximum breadth of 60 metres.

In 2006, Emma Maersk was launched and marked the era of ultra large container ships. It was rumoured that her carrying capacity was in the range of 11,000 to 14,500 TEUs. Nevertheless, it has been stated by Maersk Lines recently that the capacity is actually 15,500 TEUs.

Another landmark has emerged. At the beginning of 2011, Maersk Lines notified an order for a Triple E series of 10 x 18,000 TEU ships worth $1.9b, with an option to 20 ships more. The first ship was launched in mid-2013. The Triple E ships are currently the largest, longest and widest and become the new benchmark for size in liner shipping. They aim to be economy of scale, energy efficient and environmentally improved. Their unit transportation cost is 26% lower than current large ships in service. Additionally, $C0_2$ emission per container can be reduced by more than 50% as compared to the industry average on the Asia – Europe route.

Merely entered the industry recently, but ultra large container ships have grown significantly. Their growth is faster than that of any other size segments in the past. Between 2006 and 2013, 182 mega ships (2.33m TEUs) joined the world fleet (Table 3). Until 2016, 113 new titans (1.6m TEUs) accounting for more than 47% of the global new-building capacity will be delivered (Drewry, 2013a).

Table 5-3: Development of mega container ships

	2007	2008	2009	2010	2011	2012	2013
Number of vessels	5	12	27	39	95	149	182
Capacity (mTEUs)	0.07	0.15	0.32	0.48	1.2	1.89	2.33
% fleet capacity	0.67	1.3	2.5	3.6	8.0	11.9	13.9
Average age (years)	0.6	1	1.1	-	1.4	1.6	2.2

Source: Drewry (2007-2013a)

Ship size has increased continuously. There is no sign that the tendency will cease, new size frontiers will continue emerging. The biggest ship was less than 2,000 TEUs at the beginning of the 1970s, less than 5,000 TEUs at the beginning of the 1990s, today it is 18,000 TEUs. In terms of technique, perhaps there is no constraint for new series of giant box carriers. As stated by Payer (2002), technical challenges of mega ships could be coped with by designers and engineers. Malacca-max, used to be considered as the limitation of ship size, has been passed. The industry will look forward to new size benchmarks.

5.4 Impacts of fleet capacity and ship size on financial performance

5.4.1 Model description

There are various parameters impacting on CSLs' revenue and cost. The ship fleet is obviously an important input for the production process. On the one hand, it determines transportation capability, and in turn, revenue of the operator. On the other hand, a great amount of money is required to invest in the most expensive asset of CSLs as well as to organize the network. Ship size is among the most influential factors on shipping expenses. Small ships may be limited in short haul regional or feeder markets whereas big ones need deploying in long haul corridors. Slot utilisation measures the number of carrying TEUs per ship slot and equivalent to the ratio between the shipping volume and fleet capacity. Higher value means the more deployment of the fleet whereas lower one means asset redundancy. Oil price contributes a significant part to transportation cost. In recent years, the escalation of the item has become a big challenge for the industry. Bunker surcharge is a solution of CSLs to compensate the expensive fuel cost by earning extra revenue. Freight rate can be seen as a thermometer of the market or reveals the balance between supply and demand. Not only does it influence on carriers' income but also their operational strategies. High freight rate may encourage them to use faster services in order to lower transit time and enhance the shipping supply.

The major research question is how fleet capacity and ship size of CSLs influence on their revenue and cost (total and unit)? To answer it, we assume that variations of revenue and cost are dependent on variations of the two parameters as well as slot utilisation and market conditions (oil price and freight rate). Multiple regression models are built to establish the relationships between the explanatory and outcome variables.

Model of total revenue variation: $rev_{i,t} = \beta_0 * cap_{i,t}^{\beta_1} * size_{i,t}^{\beta_2} ** slot_{i,t}^{\beta_3} * oil_t^{\beta_4} * fr_t^{\beta_5} * \varepsilon_{i,t}$ or

$$ln(rev_{i,t}) = ln\,\beta_0 + \beta_1 * ln(cap_{i,t}) + \beta_2 * ln(size_{i,t}) + \beta_3 * ln(slot_{i,t}) + \beta_4 * ln(oil_t) + \beta_5 * ln(fr_t) + ln\,(\varepsilon_{i,t})$$

Model of unit revenue variation: $u\_rev_{i,t} = \beta_0 * cap_{i,t}^{\beta_1} * size_{i,t}^{\beta_2} * slot_{i,t}^{\beta_3} * oil_t^{\beta_4} * fr_t^{\beta_5} * \varepsilon_{i,t}$

Model of total cost variation: $cost_{i,t} = \beta_0 * cap_{i,t}^{\beta_1} * size_{i,t}^{\beta_2} * slot_{i,t}^{\beta_3} * oil_t^{\beta_4} * fr_t^{\beta_5} * \varepsilon_{i,t}$

Model of unit cost variation: $u\_cost_{i,t} = \beta_0 * cap_{i,t}^{\beta_1} * size_{i,t}^{\beta_2} * slot_{i,t}^{\beta_3} * oil_t^{\beta_4} * fr_t^{\beta_5} * \varepsilon_{i,t}$

Where:

$ln\, \beta_0$: intercept coefficient

$ln\, \varepsilon_{i,t}$: residual

$\beta_1, \beta_2, \beta_3, \beta_4, \beta_5$: slope coefficients

$rev_{i,t}$: variation of carrier i's total revenue in year t; $rev_{i,t} = \frac{total\ revenue\ (year\ t)}{total\ revenue\ (year\ t{-}1)}$

$u\_rev_{i,t}$: variation of carrier i's unit revenue in year t; $u\_rev_{i,t} = \frac{unit\ revenue\ (year\ t)}{unit\ revenue\ (year\ t{-}1)}$

$cost_{i,t}$: variation of carrier i's total cost in year t; $cost_{i,t} = \frac{total\ cost\ (year\ t)}{total\ cost\ (year\ t{-}1)}$

$u\_cost_{i,t}$: variation of carrier i's unit cost in year t; $u\_cost_{i,t} = \frac{unit\ cost\ (year\ t)}{unit\ cost\ (year\ t{-}1)}$

$cap_{i,t}$: variation of carrier i's fleet capacity in year t; $cap_{i,t} = \frac{fleet\ capacity\ (year\ t)}{fleet\ capacity\ (year\ t{-}1)}$

$size_{i,t}$: variation of carrier i's average ship size in year t; $size_{i,t} = \frac{average\ ship\ size\ (year\ t)}{average\ ship\ size\ (year\ t{-}1)}$

$slot_{i,t}$: variation of carrier i's slot utilisation in year t; $slot_{i,t} = \frac{carrying\ TEUs\ per\ slot\ (year\ t)}{carrying\ TEUs\ per\ slot\ (year\ t{-}1)}$

oil_t: variation of oil price in year t; $oil_t = \frac{average\ oil\ price\ per\ barrel\ (year\ t)}{average\ oil\ price\ per\ barrel\ (year\ t{-}1)}$

fr_t: variation of freight rate in year t; $fr_t = \frac{average\ freight\ rate\ per\ TEU\ (year\ t)}{average\ freigh\ rate\ per\ TEU\ (year\ t{-}1)}$

5.4.2 Data description

The models are estimated with 224 observations. Each describes variations of financial and operating factors of a CSL, often belonging to the top 20, in the period 1997-2012. Yearly revenue, cost and transportation volume (by TEUs) of each CSL are collected from various annual reports "Container market annual review and forecast" of Drewry (2000a-2013a) and series "Who is making money?" of

American Shipper (2005-2012). CSLs' fleet information regarding capacity (by TEUs) and number of ships are extracted from the database of Containerisation international yearbooks and monthly magazines (1998-2013). Some missing information is added from annual reports "The top 25 Container Liner Operators Trading profile" of Dynamar (2002-2013) and reports of CSLs. From such collected data, yearly unit revenue and cost, average ship size and carrying TEUs per slot (ratio of transportation volume to fleet capacity) are calculated.

Average annual oil price is retrieved based on the statistics of Europe Brent Spot price FOB ($ per barrel) published by U.S Energy Information Administration (2013). Average freight rate per TEU is taken from estimated average unit rate on the East/West container market of Drewry (2000a-2013a).

5.4.3 Results

Results of multiple regression analyses are presented in tables 4-7. The usefulness of the 4 models is investigated through the classical F – test to test the null hypotheses that all slope coefficients are zero - $H_0: \beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = 0$. The extremely small values of significance F in all models imply the hypotheses are rejected at marginal significance levels ($\alpha = 10^{-49}$ for the TR model, 10^{-28} for the UR model, 10^{-27} for the TC model, 10^{-9} for the UC model). It is possible to conclude that they are statistically useful for predicting variations of revenue and cost. In addition, variance inflation factor (VIF) of each predictor variable is taken into account to prevent the multicollinearity which can make the result inaccurate. Small values of VIFs mean the absence of the phenomenon in the models ($VIF_{capacity}$= 1.61; $VIF_{ship\ size}$ =1.02; $VIF_{slot\ utilisation}$ = 1.64; $VIF_{oil\ price}$ =1.5 and $VIF_{freight\ rate}$ =1.53).

Table 5-4: Total revenue (TR) variation estimation

Estimated regression equation: $\widehat{rev} = 1.03 * cap^{0.81} * size^{-0.16} * slot^{0.45} * oil^{-0.04} * fr^{0.86}$

$R^2 = 0.67$ *Adjusted* $R^2 = 0.66$ F = 87.02 *Significance* F = $5.45*10^{-50}$

	Coefficients	*t Stat*	*P-value*	Meaning
Cap	0.814239	10.27259	$1.92*10^{-20}$	Reject H_0 ($\alpha=10^{-19}$): capacity has effect on TR
Size	-0.15823	-1.36749	0.172881	Fail to reject H_0: no evidence of ship size's effect on TR
Slot	0.446267	5.503781	$1.04*10^{-7}$	Reject H_0 ($\alpha=10^{-8}$): slot utilization has effect on TR
Oil	-0.03721	-0.87688	0.381514	Fail to reject H_0: no evidence of oil price's effect on TR
Fr	0.862823	11.85552	$2.39*10^{-25}$	Reject H_0 ($\alpha=10^{-24}$): market freight rate has effect on TR

Table 5-5: Unit revenue (UR) variation estimation

Estimated regression equation: $\widehat{u\_rev} = 1.03 * cap^{-0.19} * size^{-0.16} * slot^{-0.55} * oil^{-0.04} * fr^{0.86}$

R^2 = 0.48 *Adjusted R^2 = 0.47* *F = 40.58* *Significance F* = $2.14*10^{-29}$

	Coefficients	*t Stat*	*P-value*	Meaning
Cap	-0.18576	-2.3436	0.019999	Reject H_0 (α=0.02): capacity has effect on UR
Size	-0.15823	-1.36749	0.172881	Fail to reject H_0: no evidence of ship size's effect on UR
Slot	-0.55373	-6.82915	$8.38*10^{-11}$	Reject H_0 (α=10^{-10}): slot utilization has effect on UR
Oil	-0.03721	-0.87688	0.381514	Fail to reject H_0: no evidence of oil price's effect on UR
Fr	0.862823	11.85552	$2.39*10^{-25}$	Reject H_0 (α=10^{-24}): market freight rate has effect on UR

Table 5-6: Total cost (TC) variation estimation

Estimated regression equation: $\widehat{cost} = 1.02 * cap^{0.86} * size^{-0.16} * slot^{0.43} * oil^{0.09} * fr^{0.14}$

R^2 = 0.47 *Adjusted R^2 = 0.45* *F = 38.12* *Significance F* =$5.16*10^{-28}$

	Coefficients	*t Stat*	*P-value*	*Meaning*
Cap	0.85916	10.75009	$6.67*10^{-22}$	Reject H_0 (α=10^{-21}): capacity has effect on TC
Size	-0.15675	-1.34356	0.180486	Fail to reject H_0: no evidence of ship size's effect on TC
Slot	0.432776	5.293464	$2.92*10^{-7}$	Reject H_0 (α=10^{-6}): slot utilization has effect on TC
Oil	0.088482	2.067847	0.039835	Reject H_0 (α=0.04): oil price has effect on TC
Fr	0.136515	1.860325	0.064186	Reject H_0 (α=0.07): market freight rate has effect on TC

Table 5-7: Unit cost (UC) variation estimation

Estimated regression equation: $\widehat{u\_cost} = 1.02 * cap^{-0.14} * size^{-0.16} * slot^{-0.57} * oil^{0.09} * fr^{0.14}$

R^2 = 0.22 *Adjusted R^2 = 0.20* *F = 12.42* *Significance F* = $1.3*10^{-10}$

	Coefficients	*t Stat*	*P-value*	*Meaning*
Cap	-0.14084	-1.76224	0.07943	Reject H_0 (α=0.08): capacity has effect on UC
Size	-0.15675	-1.34356	0.180486	Fail to reject H_0: no evidence of ship size's effect on UC
Slot	-0.56722	-6.93794	$4.47*10^{-11}$	Reject H_0 (α=10^{-10}): slot utilization has effect on UC
Oil	0.088482	2.067847	0.039835	Reject H_0 (α=0.04): oil price has effect on UC
Fr	0.136515	1.860325	0.064186	Reject H_0 (α=0.07): market freight rate has effect on UC

The next step is to evaluate whether explanatory variables impacts on outcome variables or not. The Student's t-test is applied to test the null hypotheses - $H_0: \beta_i = 0 \;\; i = 1..5$. For the revenue models, it fails to reject the null hypotheses - $\beta_2 = 0$ and $\beta_4 = 0$ - at the significance level $\alpha = 0.1$, which means that impact on TR and UR of ship size and oil price cannot be found. On the other hand, TR and UR are related to capacity, slot utilization and market freight rate. Capacity expansion and more efficient slot utilization bring about higher TR, but they make UR smaller. Adding new capacity by 10% will drive TR up by 8.1% and drive UR down by 1.8%. Diminishing returns can be seen as TR grows at slower pace than carrying capacity. If slot utilization is enhanced by 10%, TR will go up by 4.3% whereas UR will drop by 5.1%. TR and UR are most influenced by freight rate; both indicators will rise by 8.6% when the rate goes up by 10%.

Table 5-8: Relationships between variations of explanatory factors and variations of total and unit revenue

	10%		20%		50%		100%	
	TR	UR	TR	UR	TR	UR	TR	UR
Carrying capacity	8.1%	-1.8%	16.0%	-3.3%	39.1%	-7.3%	75.8%	-12.1%
Average ship size					No effect			
Slot utilization	4.3%	-5.1%	8.5%	-9.6%	19.8%	-20.1%	36.3%	-31.9%
Oil price					No effect			
Freight rate	8.6%	8.6%	17.0%	17.0%	41.9%	41.9%	81.9%	81.9%

For the cost models, it fails to reject the null hypotheses: $\beta_2 = 0$ at the significance level $\alpha = 0.1$, so there is no evidence of effect of ship size on TC and UC. The outcome variables are determined by fleet capacity, slot utilization, oil price and market freight rate. Growths of fleet capacity and slot utilization lead to higher TC, but smaller UC. Capacity growth by 10% will raise TC by 8.5% whereas lower UC by 1.3%. Improvement of slot utilization by 10% will make TC higher by 4.2% whilst reduce UC by 5.3%. TC and UC vary in the same direction as oil price and market freight rate; as it is 10% higher, they will rise by 0.8% and 1.3% respectively.

Table 5-9: Relationships between variations of explanatory factors and variations of total and unit cost

	10%		20%		50%		100%	
	TC	UC	TC	UC	TC	UC	TC	UC
Carrying capacity	8.5%	-1.3%	17.0%	-2.5%	41.7%	-5.6%	81.4%	-9.3%
Average ship size					No effect			
Slot utilization	4.2%	-5.3%	8.2%	-9.8%	19.2%	-20.5%	35.0%	-32.5%
Oil price	0.8%	0.8%	1.6%	1.6%	3.7%	3.7%	6.3%	6.3%
Freight rate	1.3%	1.3%	2.5%	2.5%	5.7%	5.7%	9.9%	9.9%

As carrying capacity increases, the growth rate of total revenue is smaller than that of total cost. It implies that total profit may go down albeit fleet scale becomes bigger. In contrast, the profit may move up in consequence of better slot utilization or freight rate because the revenue increases at higher pace than the cost.

5.5 In-depth analysis

5.5.1 Capacity expansion and firm performance

In contrast to the strong growth of its fleet, container liner shipping has been in an unhealthy situation in recent years. The industry has been commented by the CEO of Maersk Line to create no value for shareholders over the past 6 or 7 years (Johnson, 2012b). According to a risk analysis of AlixPartners (Johnson, 2012a), 12 CSLs in the top 20 were in the danger zone of bankruptcy at the end of 2011. The 16 publicly traded lines[5] lost collectively $11.94b ($164 per TEU) in 2009 and $4.87b ($55 per TEU) in 2011. No one except Wanhai made money in the former year whereas only CMA-CGM, Wanhai, OOCL and Hapag Lloyd were profitable in the latter one.

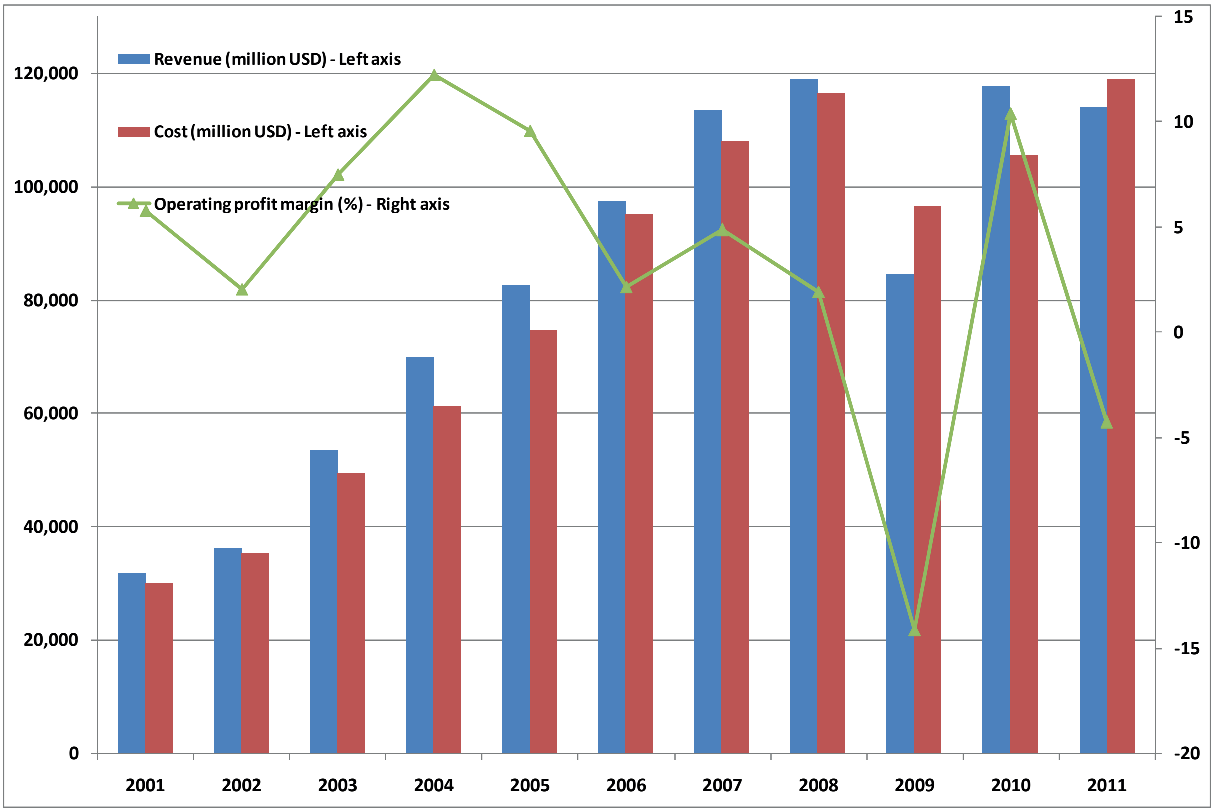

Figure 5-4: Collected financial return of the top 16 publicly traded carriers.

Data source: Compiled based on Drewry (2002a-2012a), American Shipper (2005-2012), and CSLs' website.

The 16 public CSLs' fleet capacity moved up from 2.5m TEUs (34% of the global capacity) in 2001 to 9.9m TEUs (57%) in 2011. Consequently, their carrying traffic went up from 31m TEUs to 89m TEUs, total revenue from $31.8b to $114.2b, and total cost from $30b to $119b. There were highly positive correlations of fleet capacity with carrying volume, total revenue and total cost with the corresponding Pearson product-moment correlation coefficients (PCC) of 0.97, 0.93 and 0.96.

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[5] The 16 lines include: APL, CMA-CGM, Coscon, CSAV, CSCL, Evergreen, Hanjin, Hapag Lloyd, Huyndai, MOL, Maersk Line, NYK, OOCL, Wanhai, Yangming and Zim.

Table 5-10: Combined operating and financial indicators of the selected carriers

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Capacity (10^6 TEUs)	2.5	2.9	3.8	4.5	5.5	6.5	7.3	8.2	8.2	9.1	9.9
Ship size (TEU)	2,587	2,608	2,561	2,667	2,784	3,023	3,214	3,379	3,553	3,745	3,927
Traffic (10^6 TEUs)	31.1	36.8	46.2	56.4	63.7	69.9	78.9	80.8	72.9	82.7	88.9
Carrying TEUs per slot	12.5	12.5	12.1	12.7	11.5	10.7	10.8	9.9	8.9	9.1	9.0
Revenue (10^9 USDs)	31.8	36.1	53.5	69.7	82.5	97.4	113.5	118.9	84.6	117.7	114.2
Cost (10^9 USDs)	30.0	35.3	49.5	61.2	74.6	95.3	107.9	116.6	96.5	105.5	119.0
Profit (10^9 USDs)	1.8	0.7	4.0	8.5	7.9	2.1	5.5	2.3	-11.9	12.3	-4.9
Unit revenue (USD)	1023	981	1157	1237	1296	1393	1438	1471	1160	1424	1284
Unit cost (USD)	964	960	1070	1085	1171	1363	1368	1443	1324	1276	1339
Unit profit (USD)	59	20	87	151	124	30	70	28	-164	148	-55
Profit margin (%)	5.8	2.1	7.5	12.2	9.6	2.2	4.9	1.9	-14.1	10.4	-4.3

Data source: As Figure 5-4 and Containerisation International Yearbooks (2002-2012), Dynamar (2002-2012).

Increasing with the added capacity, but the throughput could not keep pace with it (11.5% vs. 15% per year), which caused the downward trend of slot utilisation (PCC of -0.95). The ambition to capture more market share has promoted the CSLs to invest in their fleet aggressively. Consequently, over-capacity has emerged and become much more serious in the context of the world economic crisis recently. Whereas capacity growth was 2.3 percentage points higher than traffic growth between 2001 and 2005, the difference was over 4.2 points between 2006 and 2011. Average carrying TEUs per slot were 12.2 in the former period, but fell to 9.6 in the latter. The indicator was only 8.9 in the trough year 2009 in comparison with 12.7 in 2004 or 11.5 in 2005.

The less efficient deployment of ship slots could be an explanation for the diminishing revenue in the period 2006-2011. The phenomenon has been realised in the total revenue model whereby total revenue grows slower than fleet capacity (Table 8). In the period, its annual average growth rate was 7.8% as compared with 10.3% of fleet capacity. The situation was in contrast to the previous period with the corresponding figures of 27.6% and 22.1%.

Regarding cost aspect, total cost advanced at an annual rate of 15.7% in comparison with 15% of fleet capacity between 2001 and 2011; whilst unit cost edged up at a rate of 3.6% per year. Our cost models have forecasted positive effects of capacity expansion on total and unit cost (Table 9). The former will increase at percentage points lower than the growth of fleet capacity whereas the latter will drop as consequences of such operating change. Nevertheless, the good effects on the cost indicators have been dimmed in practice by the poorer slot usage as mentioned in previous paragraphs, and upswing of oil price.

A significant portion of CSLs' expenses is generated by bunker cost. In accordance with the model of Stopford (2009), the cost represents around 39-48% of the voyage cost. It is estimated based on Drewry (2012a) that CMA-CGM spent in the region of \$2.88b-\$3.6b (20-25% of total expense) for fuel in 2011, whereas CSCL paid \$1.48b (30%) for the item. Another expense related to oil products is for lubricating oil. Less than 5% of bunker cost, but the cost should been also taken into account. Lubes incur some \$0.7m per year for a 5,000 TEU vessel, and \$1m for a 10,000 TEU one (Drewry, 2012e). It is the second largest component of operating cost budget, only after manning.

Table 5-11: Percentage of cost items on the voyage cost of different ship sizes

	1,200 TEUs	2,600 TEUs	4,300 TEUs	6,500 TEUs	8,500 TEUs	11,000 TEUs
Operating cost	16.24%	11.97%	8.57%	7.18%	6.92%	6.99%
Capital cost	31.13%	35.79%	34.12%	35.12%	38.75%	43.17%
Bunker cost	38.66%	40.44%	47.16%	48.37%	43.37%	39.48%
Port cost	13.97%	11.80%	10.14%	9.32%	10.96%	10.36%

Source: based on Stopford (2009)

The escalation of oil price has been obviously stepped up shipping cost substantially. Following our estimation, total and unit cost will go up by 9.9% as oil price doubles (table 9). Maersk Line has complained of 14% increase of its unit cost in the first half of 2008, mainly because of higher bunker prices (Drewry, 2008a). In 2011, the industry's fuel bill was \$63b, which is 573% increase against 2004 (Drewry, 2012a). Besides the incurred expenses due to more vessels in the fleet, a considerable rise resulted from threefold increase of oil price, from \$38.26 to \$111.26 per barrel. To overcome expensive bunker and over-capacity, CSLs have widely applied slow steaming in recent years (Cariou, 2011; Ferrari et al. 2012; Maloni et al. 2013). In addition, fuel surcharges have been used to compensate for higher bunker costs (Cariou & Wolff, 2006; Notteboom & Cariou, 2009).

Though capacity growth led to more total and unit revenue, it did not mean that the CSLs became more profitable. It was the fact that the bigger the fleet capacity, the smaller their total and unit profit, and profit margin. The negative correlation coefficients of fleet capacity with the three latter indicators demonstrate clearly their downward trend as the fleet grew (PCCs of -0.2, -0.42 and -0.49 respectively). Higher unit and total revenue could not offset the substantial raise of unit and total cost due to inefficient slot usage and incurred fuel expense. By comparing the periods 2001-2005 and 2006-2011, unit revenue moved up from \$1,168 to \$1,363 (\$195); at the same time, unit cost edged up from \$1,070 to \$1,352 (\$282). As a result, unit profit slumped by 8.7 times, from \$98 to merely \$11, and in turn, pulled down firms' total profit and profit margin (PM).

Between 2006 and 2011, the public CSLs earned the revenue of \$646.1b, but their operating profit was merely \$5.4b, or PM of 0.83%. The outcome was extremely poor in comparison with the years

2001-2005 when their collecting revenue was $273.6b, but their profit was $23b (PM of 8.4%). 6 lines suffered from negative return (Coscon, CSAV, Hanjin, MOL, NYK, Zim) and 4 earned slim PM less than 1% (APL, CSCL, Huyndai, Yangming).

CMA-CGM (the 3rd largest operator), Maersk Line (the largest), OOCL and Wanhai were the most profitable with respective profits of $3.9b (PM of 5.2%), $2.3b (1.5%), $1.7b (6.3%) and $0.6b (6%). The two latter CSLs were the best ones concerning profit margin. It should be taken into account that OOCL has often not belonged to the top 10 players whereas Wanhai has been even out of the top 20 in some years. It can be implied that some players not deploying mega fleet capacity can be very efficient in terms of finance. The success of OOCL has been partly thanks to their prudent strategies of fleet investment (see more in Jallal, 2013).

Table 5-12: Fleet capacity, throughput and financial incomes of selected carriers from 2006 to 2011

	Average fleet capacity (TEU)		Throughput (10^6 TEU)		Total revenue (10^9 USD)		Total profit (10^9 USD)		Profit margin (%)	
	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank
Maersk Line	1,885,952	1	14.06	1	151,845	1	2,320	2	1.53	5
CMA-CGM	1,004,111	2	8.23	2	74,955	2	3,928	1	5.24	3
Evergreen	595,999	3	5.84	4	22,905	13	549	6	2.40	4
Hapag Lloyd	509,810	4	5.12	6	47,997	3	577	5	1.20	6
Coscon	494,979	5	5.82	5	35,586	6	-1,141	15	-3.21	14
APL	485,003	6	5.00	7	42,236	4	119	10	0.28	10
CSCL	443,112	7	6.89	3	27,023	10	235	7	0.87	7
Hanjin	391,773	8	3.56	10	35,525	7	-312	11	-0.88	11
NYK	367,788	9	3.69	9	32,231	9	-700	12	-2.17	13
MOL	360,975	10	3.06	12	36,778	5	-720	13	-1.96	12
CSAV	351,978	11	2.39	15	26,529	11	-1,747	16	-6.59	16
OOCL	345,717	12	4.55	8	33,021	8	2,066	3	6.26	1
Yangming	298,159	13	3.06	11	22,808	14	139	9	0.61	9
Zim	274,900	14	2.24	16	21,142	15	-812	14	-3.84	15
Huyndai	239,842	15	2.65	14	23,978	12	161	8	0.67	8
Wanhai	144,027	16	2.85	13	11,605	16	696	4	6.00	2

Data source: as Table 5-10

Several other factors could also contribute to the poorly financial performance of CSLs. Firstly, shipping is characterized as capital-intensive and the majority of asset is tied up in vessels and boxes. For example, in 2011, asset value of Maersk Line was some $21.5b, of which 83.3% was non-current assets; the corresponding figures were €6.6b and 78.1% for Hapag Lloyd. High level of fixed assets inevitably makes capacity supply inelastic and raise exit barrier of CSLs. They cannot easily reduce the capacity or leave the game in short-term. They must still compete in depressed markets, which lead to severe freight rates.

Secondly, shipping demand is inelastic in nature as shipping supply. It is derived by the demand to exchange goods. The ratio of maritime freight in shipments' value is marginal, about 6.5% in develop economies and 7.9% in developing Asia in 2010 (UNCTAD, 2012). Consequently, low freight rate cannot generate significant transportation volume for container shipping, but eat into the industry's profitability. Additional demand can only come from such low-value products as waster paper and metal scrap, which can be only carried overseas in case of very low freight rate (Notteboom, 2012, p 245).

Thirdly, empty containers have growingly become a burden for CSLs. The empty traffic has grown even faster than the world traffic, 234% vs. 223% in the 2000s. CSLs must carry an increasing number of empty boxes to overcome trade imbalance without earning any revenue. In 2011, it was estimated that in the global scope, there were 61 mTEUs of seaborne empty container movements which cost $24.4b for the repositioning (Drewry, 2012a).

5.5.2 Efficiency of large container ships

5.5.2.1 Cost advantage

The motivation for deploying mega vessels may stem from the basic rule in transportation, the bigger the transportation means, the cheaper the unit cost. "Irrespective of ship type, as ship size increases ship costs at sea per tonne or TEU decrease" (Pearson, 1988, p 99). Scale economies can be described through the inequality: $\frac{TC_q}{q} < \frac{TC_p}{p}$ as $q > p$ where TC_q and TC_p are total shipping cost of vessels with respective sizes of q and p. In other words, the unit cost function $f(q) = \frac{TC_q}{q}$ is monotonically decreasing.

Regression analyses demonstrate that the relationships between the three major categories of shipping cost (capital cost, operating cost and bunker cost) and ship size strictly follow power functions ($cost = \alpha * size^{\beta}$) with very high coefficients of determination ($R^2 > 0.9$). The power coefficients (β) are less than 1, which means that these costs increase at lower levels than ship size. The unit costs are also highly associated with ship size through power functions. Their negative power coefficients point out that the unit costs will decrease as vessel capacity goes up.

Following the "cube law", by doubling a ship's dimensions, carrying capacity is cubed (Rodrique & Browne, 2008). In other words, carrying capacity is equal to the volume whereas building cost tends to be proportional to the surface area of the vehicle. As a rule of thumb, ships' capital cost is proportional to the two-thirds power of its size. The power coefficient of the regression function (β = 0.7) is fairly close to the rule's value. As ship size grows 2 times, daily capital cost will increase by 62%. As a result, the unit cost will fall by 18%.

Table 5-13: Daily capital costs

Ship size (TEU)	2,500	3,500	6,500	8,000	10,000	12,000
Cost ($)	5,384	6,370	10,110	12,192	13,793	15,233
Unit cost ($)	2.15	1.82	1.56	1.52	1.40	1.27
Estimated regression model: $cost = 22.89 * size^{0.70}$		R^2=0.995				
$unit\ cost = 22.89 * size^{-0.30}$		R^2=0.975				

Data source: based on new building prices in 2011 published by Drewry (2012c) and assumed operating life of ships of 20 years, operating time of 365 days per year.

Operating cost is the category which is subjected to least variation with ship size. Doubling vessel capacity will step up the cost only by 32% whereas step down the unit operating cost by 34%. Manning, the biggest component of operating cost, brings about the most saving when deploying large ships. A 2,468 TEU vessel requires 17 crew members on board, while the amount is only 19 for a 5,364 TEU vessel and 20 for a 10,000 TEU one (Drewry, 2012e). As a consequence, daily manning cost merely increases $549 (24%) and $949 (41%) respectively.

Table 5-14: Daily operating cost (2011)

	Ship size (TEUs)				
Cost item ($)	2,468	3,752	5,364	8,200	10,000
Manning	2,306	2,670	2,855	3,030	3,235
Insurance	557	889	1,007	1,040	1,474
Stores	400	466	511	514	560
Spares	471	663	795	826	1,016
Lubricating oils	814	1,689	1,886	1,899	2,762
Repair & Maintenance	451	546	587	596	662
Management & Administration	508	551	578	710	767
Daily operating cost	5,507	7,474	8,219	8,615	10,476
Unit operating cost	2.231	1.992	1.532	1.051	1.048
Estimated regression model: $cost = 267 * size^{0.40}$	R^2=0.911				
$unit\ cost = 267 * size^{-0.60}$	R^2=0.96				

Data source: based on daily operating costs published by Drewry (2012e)

Bunker is the most expensive item of shipping expenses, especially in the context of high oil price. At the operating speed of 20 knots and fuel price of $700 per tonne, a 10,000 TEU vessel' fuel cost are 6.5 times higher than its capital cost and nearly 10 times higher than operating cost. Bigger vessels will generate great saving of bunker consumption per TEU. From 6,000 to 12,000 TEUs, unit fuel saving per day is 0.009 tonne, equivalent to $5. According to the regression model, enlarging ship size by 100% will drive up fuel cost by 42% and lower the unit cost by 29%.

Table 5-15: Daily fuel cost

Ship size (TEUs)	4,000	6,000	8,000	10,000	12,000	14,000
Daily fuel consumption (tonne)	78.3	117.4	124.5	128.0	148.5	158.7
Cost ($)	54,810	82,180	87,150	89,600	103,950	111,090
Unit cost ($)	13.70	13.70	10.89	8.96	8.66	7.94

Estimated regression model: $cost = 850 * size^{0.51}$ R^2=0.920
$unit\ cost = 850 * size^{-0.49}$ R^2=0.913

Data source: based on fuel consumption at 20 knots published by Drewry (2009) and assumed fuel price of $700 per tonne.

5.5.2.2 Challenges of large container ships

High investment – marginal saving

Investing large ships requires a great deal of money. In 2011, the price of a new 12,000 TEU ship is $111.2m. The large number of containers, about 21,600 TEUs costing roughly $72,8m, must be in use to support the operation of the new ship. Additionally, purchasing a single ship may be inadequate to operate in liner shipping. As a matter of course, CSLs often invest in a series of ships, instead of a single one, to provide a service. For example, at least 8 ships are required to operate a service on the Far East-Asia route. In this case, the total investment of the 12,000 TEU containership fleet is about $1.39b as compared with $517.7m of the 3,500 TEU containership fleet (Table 5-16).

Table 5-16: Estimation of ship and container investment

Ship size (TEU) (1)	Container fleet (TEU) (2) = (1) x 1.8	Ship price ($) (3)	Container cost ($) (4) = (2) x 2,890	Investment per ship operation ($) (5)= (3) + (4)	Total fleet investment ($) (6) = (5) x 8
2,500	4,500	39,300,000	13,005,000	52,305,000	418,440,000
3,500	6,300	46,500,000	18,207,000	64,707,000	517,656,000
6,500	11,700	73,800,000	33,813,000	107,613,000	860,904,000
8,000	14,400	89,000,000	41,616,000	130,616,000	1,044,928,000
10,000	18,000	102,000,000	52,020,000	154,020,000	1,232,160,000
12,000	21,600	111,200,000	62,424,000	173,624,000	1,388,992,000

Data source: (2), (4) According to Drewry (2012d), the container-to-slot operating ratio is 1.8; World container fleet is 31,250,127 TEUs, total container cost is $90,311m, so average cost per TEU is $2,890. (3) Ship price is retrieved from Drewry (2012c). (6): We suppose the fleet for an Europe-Asia service with 8 ships.

Cost advantage of mega ships is paid off by their expensive investment. Nevertheless the saving tends to become marginal as ships are bigger. The unit cost functions take the form of $f(size) = \alpha * size^{\beta}$ $(\alpha > 0; \beta < 0)$, so their derivatives take the form of $f'(size) = \alpha * \beta * size^{\beta-1} < 0$, their second derivatives $f''(size) = \alpha * \beta * (\beta - 1) * size^{\beta-2} > 0$. That the derivatives are negative means that unit cost functions are monotonically decreasing whereas that the second derivatives are positive means that the derivative functions are monotonically increasing. Consequently it can be inferred that unit cost saving will tend to be smaller as ship size increases[6].

Diminishing returns of ship size have been also postulated by several researches. Gilman (1980, 1983) mention great scale economy at sea up to about 1,500 TEUs whereas the saving tends to level out somewhat above this frontier. The phenomenon is explained by the increase in capital cost and fuel cost associated with new system of twin engines and twin screws. On the Transpacific route, Stopford (2009) recognizes that in the region of 1,200 - 2,600 TEUs, every TEU increase of ship size will reduce daily shipping cost $0.107 whereas between 6,500 and 8,500 TEUs, the saving is $0.019 and between 8,500 and 11,000 TEUs, it is merely $0.014.

In principle, capital cost is a source of cost saving. Nevertheless, the advantage is still confused in practice, especially in short-term. Drewry (1996) argues that there is only little difference in unit capital cost because of the reliance of new ship price upon such conditions as yard selection, ship specification and financing agreement. In 1996, slot capital cost of a 5,000 TEU vessel was roughly $16,000 – 16,500 while that of a 4,400 TEU panamax one was $15,900 (Lloyd’s Shipping Economist, 1996); in 2007, the unit price of a 12,000 – 13,000 TEU ship was $12,800 and higher than that of a 8,600 TEU one only close to $10,000 (Matthews, 2007). The paradoxes can be partly for technical reasons due to the requirements of advanced technologies, modern and sophisticated equipments of new generations (Gilman, 1980; Tozer & Penfold, 2002; Stopford, 2009, p 544) or stem from the strong and competitive market of smaller ships (Stopford, 2002), so buyers can benefit from favourable prices of the smaller segments. Other factors such as shipping cycles and buyers’ negotiation power can also contribute to the cheaper capital costs of smaller ships.

It is inadequate to assess ship size economy in the context of water side alone, but should be in the context of overall transport chain. Cost advantage of the titans in sea leg is non-controversial. Nevertheless, shipping is only one stage of the supply chain. Breaking down into smaller elements, the through transport cost includes shipping cost (20%), terminal cost (17%), inland/feesder cost (35%) and inventory carrying cost (28%) (Tran, 2011). Besides shipping cost, other ones should be taken into consideration when determining total cost. Saving in one stage does not mean saving in the whole process. Whereas shipping cost benefits from capacity upsize, there is no concrete argument that other ones are in the same direction. According to Hayuth (1987), concentrating traffic may reduce unit port cost or inland transportation cost thanks to economies of scale.

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[6] Unit cost saving function can be expressed as $g(size) = f(size-1) - f(size); g'(size) = f'(size-1) - f'(size); f''(size) > 0 => f'(size-1) < f'(size) => g'(size) < 0$, or unit cost saving function is decreasing.

Nevertheless, there were opposite opinions arguing that these costs may suffer from diseconomy scale of ship size (Stopford, 2002; Prince, 1997).

The deployment of mega vessels restricts ports of call, so transhipment cost or inland transportation cost will be driven up. Unit shipping cost of a Malacca max carrier is calculated to be 16% lower than that of a super panamax one, but when adding transhipment cost, the saving remained only 3% (Wijnolst et al., 1999, p 62). Simulations of Stopford (2002) and Sys et al. (2008) both reveal cost reduction of the mega ships on sea leg; yet when taking other distribution costs, they may become diseconomies of scale. In accordance with Containerisation International's 2011 shipper survey, transhipment increase is not viewed favourably by respondents because it causes longer transit time, higher safety stock and less service reliability (Moore, 2011).

High risk

Evidently operating mega ships is to take high risk. On the one hand, the mega ones raise entry barrier for new CSLs who want to join the services. On the other hand, they make exit barrier for their operators higher. The operators are subjected to extremely high fixed cost, so it is very difficult for them to withdraw from markets. They can pay high penalty for their wrong strategies related to service design, route selection or operational conditions, as the bad disaster of US Lines in the mid-1980s. Large ships are inflexible and limited in specific trade lanes, it is not easy to change them from one lane to another like smaller ones due to navigational constraints or insufficient traffic. Over 10,000 TEU ships may be only suitable for the Europe-Far East lane.

The emergence of new mammoths possibly triggers a size race between CSLs in order to maintain their cost advantage. Consequently, shipping supply can become over-tonnage and later decrease freight rate. Stopford (2009) mentions the progressive fall of freight rate once 11,000 TEU vessels entered the service. A mass deployment of 32 mega ships, totalling nearly 400,000 TEUs, on the Asia and Europe route in the last quarter of 2010 and the first quarter of 2011 made average freight rate collapse by 32% (Beddow, 2011).

Bigger vessels, on the one hand, provide cheaper shipping cost per slot; on the other hand, require higher volume of cargo fulfilment. A broader marketing and operational network, covering many countries, ports and hinterlands, is required to generate enough cargo for them. Otherwise, it is impossible to pay-off their higher expense. Unit cost saving of a large ship only exists when its utilisation level is maintained (Gilman, 1975, p 3). Slot cost advantage of a 14,000 TEU ship will become a disadvantage at load factor of 60% compared with a full load 4,000 TEU one (table 17).

Clearly, in case a ship becomes under-utilised, scale economies will be negated and become scale diseconomies. According to the estimation in section 4, 10% decrease of slot utilisation will drive up unit cost by 5.3% (Table 9). The worry about insufficient cargo to fill large ships prevented a Japanese carrier K-Line to buy new Post-panamax ships in the mid-1990s (Boyes, 1996b) and Taiwanese operator Evergreen to join the mega race in the latter half of the 2000s (Mathews, 2007).

Table 5-17: The relationship between capacity utilisation and slot cost ($) on Asia – Europe round voyage

	Capacity utilisation					
Ship size (TEU)	100%	90%	80%	70%	60%	50%
4,000	436	484	545	623	726	872
6,000	416	462	520	594	693	831
8,000	375	416	468	535	625	750
10,000	331	368	414	473	552	663
12,000	310	344	387	442	516	619
14,000	288	320	360	412	480	577

Source: Drewry (2009)

Deploying large vessels incurs a lot of costs, so operators and shippers are subjected to more expense in case of any delay, either in port or at sea. Total daily cost in port or at sea for an 18,000 TEU giant is roughly 2.4 - 2.6 times higher than those of a 6,000 TEU carrier. Customers benefit from cheaper freight of mega ships; yet they may pay more for inventory cost, which is even more expensive than other costs (Table 5-18). The cost is pulled up by longer handling time in port as well as extra transit time to connect hub and spokes. Customers of high value cargo or at the extremes of feeder networks are the ones who suffer considerably from scale diseconomy of mega ships regarding inventory cost. Additionally bigger vessels possibly reduce call frequency in ports which drive up shippers' inter-arrival stock (see more in Veldman, 1993).

Table 5-18: Estimation of total costs per day in port and at sea

Ship size (TEU)	Fixed cost ($)	Fuel cost in port ($)	Fuel cost at sea ($)	Inventory cost ($)	Total cost in port ($)	Total cost at sea ($)
6,000	38,099	40,400	78,100	120,000	198,499	236,199
12,000	62,568	66,000	116,000	240,000	368,568	418,568
18,000	83,826	88,200	147,100	360,000	523,026	581,926

Data source: Fixed cost and fuel cost in port/at sea are retrieved from Veldman (2009); According to UNCTAD (2009a), world total of containerized trade was estimated at 137m TEUs with the value of $4 trillion in 2008; so, the average value per TEU is roughly $29,197. Opportunity cost of cargo is assumed at 25% per year. Consequently, daily inventory cost per TEU is $29,197 x 25%/365 = $20.

Scale economies at sea, scale diseconomies in port

Although benefiting from economies of scale at sea, large ships have been claimed to suffer from diseconomies of scale in port (Gilman, 1980, 1983; Jansson & Shneerson, 1978, 1987). A ship's turnaround time in ports is more or less proportional to its capacity. The bigger the ship, the longer time it spends in ports. Consequently, greater capital cost and operating cost must be paid in the port time. Additionally, a large amount of goods on board produce considerable inventory cost every day. Daily arised cost for a Malacca-max vessel in port is $523,026, in which fixed cost is $83,826 (16%), fuel cost $88,200 (17%) and inventory cost $360,000 (67%) (Table 5-18).

High expenses incurred by mega vessels demand extreme efficiency of visited ports in order to reduce their turnaround time in port. More state-of-the-art gantry cranes, owning very high handling rates, must be installed to load and unload containers quickly (see more in Dragovic et al. 2007, 2010). In addition to berth operation, the compatibility and productivity of quay transfer, yard, gate and inland operations are not less important to ensure continuous and fast operation of the costly behemoths. The productivity of container yard is even regarded at the heart of a terminal's efficiency (Young, 2006). Storage capacity must be expanded, either by higher stacking or by bigger yard area to adapt to the storage of huge amount of boxes. Inland transportation system must be well connected so as to deliver cargo on time as well as shorten dwell-time of containers in port.

The call of mega ships possibly causes rush and off-peak hours in ports. In rush hours, the ports face congestion by a surge of internal and external traffic. A large quantity of skilled labour and equipment must be mobilized to serve these ships. Equipment is argued to rise exponentially with the increase in the number of moves within the allotted turnaround time (Matthews, 2003). Additional costs must be paid for overtime, which is very expensive in many ports (Prince, 1997). In contrast, port facility becomes under-utilised in off-peak time. If only few ships call at the ports, the costly investment becomes inefficient. A comparison of ports' operating cost shows that serving 18,000 TEU vessels is 17% more expensive than serving 4,000 TEU ones (Saanen, 2013).

5.6 Conclusions

The world container ship fleet has been continuously enlarged. In line with the enlargement, new ship generations have been launched, especially since the 1990s. Empirical analysis has been carried out to evaluate effects of capacity expansion and ship size growth on financial results of CSLs in the period 1997-2012. New capacity will help CSLs to get more revenue, but at lower percentage points than capacity growth. Unit revenue will go down as a result of diminishing revenue. In terms of cost, scale economies make total cost increase at lower level than capacity; consequently unit cost becomes smaller. There is no evidence of the effect of ship size growth on the financial indicators.

The regression models reveal the decrease of total and unit cost as a consequence of the upturn in vessel capacity, but the statistical results are not strong enough to confirm the trend. Additionally, it is possible to realize positive influence of slot utilisation level, market freight rate and negative influence of oil price on financial results of CSLs.

The increase of CSLs' transportation volume is highly positive correlated with their capacity expansion. Nevertheless the growth rate of the former is smaller than that of the latter, which results in diminishing revenue. Furthermore, total cost also moves up in tandem with capacity expansion, even with higher pace. Practices from the industry indicate that growth of total cost has been higher than that of total revenue, which caused decline of CSLs' total and unit profit. Economies of scale of fleet and ship size have been outweighed by the upswing of oil price and low slot utilisation. The former factor is objective and out of control of CSLs, whereas the latter one partly stems from their aggressive fleet investment leading to over-capacity.

There is no doubt about scale economies of large container ships on sea leg. Nevertheless, in addition to shipping cost, other factors should be taken into consideration. Port cost, inventory cost and transhipment/inland transportation cost could increase in line with the expansion of ship capacity. More expenses will be paid not only by CSLs, but also port operators and shippers. CSLs also face with more risks in their operation, especially under-utilisation of slots which will make scale diseconomies of ship size.

Chapter 6: Literature survey of network optimisation in container liner shipping[7]

Hightlights:

- Classification of network optimisation studies

- Trends in optimisation studies

6.1 Introduction

Network optimisation plays a crucial role in positioning shipping lines' competitive advantage. Various network decisions must be determined to make optimal liner operation. The combination between different ports establishes the infrastructure of shipping industry. On such a system, vessels are deployed under specific routes with pre-determined ports, schedule and service frequency. It is necessary to arrange reasonable movement of containers among possible routes in order to take full advantage of ship size, port coverage and connection between different services. Christiansen et al. (2004) classify different levels of optimal decisions in liner shipping: route and schedule design, fleet size and mix at strategic level, fleet assignment at tactical level, cargo booking at operational level.

Ronen (1983, 1993) and Christiansen et al. (2004, 2007) provide pioneer papers regarding status of ship routing and scheduling in maritime transportation, including tramp, industrial and liner shipping. Christiansen et al. (2013) continue the series to take account of literature in the new millennium. Also based on decision-making levels as Christiansen et al. (2004, 2007, 2013), Meng et al. (2013) review studies related to the optimal problems in liner shipping. Kjeldsen (2011) develops a classification scheme consisting of 18 characteristics for the problems of ship routing and scheduling in liner shipping. 24 articles are selected to be classified by the new scheme.

These works have inspired us to do a deeper research concerning network optimisation literature in container liner shipping, especially in the context of more dynamics and change of the shipping market. We only select a branch of maritime transportation to do a survey. Tramp shipping, industrial shipping as well as break-bulk liner shipping are out of our scope. Instead of approaching optimal studies by the levels of decision, we focus on three major categories of container shipping network: container routing, fleet management and network design. Container routing is related to optimal flow movement of laden and empty boxes. Fleet management is involved with optimal

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decisions of ship assignment and scheduling. Network design is the problem of choosing ports and combining them to create the infrastructure of shipping operation.

In this chapter, problems of network optimisation in container liner shipping will be classified and reviewed into three key categories: optimal routing of container flow (Section 6.2), efficient fleet operation (Section 6.3) and optimal design of liner network (Section 6.4).

6.2 Container routing

How to transport containers economically in a sophisticated network is an intricate question in liner shipping. Different from the cargo routing problem in tramp shipping or general cargo shipping, that in container shipping is related to a large number of shipments, various pick-up and delivery points, many routing options, strict schedule of service and high potential of exchange containers between different services. Additionally the repositioning of empty containers is exclusive of container shipping and contributes greatly to the complexity of the routing problem.

The basic question of container routing is to find an optimal plan of box movement in given shipping routes to satisfy transportation demand between ports under constraints of fleet capacity and operation. The containers can be full of cargo to deliver to customers, or can be empty to overcome imbalance between export and import flows in some ports, or can include both full and empty boxes. To be confronted with box shortage, empty container inventory policy can be incorporated into the routing problem. The policy includes decisions of leasing and storing containers, thresholds to export and import empty containers. Transportation option can be restricted with merely one route or in the context of multiple routes. In the latter case, optimal container routing will not only include route selection but also possibly combine different routes through transhipment operation to make optimal container routing. Shipping demand is often in the form of origin-destination traffic between ports pairs. It can be fixed under deterministic condition or fluctuated under stochastic condition. Finally an allocation plan can deal with a single period or multiple periods. In the latter case, it is involved with many parameters and states of container allocation.

6.2.1 Container routing in a single period

Optimal containership slot allocation in a pre-defined route to maximize profit is addressed by Feng and Chang (2008b), Ting and Tzeng (2004) and Lu et al. (2010a,b). The problem here is to allocate enough space for cargo in exchange of freight as well as select profitable shipment, whereas ensure the constraint of ship capacity. Feng and Chang deal only with the movement of laden containers on an Intra Asia route. More sophisticatedly, Ting and Tzeng and Lu et al. (2010a,b) consider that of empty containers to overcome the shortage in some ports, together with laden container flow. The former is illustrated on a long haul Far East – Europe route while the two latter are applied on a short haul Intra – Asia.

Song and Dong (2009) also study optimal flow of loaded and empty boxes in a single service. Their model aims to minimize cost, instead of profit, of container transportation. Penalty cost, caused by lost demand, is taken into consideration. Two policies of container flow balancing to tackle the empty repositioning problem are established. One is based on port-to-port balancing; another is based on coordinated balancing in a whole service. Numerical examples indicate the outperformance of the latter strategy over the former.

Another work to optimise ship slot is carried out by Zeng et al. (2010). They introduce the principle of equilibrium which reflects a reasonable distribution of containers among visited ports and full utilisation of containers. It is the basis for them to develop a deterministic model to optimize container allocation. The model is then expanded into a robust optimisation model which takes into account uncertain factors, model robustness and risk preference of decision makers to approach closer to actual practice.

Transhipment is an important operation of liner shipping. It can only take place when putting container movement in the network including diverse routes. Bell et al. (2011) propose a model to optimise container movement with the support from transhipment operation. Its objective is to minimize total sailing time and container dwell time at ports whereas make sure container balance thanks to the repositioning of empty ones. Zurheide and Fischer (2012) also take advantage of transhipment practice in the industry, together with high freight segmentation and booking cycles, in the use of revenue management methods in slot allocation management. A 4-level model is set up to determine storing/leasing containers at port, to allocate different container types and service segments, to select routes and ships to transport containers and to exchange containers between different services. Almost network models concentrate on one or several specific areas, Song et al. (2005) can be an exception with a model to solve a global problem of container flows. A cost-efficiency network of container shipping worldwide is figured out to optimize container flows. The first priority is to maximize transportation volume, and the second is to minimize the total shipping cost.

Hsu and Hsieh (2005, 2007), Lee et al. (2006) and Wang et al. (2013) develop models to optimize container routing between pick-up and delivery points. Hsu and Hsieh (2005) determine whether cargo from an origin port should be transhipped or carried directly to a destination. Pareto optimal solutions of different routes are found based on trade-off between shipping cost and inventory cost. Thanks to the solutions, the best route for a shipment is indicated. The two-objective model is enhanced and generalized in the later work (Hsu & Hsieh 2007). Sensitive analyses are made in the later one to study the effect of charges and efficiency of a hub port on routing decision. Lee et al. (2006) develop a multi-commodity flow model to optimize laden container routing from door to door. The model is to analyse container flows within the Asia-Pacific network as well as to predict variations of cargo flows among Asian ports with respect to port turnaround time, terminal handling charge, and land link efficiency. One salient feature of this model is the separation of container flow by commodities which can give more precise evaluation of inventory cost. Wang et al. (2013) provide the first work to consider container routing in the context of maritime cabotage. An integer binary linear programming model is formulated to generate container paths between two ports satisfying the constraints of maritime cabotage as well as transit time and cost. The application on the route between Shanghai and San Pedro demonstrates the impact of transit time constraint, cabotage and transhipment policy on the number of viable paths between the two ports.

Only dealing with empty container, Song and Carter (2009) study the influence of different route coordination and container sharing mechanisms between shipping lines on empty box movements. Thanks to these cooperation strategies, shipping lines can benefit from lowering total costs of empty container repositioning at different levels. Chao and Yu (2012) formulate a model to solve the problem of empty container repositioning for a Taiwanese shipping line in East and North China ports. Empty boxes can be reallocated through mainline vessels or owned feeder vessels of the shipping line as well as vessels of other operators. Additionally, the shortage of containers in ports can be compensated by reasonable storing and leasing options.

Table 6-1: Summary of literature on container routing in a single period

Author	Container flow	Objective	Route	Market	Remarkable factor
Bell et al. (2011)	Full	Min container sailing and dwell time	Multiple	Deterministic	
Chao & Yu (2012)	Empty	Min cost	Multiple	Deterministic	Storing/leasing boxes
Feng & Chang (2008b)	Full	Max profit	One	Deterministic	Container type, demand range
Hsu & Hsieh (2005, 2007)	Full	Min cost	Multiple	Deterministic	Inventory cost, transshipment vs. direct call
Lee et al. (2006)	Full	Min cost	Multiple	Deterministic	Inland link, door-to-door traffic
Lu et al. (2010 a,b)	Full + Empty	Max profit	One	Deterministic	Container type
Song & Carter (2009)	Empty	Min cost	Multiple	Deterministic	Route coordination and container sharing mechanisms

Song & Dong (2009)	Full	Min cost	One	Deterministic	Empty box repositioning policy, lost-sale penalty
Song et al. (2005)	Full + Empty	Max shipping volume; Min cost	Multiple	Deterministic	World-wide network
Ting & Tzeng (2004)	Full + Empty	Max profit	One	Deterministic	Container type, demand range
Wang et al. (2013)	Full	Min cost	Multiple	Deterministic	Maritime cabotage, cost and time constraint
Zeng et al. (2010)	Full + Empty	Max profit	One	Stochastic	
Zurheide &Fischer (2012)	Full + Empty	Max profit	Multiple	Deterministic	Container type, flow segmentation, weekday traffic, storing/leasing boxes

6.2.2 Container routing in multiple periods

In multiple periods, container routing problem is not only deal with parameters of origin and destination but also time of demand. Time-space network is often the base to solve the problem. Olivo et al. (2005) and Zambuzi and Cunha (2010) address empty container management in multimodal networks. Both models are to make optimal decisions about transporting, storing and leasing empty containers every time period. The former model chooses the hour as time-period whereas the latter one selects the day.

Optimal shipping of full and empty containers in multiple periods and multiple routes is studied by Wang and Tang (2010), Lofstedt et al. (2011) and Song and Dong (2012). In addition to box transportation, Wang and Tang are involved with leasing strategy of containers in order to maximize profit in the context of stochastic market. Lofstedt et al. suggest two approaches to solve the multi commodity problem, an arc flow formulation and a path flow formulation. The latter approach is able to solve a huge case with more than 200 ports and is proved to outperform the former one, even for very small case. Song and Dong limit the transportation of laden containers between origin and destination ports of at most three service routes. Another remarkable factor in their model is the use of demand backlog, by which unsatisfied demand in a period can be served in the next one.

Stochastic situation of the market is taken into account in the models of empty container allocation by Cheung and Cheng (1998), Lam et al. (2007), and Francesco et al. (2009, 2013). Cheung and Cheng formulate the multiple period problem of empty container relocation as a two-stage model. In the first stage, parameters such as supply, demand and ship capacity for empty containers are deterministic whereas in the second ones, they are random variables. The objective is to maximize the total of the first stage profit and the second stage expected profit. Lam et al. (2007) are not dependent on the time-space network as others to solve the empty repositioning problem, but dynamic programming (DP). A dynamic stochastic model for a simple two-port two-voyage system is proposed first; then expanded into a realistic multi-port multi-voyage system. A DP algorithm can be applied to find an optimal result, but it is limited to a case with a limited number of inventory states in each period. Therefore, a simulation-based approximate DP is developed to obtain approximate optimal solutions. Francesco et al. (2009) establish deterministic and stochastic optimisation models to study empty container repositioning in the Mediterranean Sea. The former one is proved to be only appropriate in case of perfect information while the latter, a multi scenario model based on expert opinions, can cope well with uncertainty of container flow. Francesco et al. (2013) study the movement of empty containers under two cases of port disruption. One is partial disruption caused by the standstill of berth operation. Another is complete disruption caused the collapse of both berth operation and inland operation.

The dual problem of empty container inventory and container movement has been carried out in some researches. Basically, inventory policy is related to determine thresholds to import or export empty containers. Hay et al. (2007) approach empty container allocation problem at both operational level and strategic level. On the operational level, a model based on time-space network is developed to make conventional decisions of loading, unloading and storing empty containers. Penalty costs, caused by lost demand, are also measured. On the strategic level, a gradient search algorithm is applied to determine an optimal threshold of empty container stock. Dong and Song (2007) and Song and Dong (2008) develop three-phase threshold policies considering demand uncertainty and dynamic operations. The policies aim to reposition empty containers in order to minimize the total costs consisting of inventory holding cost, penalty cost and transportation cost. The former model (Dong & Song 2007) uses a grid parameter search method to find threshold values whereas the latter one (Song & Dong 2008) is based on the balance between export and import flows at ports. Simulations in different instances reveal cost advantage of both policies over other heuristic ones. Based on threshold values, Song and Dong (2011) compare two empty container strategies, determined destination port policy (DDP) and flexible destination port policy (FDP). Under DDP, the unloading ports of empty boxes are determined before they are loaded onto a vessel whereas under FDP, the ports are not specified in advance and the empty ones are loaded when needed. The experiments reveal that the former policy outperforms the latter one in case of balanced trade; inversely, the latter is better. Feng and Chang (2008a) address the two-phase problem of empty container repositioning planning for Intra-Asia routes. The upper problem is to identify safety stock at each port whereas the lower problem solves the conventional container transportation problem by linear programming.

Table 6-2: Summary of literature on container routing in multiple periods

Author	Container flow	Inventory policy	Objective	Route	Market	Remarkable factor
Cheung & Cheng (1998)	Empty	Leasing	Max profit	One	Stochastic	
Dong & Song (2007)	Full + Empty	Threshold policy	Min cost	One	Stochastic	Lost sale penalty, inventory cost
Feng & Chang (2008a)	Empty	Safety stock	Min cost	Multiple	Deterministic	Container type
Francesco et al. (2009)	Empty		Min cost	One	Stochastic	
Francesco, et al. (2013)	Empty		Min cost	Multiple	Stochastic	Port disruption
Hay et al. (2010)	Empty	Threshold policy, storing	Min cost	Multiple	Deterministic	Penalty cost
Lam et al. (2007)	Empty	Leasing	Min cost	One	Stochastic	Inventory cost, penalty cost
Lofstedt et al. (2011)	Full + Empty	Leasing	Max profit	Multiple	Deterministic	Rejected demand
Olivo et al. (2005)	Empty	Storing/Leasing	Min cost	Multiple	Deterministic	Container type, hourly period
Song & Dong (2008)	Full + Empty	Threshold policy	Min cost	One	Stochastic	Lost sale penalty, inventory cost
Song & Dong (2011)	Full + Empty	Threshold policy	Min cost	One	Stochastic	Penalty cost, inventory cost
Song & Dong (2012)	Full + Empty		Min cost	Multiple	Deterministic	Inventory cost, demurrage cost, demand backlog cost
Wang & Tang (2010)	Full + Empty	Leasing	Max profit	Multiple	Stochastic	Three day period
Zambuzi & Cunha (2010)	Empty	Storing/Leasing	Min cost	One	Deterministic	Container type, daily period, ship schedule constraint

6.3 Fleet management

Fleet management is critical to any shipping lines since vessels are their most costly asset. A triple E series of 10 x 18,000 TEU ships of Maersk Line is worth $1.9b. Daily time charter rate of a 4,250 TEU vessel was $17,775 in 2010 and much higher $33,375 in the prosperous year 2007 (Drewry 2011a). On the one hand, operators must ensure enough capacity to carry goods in exchange of freight rate; on the other hand, they must care about operating costs as well as constraints of their fleet.

There are various decisions in the realm of fleet management. A typical decision is to assign given vessels into pre-defined shipping routes in order to serve sea transportation demand. Purchasing new or second hand vessels is to recruit new capacity. Type and number of ships must be allocated accurately to be compatible with operational and traffic situation. Adequate ships should be supplemented through chartering market to supplement the carrying capacity in case of high demand whereas leasing should be applied to lighten cost burden in case of over-capacity. Frequency must follow the market norm or customer requirement; on the other hand, it should be in balance with fleet capability. Scheduling is related to temporal aspect of ship operation, especially time plan in ports such as arrival or departure time. Optimal scheduling is definitely an important factor which decides the competitive advantage of shipping service. Operating speed directly impacts on ship schedule; on the other hand it is closely involved with operating cost.

6.3.1 Ship deployment

Claessens (1987) proposes a linear programming model to allocate ships on potential routes. Not only does it concern with ship cost but also penalty cost because of skipped cargoes. Perakis and Jaramillo (1991) develop a model to minimize the total of operating cost and lay-up cost. While the model of Claessens merely considers traffic demand on route, that of Perakis and Jaramillo considers more detailed port-to-port demand on route. Additionally ship-route compatibility is also taken into consideration in their model. The model is implemented by Jaramillo and Perakis (1991) based on the fleet and routing data from a liner company. A drawback is the number of ships allocated in routes in some cases is non-integer numbers, so it requires the rounding of these figures which makes deviate final results. Afterwards the rounding error is eliminated by an integer programming model of Powell and Perakis (1997).

Gelareh and Meng (2010) deal not only with assignment and lay-up decisions, but with chartered-in and out decisions as well. Their model aims to optimally allocate ships among candidate routes and formulate the route frequency whereas ensure the time window constraints of shipments. Afterwards the model is revised by Wang et al. (2011) in order to make realistic the voyage number of ships in planning horizon as well as improve computational efficiency.

Traffic uncertainty in the fleet planning problem is investigated by Meng and Wang (2010). Volatility of customer demand is taken into account by setting the constraint which guarantees that liner services will satisfy transportation requirement at predetermined probability or customer service level. Two sensitive analyses are carried out to see impacts of cargo shipment demand and customer service level on total cost. One reveals that higher cargo demand will lead to more cost in order to keep the same level of service. Another expresses the growing tendency of total cost when customer service level goes up.

Specializing in ship assignment for a hub and spoke (H&S) network in Portugal, Mourao et al. (2001) put their model under constraints of ship schedule in two scenarios. One is to allocate ships with the pre-determined number of voyages per year. Another is not only to deal with ship assignment but to determine optimal number of operating voyages as well. A marked feature in the model is the inclusion of inventory carrying cost caused by waiting time of cargo between feeder and mainline transportation. Zacharioudakis et al. (2011) establish a non-linear programming model to assign ships as well as calculate corresponding operating speed on given main routes and feeder routes. A heuristic approach, based on genetic algorithm, is proposed to find solutions for the problem. The model is then employed to choose optimum fleet strategy for a sub-network of APL including one Transpacific and three Intra-Asia feeder routes.

Global alliances have played a strategic position in liner shipping. Nevertheless, only few models have been proposed to deal with alliance fleet. In the model of Cariou and Haralambides (1999), all ships of shipping lines are put in the same pool and allocated in order to maximize revenue. Two incentives for capacity pooling are shown, one is the enhancement of service frequency; another is the expansion of service coverage. Cariou (2002) assigns vessels to minimize total cost with the constraint of service frequency. Two computations are undertaken. One is with independent allocation of carrier fleets; another is with allocation of alliance fleets. The results indicate cost advantage of shipping alliances over independent carriers. Furthermore, the second case employs a smaller number of ships than the first one. The cost and ship savings are explained by the broader choice of operators to allocate the most economic and suitable ships.

Most of studies in respect of fleet management deal with short-term period. Xie et al. (2000) approach fleet planning in long-term period in two steps. The first step is to divide a long-term period into short-term ones. In each short-term period, different states are identified; then optimal planning corresponding with each state is defined thanks to a linear programming model as the conventional fleet assignment problem. In the second step, a dynamic programming model is used to select a suitable state in each short-term period so that the present value of total cost is minimized. Another research to deal with multiple periods is by Meng and T. Wang (2011). Similar to Xie et al., they divide the long-term problem into various phases. However, their objective function is different from the previous work whereby they try to maximize present value of profit. Furthermore container routing is combined with fleet management in their formulation. The model is applied in a 10 year period, so different optimal strategies of fleet deployment can be realized. The long-term instance indicates the superiority of purchasing over chartering which cannot observe in short-term.

Some authors have approached the dual problem of fleet assignment and container routing in known shipping routes. Chen et al. (2007) plan optimal fleet assignment and flows of laden and empty containers to satisfy transportation demand between origin and destination ports in multiple periods. Liu et al. (2011) formulate a two-level model to deal with the two problems separately, the first level is to determine optimal flow of both full and empty boxes, and the second is to choose optimal ship deployment based on results from the previous work. Additionally a joint model is established to solve the dual problem simultaneously. The calculation indicates that the joint consideration of the two problems benefit operators from higher capacity utilisation and profitability.

Wang and Meng (2012a) emphasize the importance of transhipment in liner shipping. In addition to fleet decisions such as ship deployment, chartered in and out tonnage, their model allows container transhipment at any port and any number of times. Traffic demand is not limited between port pairs on the same route, but between those on the whole network. Numerical experiments demonstrate that 17-22 ports out of 46 ports in the application carry out transhipment operation. Another work is done to address the dual problem by Meng and Wang (2012). Time space network is applied to generate container routes satisfying transit time constraint between ports. Then optimal fleet assignment is found by using global optimisation algorithm. Wang (2013) takes account of novel factors such as slot purchasing, container type, empty container and ship repositioning in tackling the dual problem.

Wang and Meng (2010) and Meng et al. (2012) solve the joint problem of fleet assignment and container routing under demand uncertainty. Unlike Meng and Wang (2012), their processes start by optimizing fleet decision; then determine container flow between port pairs in order to maximize profit. Whereas the fleet of Wang and Meng is fixed, that of Meng et al. is more flexible by allowing chartered-in and out tonnage.

6.3.2 Ship scheduling

Ting and Tzeng (2003a,b) design optimal vessel speed, berth time and departure time, and port operation in order to satisfy berth time window constraint, including both hard and soft windows, by using a dynamic programming model. The models are mainly based upon time variation without comparing cost difference between options. In practice, operators hesitate to increase vessels' speed so as to keep the schedule because of significant increase in fuel costs.

Qi and Song (2012) optimize speed in different sea legs to minimize fuel consumption cost and vessel delay cost. Their formulation is put in the context of port uncertainty and service level constraint. In practice of slow steaming in liner industry, Cheaitou and Cariou (2012) propose a model to optimize speed in a service between Northern Europe and East Coast of America. Numerical studies show the inappropriateness of slow steaming in case of time-sensitive cargo. Hvattum et al. (2012) provide an exact algorithm to calculate optimal speed on a route with a fixed sequence of port calls and associated time window.

Meng and Wang (2011a) study optimal operating strategy for a single Asia-Europe route. They try to optimize sailing speed, service frequency together with specific type of ship in operation. An efficient and exact branch-and-bound based-ε optimal algorithm is utilized to find the solution. Wang and Meng (2012d) calibrate the relation between sailing speed and fuel consumption. The regression analysis indicates that it is approximate to third power relationship. Using the estimation, a mixed integer non-linear programming model is formulated to optimize sailing speed per leg, select appropriate number of deployed ships and shipment routes. Solving the same questions as Wang & Meng (2012d), Wang et al. (2013a) take account of demand elasticity. In their model, shipment demands are not static, but vary with transit time from their origin to destination ports. Wang et al. (2013b) review critically methods to optimize operating speed and deployed ships under constraint of transit time as well as analyze both advantages and disadvantages of each existing method. Some novel optimisation algorithms are introduced to tackle the problem efficiently.

Yao et al. (2010) establish a planning level optimisation model to select optimal ship speed, bunker ports and bunker inventory under constraints of port arrival time windows. The objective is to minimize total bunker cost for a single shipping liner service. Yao et al. (2012) expand the model to embrace revenue loss because of the weight of bunker inventory in the ship. Sheng et al. (2013) develop further by incorporating stochastic nature of bunker price and consumption into their formulation. Concerned with the same research question as these works, yet Kim et al. (2010) not only take account of bunker cost, but also ship cost and especially environmental cost regarding greenhouse gas emission.

Disruption has become a major concern in liner shipping, which can be caused by bad weather condition, port congestion, and ship breakdown. Based on disruption management work from airline industry, Brouer et al. (2012) propose a model to make decisions of liner vessel schedule recovery. They consist of adjusting vessel speed, omitting a port call and swapping order of calls. Practical instances from Maersk Line are applied to try the model. Wang and Meng (2012b) design a robust schedule to hedge against port uncertainty due to congestion and fluctuation in handling operation. A sample average approximation method is employed to calculate number of deployed ships, start handling time and target arrival time in order to balance the trade-off between ship cost, bunker cost and late start handling cost. Wang and Meng (2012c) optimise ship schedules for several routes in the same shipping network to confront with both port and sea uncertainty. Maximum allowable transit time between ports is considered as well. Two models are proposed to solve the problem. The first one is to calculate optimal speed and bunker consumption at sea whereas the second is to choose ship arrival time and number of deployed ships so as to minimize ship cost and expected bunker cost.

Yan et al. (2009) question the use of trial-and-error process in liner industry to solve efficiently the dual problem of ship schedule and container routing. The time-space network technique is utilised to construct a viable model for such activities of a Taiwanese shipping line. Wang and Meng (2011) pay more attention to transhipment operation for the dual problem, so both transhipment cost and time are put in their model. Different from the model of Yan et al. which aims to minimize total operating shipping cost, that of Wang and Meng tries to minimize transhipment cost and penalty cost caused by longer transit time.

Table 6-3: Summary of literature on fleet management

Author	Main question	Objective	Route	Market	Remarkable factor
Brouer et al. (2012)	Schedule recovery decision	Min cost	One	Deterministic	Penalty cost, berth time window
Cariou & Haralambides (1999)	Assi|num|voy	Max profit	Multiple	Deterministic	Liner alliance, market share restriction
Cariou (2002)	Assi|num	Min cost	Multiple	Deterministic	Liner alliance, frequency constraint
Cheaitou & Cariou (2012)	Spd	Max profit	One	Stochastic	Slow steaming vs. time sensitive cargo
Chen et al. (2007)	Num|cont	Min cost	One	Deterministic	Multiple periods, inventory cost
Claessens (1987)	Assi|voy	Min cost	Multiple	Deterministic	Penalty cost
Gelareh & Meng (2010); Revised by S.Wang et al. (2011)	Assi|num|charter|voy|freq|sche	Min cost	Multiple	Deterministic	Transit time constraint
Hvattum et al. (2012)	Spd	Min cost	One	Deterministic	Time window in ports
Kim et al. (2010)	Spd + bunker port + bunker inventory	Min cost	One	Deterministic	CO_2 tax, inventory cost of fuel
Liu et al. (2011)	Assi|cont	Max profit	Multiple	Deterministic	
Meng & Wang (2010)	Assi|num|voy|charter|freq	Min cost	Multiple	Stochastic	
Meng & Wang (2011a)	Assi|num|freq|sche|spd	Min cost	One	Deterministic	Transit time constraint
Meng & Wang (2011b)	Assi|num|charter|cont|voy + ship investment/scrap	Max profit	Multiple	Deterministic	Multiple periods
Meng & Wang (2012)	Assi|cont|sche	Min cost	Multiple	Deterministic	Transit time constraint
Meng et al. (2012)	Assi|num|charter|cont|voy	Max profit	Multiple	Stochastic	

Mourao et al. (2002)	Assi|num|voy	Min cost	Multiple	Deterministic	Inventory cost, H&S network, schedule constraint
Perakis & Jaramillo (1991); Jaramillo & Perakis (1991); Powell & Perakis (1997)	Assi|num|voy	Min cost	Multiple	Deterministic	Ship-route compatibility
Qi & Song (2012)	Sche|spd	Min cost	One	Stochastic	Delay cost
Sheng et al. (2013)	Sche|spd + bunker port + bunker inventory	Min cost	One	Stochastic	Port time window, bunker price discount
Ting & Tzeng (2003a,b)	Sche|spd	Min variation time	One	Deterministic	Berth time window constraint
Wang (2013)	Assi|num|voy|cont	Min cost	Multiple	Deterministic	Container type, slot purchasing, box& ship repositioning
Wang & Meng (2010)	Assi|cont	Max profit	Multiple	Stochastic	
Wang & Meng (2011)	Sche|cont	Min cost	Multiple	Deterministic	Penalty cost, bonus, transit time constraint
Wang & Meng (2012a)	Assi|num|charter|cont	Min cost	Multiple	Deterministic	Ship-route compatibility
Wang & Meng (2012b)	Sche|num	Min cost	One	Stochastic	Penalty cost
Wang & Meng (2012c)	Sche|spd|num	Min cost	Multiple	Stochastic	Transit time constraint
Wang & Meng (2012d)	Spd|num|cont	Min cost	Multiple	Deterministic	
Wang et al. (2013a)	Spd|num	Min cost	One	Deterministic	Transit time constraint
Wang et al. (2013b)	Spd|num|cont	Max profit	One	Deterministic	Demand elasticity
Xi et al. (2000)	Assi|num + ship investment /scrap	Min cost	Multiple	Deterministic	Multiple periods
Yan et al. (2009)	Sche|cont	Min cost	Multiple	Deterministic	
Yao et al. (2010)	Sche|spd + bunker port + bunker inventory	Min cost	One	Deterministic	Port time window, bunker price discount
Yao et al. (2012)	Sche|spd + bunker port + bunker inventory	Min cost	One	Deterministic	Impact of bunker inventory on revenue, Port time window, bunker price discount
Zacharioudakis et al. (2011)	Assi|charter|sche|spd|freq	Min cost	Multiple	Deterministic	H&S
Assi: ship assignment; Num: Number of deployed ships; Voy: number of ship voyage; Charter: charter –in or out decisions; Freq: service frequency; Sche: ship schedule; Spd: operating speed; Cont: Container routing					

6.4 Network design

Network design is the problem of how to select ports and combine them economically to create an infrastructure for shipping operation. On the one hand it is the matter of market coverage; on the other hand it impacts on the efficiency of shipping operation. In the sub section, we start by introducing optimal problems in a single route (6.4.1). Then the works to deal with multiple routes are reviewed in the next part (6.4.2). Lastly the hierarchical system in container shipping, the hub and spoke, is mentioned (6.4.3).

6.4.1 Optimal single route

A ship route consists of a series of visited ports. Optimal routing is involved with the choice of proper visited ports and reasonable sequence of ports of call so that carriers can service transportation demand between ports as much as possible, fully utilize ship capacity and ensure constraints of ship operation in terms of time and nautical conditions.

Gilman and William (1976) examine the possibility of adding a UK port, in addition to Southampton, on a North Atlantic liner route. In case of high proportion of traffic, around two thirds of European traffic, is generated by the UK market, an additional port will be favourable because of significant decrease in inland transport cost. Also studying on a North Atlantic route, Pearson (1988) evaluates the effect on total cost of switching from Southampton to either Tilbury or Felixstowe. Suffering from longer sea distance, but superior handling performance of the two latter ports leads to their savings in port time, in turn their maritime cost advantage over Southampton. Nevertheless when inland transport cost is considered, only Tilbury remains cost advantage. Although the option of Felixstowe is the most beneficial in respect of maritime cost thanks to its supreme handling rate, long distance from hinterland makes it less competitive.

Boffey et al. (1979) try to optimize ship voyage and time schedule so as to maximize revenue under transit time constraint between ports. The best route is selected thanks to a hill climbing heuristic method. A strange point is that the model takes only freight revenue into consideration. Transportation cost, which is often a key parameter of optimisation models, is omitted in the research.

Rana and Vickson (1988) formulate a model to choose ports of call and their sequence on inbound and outbound trips between two pre-determined ports, together with the number of containers transported between port pairs and voyage time. Chu et al. (2003) tackle more or less the same problem and apply their model on a Trans-pacific route.

Shintani et al. (2007) establish a two-stage problem to address the design of liner route by taking empty container repositioning into consideration. The lower problem is to identify optimal sequence of port calls for a specific group of visited ports. The upper problem, a knapsack problem, is to select the best set of calling ports with the highest profit. The two-stage problem is solved by a genetic algorithm which is proved to be able to attain optimal results in this case. Chao and Zeng (2010) follow more or less the same procedure as Shintani et al. in the optimal routing problem. The new development is that the latter model is put in the context of changing demand and freight rates. Additionally, optimal policy of container inventory is considered in the model.

With global warming, the Northern sea route passing through the Artic Ocean has been seen as a possible sea lane to transport cargo between Asia and Europe. Verny and Grigentin (2009) approach the feasibility of container shipping on the route. Compared with the Royal route, a traditional route passing the Suez Canal, the new one has an advantage of shorter distance. Nevertheless tough operating conditions make higher operating costs for this route and make it less competitive than the traditional one.

Chuang et al. (2010) discuss the uncertainty of container traffic demand. They propose an approach combined by fuzzy sets theory and genetic algorithm to find an optimal course of container vessels in the context of volatile market. The first one is to deal with traffic fluctuation whereas the second is to solve conventional optimal routing problem in liner shipping.

Cariou and Cheaitou (2012) provide a comprehensive formulation of shipping cost including daily fixed cost, container depreciation cost and bunker cost of both main and auxiliary engines. In addition to, the number of reefer containers is taken into consideration to calculate bunker cost precisely. The cost model is the basis to compare two route options on trade between Northern Europe and East Coast of South America. One is a direct connection or end – to – end pattern, another is to re-route through Tangier (Morocco) on northbound voyage which can be seen as triangle pattern. The latter option can become more profitable if there are significant amount of transhipment containers at the Mediterranean port.

Yang et al. (2012) pay attention to the interactions between container liner services and transportation demand in ports. Based on initial demand, optimal shipping route and container slot allocation are determined. In turn, they will adjust captive traffic of ports. The iteration takes place until equilibrium is reached between cargo demand in ports and shipping service scheme.

Tran (2011) views shipping operation as a component of global supply chain. Therefore the optimal routing problem goes beyond the sea side and includes also the land side. The model solves three matters: ports of call, the sequence of selected ports, and loading/unloading ports for each shipment. Its objective is to minimize total cost including ship cost, port tariff, inland transport cost and inventory cost. The research emphasizes the influence of logistics factors on the decision of port choice.

Table 6-4: Summary of literature on optimal single route

Author	Main question	Objective	Market	Remarkable factor
Boffey et al. (1979)	Rout|sche|cont	Max revenue	Deterministic	Transit time constraint
Cariou & Cheaitou (2012)	Rout	Min cost	Deterministic	Triangle route
Chao and Zeng (2010)	Rout|cont	Max profit	Stochastic	Container inventory policy,
Chuang et al. (2010)	Rout	Max profit	Stochastic	
Chu et al. (2003)	Rout|voy|cont	Max profit	Deterministic	
Gilman & William (1976)	Rout	Min cost	Deterministic	Diversion distance
Pearson (1988)	Rout	Min cost	Deterministic	Diversion distance, inland transport cost
Rana & Vickson (1988)	Rout|voy|cont	Max profit	Deterministic	
Shintani et al. (2007)	Rout|cont	Max profit	Deterministic	Empty container repositioning
Tran (2011)	Rout|cont	Min cost	Deterministic	Inland transport cost, inventory cost, door-to-door traffic
Verny & Grigantin (2009)	Rout	Min cost	Deterministic	Artic route
Yang et al. (2012)	Rout|cont	Max profit	Deterministic	Interaction between transport demand and shipping service scheme
Rout: ship routing; Voy: number of ship voyage; Cont: container routing; Sche: ship schedule				

6.4.2 Optimal multiple routes

In dealing with optimal multiple routes, problems are subjected to bigger solution space. Additionally interaction between routes through transhipment operation makes the problems more complicated. In the group, models are often combined to solve the dual problem of optimal routing and optimal fleet operation. In some cases, they include also the problem of container routing.

Lane et al. (1987) present a dynamic cost-based model for providing liner services to serve some trade routes with the aim to minimize total costs of operating cost, port cost and inventory cost. Firstly, the model enumerates all possible voyages based on combinatorial algorithm. Secondly, a heuristic approach is employed to allocate ships economically for each voyage option, together with their time schedule. Thirdly, the most efficient fleet composition is selected by using previous cost estimation for each voyage option.

Cho and Perakis (1996) suggest the concept of flow-route incident matrix which is used very efficiently in two optimization models. The first is a linear programming model of profit maximization which can be used to select routes and service frequencies under fleet constraints. The second is a mixed integer programming model with binary variables involving new ship investment to meet expected increasing demand in some ports. A limitation is both models are only theoretical without application, so it is impossible to fully recognize their efficiency.

Fagerholt (1999) considers the problem of deciding weekly liner routes as a multi-trip vehicle routing problem. Three phases are proposed to solve this problem. Phase 1 generates all feasible routes together with their duration and cost for each ship by using Travelling Salesman Problem. Phase 2 combines single routes into multiple routes. Phase 3 applies integer programming to choose optimal routes, either single routes or multiple routes, in the constraint of fleet with the objective to minimize total transportation cost and to ensure all ports are served. Fagerholt (2004) combines Phases 2 and 3 into a single phase. In these works, one ship can serve more than a single route which is quite different from other ones.

Kuroda et al. (2005) study network optimisation by taking supply-demand interaction into consideration. A Nash-equilibrium-based competition model is formulated by assessing behaviour of both carriers and shippers. On the one hand, carriers try to optimize routing networks among ports, including service frequency and ship size, so as to minimize their operating cost. On the other hand, shippers aim to minimize their transportation and inventory carrying cost by choosing appropriate loading and unloading ports. Similar to Tran (2011), their optimal solution is determined not only by maritime-related parameters but also by inland-related ones.

Takano and Arai (2011) consider impact of empty container repositioning on designing optimal network. Genetic algorithm and linear programming calculation are combined in their model to optimise network design. The former one is deployed to generate candidate sets of shipping routes, whereas the latter is used to optimise flows of laden and empty containers between ports based on the generated sets of routes.

Some recent researches have paid attention to transhipment between services, so they are related to not only optimal network and fleet assignment, but also container routing through the selection of transhipment points. Reinhardt et al. (2007) formulate a mixed integer linear programming model to solve the network design and fleet assignment problem with the consideration of transhipment between routes. Weekly frequency, weekday constraints of shipments and container transhipment is incorporated in the work of Agarwal and Ergun (2008). A greedy heuristic, a column generation-based algorithm and two-phase Benders decomposition-based algorithms are tried to solve the problem and compared in terms of solution quality and computational time. A shortcoming is the lack of transhipment cost in the model, so optimal options could be impacted. Alvarez (2009) suggests a two-tier solution to deal with the joint problem. The first tier uses tabu search to establish a set of routes and corresponding vessel deployment whereas the second is to solve a multi-commodity flow problem. The performance benchmark of the proposed heuristic algorithm against an exact branch and bound algorithm shows that the heuristic approach can obtain acceptable solutions in a short period of time. Finally, the model is applied in a case study with 120 ports of call scattered around the world. Reinhardt and Pisinger (2011) suggest an exact branch and cut method to solve the combined problem. In addition to transhipment operation, the model is placed on butterfly routes allowing a port to be visited two times.

Agarwal and Ergun (2010) develop their previous work (Agarwal & Ergun 2008) in the context of shipping alliances. Firstly the previous model is deployed to choose optimal strategy of routing and ship deployment of an alliance. Afterwards mechanisms of fleet assignment member are determined thanks to inverse optimization technique. The mechanisms are to provide incentive for shipping lines to join alliances while still maximize their own profits.

Jepsen et al. (2011) and Brouer and Delsaulniers (2012) aim at choosing a set of routes to design a shipping network. Jepsen et al. introduce a path-based formulation to minimize shipping cost and fuel consumption so as to facilitate green network. The model combines different potential services into a generic liner shipping network under the constraint of liner fleet. Problem size is reduced by a novel aggregation of shipping demands. Instead of conventional origin-destination traffic between ports, the model deals only with the traffic between port and region. Brouer and Delsaulniers propose a matheuristic method to approach the optimal solution. At first, an initial solution is created by greedy construction heuristic based on the idea of the multiple quadratic knapsack problem. Then a mixed integer programming is used to optimise a single service by inserting or removing a port of call.

Impacts of reversing port rotation directions are analysed thoroughly by Wang and Meng (2013). They include changes in transit time between origin and destination, shipping capacity to serve some port pairs as well as transhipment cost. The authors propose a new aspect in the affair of network optimisation by taking into account optimal solutions of string directions.

Brouer et al. (2013) provide the first benchmark suite of data instances to encourage researches in the affair of container shipping network design as well as to create a platform to compare different optimisation methods. Their instances are based on the practical operation of Maersk Line and consist of key data related to ports, ships, nautical conditions and cargo demand. The joint model of Alvarez (2009) is applied to try the benchmark data sets and provides promising results.

Table 6-5: A summary of literature on optimal multiple routes

Author	Main question	Objective	Market	Remarkable factor
Agarwal & Ergun (2008)	Rout|assi|sche|cont	Max profit	Deterministic	Weekday traffic, liner alliance
Agarwal & Ergun (2010)	Rout|assi|num|cont	Max profit	Deterministic	
Alvarez (2009)	Rout|assi|num|cont	Max profit	Deterministic	Penalty cost
Brouer & Delsaulniers (2012)	Rout|assi	Max profit	Deterministic	
Brouer et al. (2013)	Rout|assi|num|cont	Max profit	Deterministic	Benchmark suite for optimisation methods
Cho & Perakis (1996)	Rout|assi|freq|voy + ship investment	Max profit; Min cost	Deterministic	
Fagerholt (1999, 2004)	Rout|assi	Min cost	Deterministic	
Jepsen et al. (2011)	Rout|assi	Max profit	Deterministic	
Kuroda et al. (2005)	Rout|assi|freq|cont	Min cost	Deterministic	Door-to-door traffic, inland transport cost, inventory cost
Lane et al. (1987)	Rout|assi|sche	Min cost	Deterministic	
Reinhardt & Pisinger (2011)	Rout|assi|cont	Min cost	Deterministic	Butterfly route
Reinhardt et al. (2007)	Rout|assi|cont	Min cost	Deterministic	Voyage time constraint
Takano & Arai (2011)	Rout|cont	Max profit	Deterministic	Empty container repositioning
Wang & Meng (2013)	Rout	Min cost	Deterministic	Reversing port rotation direction
Rout: ship routing; Assi: ship assignment; Freq: service frequency; Num: number of ships; Cont: container routing; Sche: ship schedule				

6.4.3 Hub and spoke network

The H&S network plays a key role in container liner shipping. It is the fact that liner operators cannot serve all ports in a region. Consequently, some ports play roles as hubs whereas others are spokes. These hubs are directly visited by mainline vessels and are the transhipment points for cargoes to/from the spokes thanks to feeder routes. The hierarchy has been established in liner network, in that, the routes connecting main hubs are considered as mainline or trunk routes; whilst the ones connecting hubs and spokes or between spokes are considered as secondary routes. Three aspects of hub and spoke (H&S) optimisation are introduced in the sub-section: the feasibility of H&S system and multi port call (MPC) system, models of choosing hub ports, and design of H&S system.

6.4.3.1 Hub and spoke (H&S) vs. multi port call (MPC)

The economics of H&S and MPC has been a conventional question in liner shipping for a long time. In the former pattern, mother vessels call only a key port per region and feeder services are deployed to carry cargo between hub ports and feeder ports. In contrast, in MPC pattern, mainline vessels will visit several ports per region to distribute/receive cargo. Each pattern owns both pros and cons. The H&S can be suitable for the deployment of mega vessels thanks to advantage of scale economies. However, significant increase of feeder and handling costs can be its drawback to the MPC.

Kazily (1982) examines the economics of both patterns in the Arabian Gulf under various scenarios of port throughput and ship size. The results indicate cost advantage of the former strategy over the latter one. Baird (2001) expands the containership cost model of Cullinane and Khanna (1999) to compare the two patterns on Europe-Asia route. Francesetti and Foschi (2002) analyse the viability of H&S system in the Mediterranean sea by applying Baird’s model with some adjustments on Mediterranean – Far East itinerary. By changing ship size from 4,000 TEUs to 10,000 TEUs, both the works have the same conclusion that total cost of H&S is smaller than that of MPC, but the difference tends to be noticeably mitigated when ship size goes up. The sensitivity analysis of Francesetti and Foschi demonstrates that handling tariff, crane productivity and captive cargo of a hub port have big impact on the economics of H&S pattern.

Figure 6-1: Direct call vs. Hub and spoke.
Source: Wijnolst et al., (2000).

Unlike the above outcomes, the simulation of Wijnolst et al. (2000) shows that H&S is more costly than MPC due to additional transhipment moves. Differences in cost structure, handling rate and feeder traffic can be the reasons for their dissimilarity. Wijnolst et al. emphasize two factors which determine the competitiveness of the H&S, one is substantial traffic from a hub, and another is cheap stevedoring cost. In the context of Taiwan ports, Wu (1988) finds that the MPC will be favourable if handling efficiency and costs are comparable between ports in the same region.

Notteboom (2010) presents a generalized cost model to compare the actual configuration of MPC and an alternative H&S in the South-African container port system. The model includes not only conventional costs such as ship cost and port cost but inland cost and time cost as well. The calculation shows that the latter configuration slightly suffers from cost disadvantage, stemming from higher cargo dues, terminal handling cost and inland cost. Consequently, it is argued that incentives provided by the terminal operator such as lower transhipment costs or rail rates play a crucial role in the success of the new H&S configuration.

6.4.3.2 Hub port selection

A hub is more than a port in a shipping route. It is a distribution centre for a region and an intersection where containers can be exchanged between different routes. Appropriate hub ports contribute much to the sustainability of shipping network in long term period. Not only does a hub require great amount local traffic but also require a strategic geographical position to make economic network connection between the hub and regional ports.

Pearson (1988) assesses the prospect of a new container hub in Indonesia of attracting traffic from Transpacific and Europe - Far East trades. The analysis based upon mainline cost and feeder cost reveals that the new player is located so far from intercontinental sea lanes that it is uneconomic to divert trunk line ship's itinerary to call the port. Savings from feeder cost cannot offset considerable increase of mainline ship diversion cost.

The route of Malacca-max ships between Far East and Europe is designed comprehensively by Wijnolst et al. (2000) and Waals and Wijnolst (2001). It consists of only 4 mega hubs. In addition to Rotterdam (North Europe) and Singapore (South East Asia), the two remaining hubs, Gioia Tauro (Mediterranean) and Hong Kong (North Asia) are selected by the model of gravity centre based on total transportation costs.

Aversa et al. (2005) apply P-hub median problem to create a mixed integer programming model for hub port selection in North America. Some simulations are conducted to study in which conditions a port can become a hub as well as the relationship between the total cost embracing port cost, shipping cost and inland transport cost, and the number of hub ports. One shortcoming of the model is the lack of inventory cost which can partly explain why total cost always declines when the number of hub ports goes up.

Baird (2002a,b, 2006) support Orkney (UK) as a new transhipment port in Northern Europe. By using mainline vessel "deviation cost" model, the author indicates cost saving of carriers thanks to the new hub. The two former ones (Baird 2002a,b) focus on the comparison between the H&S and MPC strategies in Northern Europe whereas the latter (Baird 2006) answers the question which port is the best choice for a single hub. Although Orkney is proven to be ideal for a transhipment hub in terms of natural conditions and economic benefit, no project has been carried out until now.

Chou (2008) simulates carriers' choice of a transhipment seaport to tranship their containers in order to maximize profit. The model is applied in the context of transpacific trade and emphasizes the advantage of the port of Kaohsiung as a transhipment hub for containers from Taiwan and Manila to the USA.

Zijian and Hong (2001) apply neural network theory to set up and optimize the H&S system of Chinese ports in three levels: international hubs, local hubs and feeder ports. Another work to do with Chinese H&S network is by Zeng and Yang (2002). They classify the hierarchical system embracing four levels: hinterlands, feeder ports, feeder hubs and trunk hub. Dynamic programming is utilised to select ports of call of each level.

Table 6-6: Summary of literature on hub and spoke economics and hub port selection

Research	Main question	Objective	Application	Remarkable factor
Aversa et al. (2005)	Hub choice	Min cost	South America East Coast ports	Inland transportation cost
Baird (2001)	H&S vs. MPC	Min cost	Asia – Europe route	
Baird (2002a,b, 2006)	Hub choice	Min cost	Asia – Europe route	Diversion distance
Chou (2008)	Hub choice	Max profit	Transpacific trade	
Francesetti & Foschi (2002)	H&S vs. MPC	Min cost	Asia – Mediterranean route	
Kazily (1982)	H&S vs. MPC	Min cost	Arab Gulf ports	
Notteboom (2010)	H&S vs. MPC	Min cost	South Africa ports	Inventory & inland transport cost
Pearson (1988)	Hub choice	Min cost	Asia route	Diversion distance
Waals &Wijnolst (2001); Wijnolst et al (2000)	Hub choice	Min cost	Asia – Europe route	Malacca max ship
Wijnolst et al. (2000)	H&S vs. MPC	Min cost	Asia – Europe route	
Zeng & Yang (2002)	H&S system	Min cost	Chinese ports	Inventory cost
Zijian & Hong (2001)	H&S system	Min cost	Chinese ports	
Wu (1988)	H&S vs. MPC	Min cost	Taiwanese ports	Diversion distance, inland transport cost

6.4.3.3 Design of hub and spoke network

Imai and Papadimitriou (1997) optimize a network by making a balance between carriers' cost and customers' cost. A multi-objective model is introduced to generate a set of non-inferior solutions for a network problem, including primary and secondary routes, hub and feeder ports, and ship size. From the set, solutions which can be accepted by cost objectives of both carriers and shippers will be realized.

Imai and Liu (2004), Imai et al. (2006) and Liu (2007) approach the economic viability of container mega ships and ordinary ships on the configurations of H&S and MPC. Game theory is used to find appropriate ship deployment (mega-ship or ordinary ship) and routing strategy (H&S or MPC) of shipping lines. Whereas the model of Imai and Liu (2004) aims to maximize profit, those of the two latter aim to minimize total transit time. The lack of container cost in these works is overcome in the two-phase model proposed by Imai et al. (2009). The first phase, based on the model of Imai et al. (2006), is to choose appropriate network configuration. The second one is to determine optimal strategy of container fleet size and number of leased containers. The outcome reveals cost advantage of MPC over H&S, especially in highly imbalanced trade.

Repositioning of empty container is incorporated in the model of Meng & S. Wang (2011b). They solve three problems of route selection, fleet deployment and container allocation simultaneously in the context of combined H&S and MPC. Numerical experiments are carried out on the Asia – Europe – Oceania network. The test results assess the significance of joining the H&S and MPC. The combined pattern is indicated to be more beneficial than the pure one in terms of cost.

Hsieh and Wong (2004) address an optimal H&S network on Trans-pacific trade in two stages. The first one is to select feasible hubs and a trunk route to connect these hubs. The second is to optimise connection between hubs and feeder ports. Studying the same problem, Takano and Arai (2009) use a genetic algorithm to solve a P-hub median problem which chooses optimal Asian hubs and feeder connection on a pendulum route plying among Europe, Asia and Northern American. According to their analysis, larger ships can be efficient in the H&S thanks to the concentration of traffic on fewer ports of call. Yang and Chen (2010) design two-level shipping network between China's Bohai area and West Coast ports of the USA. The upper level is to determine an international route whereas the lower one is Chinese feeder network to connect mainline ports and local ports. The optimal solution is attained by using genetic algorithm. Gelareh et al. (2010) study the competition between shipping lines on the basis of the H&S pattern. They try to design a H&S network for a newcomer in order to maximize its market share or service attractiveness which is a convex combination of transportation cost and service time.

Not only do Gelareh and Pisinger (2011) address the design of H&S network but also fleet assignment. Network design is to optimize end-to-end main route, together with feeder system to link mainline hubs and spokes. Feeder transportation in the model is simply a direct connection between a hub and a spoke. Fraction of demand allows a spoke to link with more than a hub port. Gelareh et al. (2013) also propose a model to solve the joint problem as Gelareh and Pisinger (2011). Nevertheless their objective is not to maximize revenue as the former model but to minimize a weighted-sum of shipping cost and transit time. Additionally feeder services are allowed to visit more than one spoke.

Design of feeder routes can be found in Karlaftis et al. (2009), Matsukura et al. (2010) and Polat et al. (2012). Using a genetic algorithm, Karlaftis et al. seek optimal routes between the hub Piraeus (Greece) and local ports in the Aegean sea under time deadline constraints of goods. Matsukura et al. optimize Japanese domestic feeder routes and ship allocation so that carbon dioxide emission can be minimal. The general steps in their model are more or less similar to those of Lane et al. (1987) and Fagerholt (1999, 2004) - first try to generate routes to meet their objectives, then assign ships into routes optimally. Polat et al. apply the method of perturbation based variable neighbourhood search to design a feeder network from a port, together with fleet mix, voyage time limitation and service frequency. The purpose is to assess the potential hub role of Candarli (Turkey) in the East Mediterranean and Black sea region by comparing the total cost of optimal options between this port and Port Said (Egypt).

Bendall and Stent (2001) establish a scheduling model for a high speed feeder services based on Singapore. Two stages are proposed to find solution. The first one is to determine spoke ports to serve and number of deployed vessels as well as service frequency to be undertaken in a specified period. The second is to schedule the voyages selected in the first stage.

Table 6-7: Summary of literature on hub and spoke network

Author	Main question	Objective	Market	Remarkable factor
Bendall & Stent (2001)	Rout|assi|num|voy|sche	Max profit	Deterministic	High speed service
Gelareh & Pisinger (2011)	Rout|assi|num	Max profit	Deterministic	
Gelareh et al. (2010)	Rout|sche	Max service attractiveness	Deterministic	Inventory cost, rate and traffic time constraint
Gelareh et al. (2013)	Rout|assi|num	Min cost	Deterministic	
Hsieh & Wong (2004)	Rout	Max profit	Deterministic	
Imai & Liu (2004)	Rout|assi	Max profit	Deterministic	

Imai & Papadimitriou (1997)	Rout|assi|cont	Min cost	Deterministic	Inventory cost
Imai et al. (2006); Liu (2007)	Rout|cont	Min transit time	Deterministic	
Imai et al. (2009)	Rout|cont	Min transit time	Deterministic	Empty repositioning, inland transport time, multi period, container inventory policy
Karlaftis et al. (2009)	Rout|assi|sche	Min cost	Deterministic	Tim deadline constraint of shipment
Matsukura et al. (2010)	Rout|assi|sche	Min CO_2 emission	Deterministic	Transit time constraint
Meng & S.Wang (2011)	Rout|assi|cont	Min cost	Deterministic	Empty repositioning
Polat et al. (2012)	Rout|sche|freq	Min cost	Deterministic	
Takano & Arai (2009)	Rout|assi|cont	Min cost	Deterministic	
Yang & Chen (2010)	Rout	Min cost	Deterministic	
Rout: ship routing; Assi: ship assignment; Freq: service frequency; Num: number of ships; Cont: container routing; Sche: ship schedule; Voy: number of ship voyage				

6.5 Conclusions

More than 120 papers in respect of network optimisation in container liner shipping have been classified and reviewed in three major categories. Container routing is to organize the flow of laden and empty boxes. The topic has become popular since the middle of the 2000s. In single period problems, authors pay more attention to the optimal flow of laden containers. In contrast, in multiple period ones, they concentrate more on empty container movements. Furthermore problems of empty inventory policy and uncertainty of market conditions are also studied more in multi period scenarios.

Researchers have been interested in optimal fleet decisions for a long time. Problems of ship assignment into specific routes, together with optimal number of deployed ships and number of ship voyages are most important in this affair. They are often put in the context of multiple routes whereas problems regarding temporal aspects of ship operation such as scheduling and speed are often put in the context of a single route. Unlike container routing decisions, those of fleet management are in favour of dealing with a single period. Ship investment has not attracted much attention from optimisation field which can stem from long life time of a ship, up to 20 - 30 years. Capacity change is often studied under forms of charter-in and out decisions. The dual problem of fleet management and container routing has been also carried out in some papers. Several new areas of fleet operation have been introduced recently such as bunker management, schedule reliability and stochastic operating conditions. Although joint operation and strategic alliance have become a tendency in the shipping market, only a few studies approach fleet cooperation between shipping lines.

Network design is related to the construction of shipping network. Optimal single route, multiple routes and hub and spoke network are taken into consideration in the category. Selection of suitable ports and determination of optimal port connection are principal questions of network design. Studies in the category not only deal with ship routing, but also quite often combine with problems of fleet assignment and container routing. The majority of models are put in the context of sea side, only a few try to expand the problem beyond maritime factors, including also land factors.

Most network optimisation studies try to attain minimum total cost or maximum profit, only several aim to deal with time objective. The objective of minimum total cost seems to be more favourable than that of maximum profit. It can be explained by the fact that whereas cost factors can be calculated approximately; precise freight rate is often kept secret as well as depends much upon the policy of operators with different customers, so its accurate estimation is quite difficult. Noticeably, motivated from the global efforts to reduce greenhouse gas emissions, the objective of environmental protection has been launched in some researches.

Linear programming (LP) and non-linear programming (NLP) are often deployed to model network matters. The former can easily define accurate solutions thanks to specific optimisation softwares. Nonetheless, the complexity of objective functions and variable constraints prevent many problems to use LP. In fact, the majority of problems are expressed thanks to NLP. Its drawback is the complication in finding the solution due to a large number of variables and constraints, and big solution space. Some studies tried to convert an NLP model into an LP one by using linearization technique, some developed sophisticated algorithms, often heuristics-based, and computer programming to find approximate solutions. Additionally, there are problems, which do not required complicated algorithms or specific softwares to determine solutions. These problems include a small number of solution options. Therefore, it is simple to calculate the value of objective function of each option and select the best one. The advantage is that various parameters can be considered in the model with accurate estimation of their values.

The majority of optimisation problems are often solved within the maritime network, so a port plays a role as origin or destination of cargo flow. It should be mentioned that today ports have become more dynamic and broken up traditional boundaries. A port has been no longer the starting point or destination of cargo transportation, but an intermediate in a whole supply chain. As we mentioned above, shipping lines have also expanded their operation into hinterland. Contemporary optimisation studies seem to lag behind the dynamic development of liner network (see more in Notteboom & Rodrique, 2005; Robinson, 2002; UNCTAD, 2004). In the light of network extension, a port should be selected not in isolation but rather as a component of a supply chain system. The optimisation model should not only determine optimal solution by sea-related factors, but also take into account other logistics factors; otherwise the solution is only locally optimal. It should solve not only with port-to-port but also door-to-door traffic.

Chapter 7: Optimal route design by incorporating maritime and inland factors

Hightlights:

- A non-linear programming model to optimize shipping routes between two market regions
- The application on the real trade between the USA and Europe
- Measurement of the impact of operational factors on route optimisation

7.1 Introduction

Ports have developed beyond traditional boundaries. They have been no longer interfaces between shores and ships, or the places where cargo transportation starts or finishes, but have become nodes on seamless cargo flow from manufacturers to customers. Such tendency has been clearly illustrated in port evolution models (see for example Carbone & Martino, 2003; Notteboom & Rodrique, 2008; Pettit & Beresford, 2009; Robinson, 2002, 2006; Unctad, 1992).

As ports have been embedded in the global supply chain, shipping network design should be placed in a broader scope, not only within maritime transportation but also in the interaction with inland transportation. Maritime factors regarding ship and port operation may be not enough to determine an optimal route. Other logistics factors such as inland transportation, value of cargo, service frequency and even environmental effect should be taken into consideration as well.

Numerous researches have tackled network optimisation in container shipping. Most of them have focused on maritime leg. This article approaches the optimisation issue in a broader scope by considering both maritime and inland parameters. A non-linear programming model is proposed to optimise container flows between two continents through an end-to-end service. Container flows are not on the basis of port-to-port, but door-to-door. Key decisive parameters in the model consist of not only conventional ship cost and port cost but also inland transport cost, inventory carrying cost and CO_2 cost. The model is solved heuristically and applied in a monthly trade between Europe and the USA.

This chapter is organised as follows. The optimisation model is presented in Section 7.2. Section 7.3 introduces data and operational parameters in the application. Section 7.4 includes experiment results and some analyses. The final section consists of some conclusions.

7.2 Optimisation model

7.2.1 Description

The model deals with container trade between two regions A and B. Each region is divided into some hinterlands. Container flows between hinterlands in two regions have been classified with the information regarding to the number of TEUs, boxes and cargo value in a specific period of time. There are some candidate ports that can be visited by mainline ships. The goods are assumed to be carried via an end-to-end shipping service with a pre-determined ship size.

The task is to design not only an optimal shipping service but also inland connection between hinterlands and ports. Three questions are placed in the model: (i) Which ports should be served by the shipping route? (ii) What is the sequence of port calls? (iii) What are loading and unloading ports of a shipment? The objective is to minimise the total cost consisting of ship cost (capital cost, operational cost and bunker cost) and port cost (port due and terminal handling charge), inventory cost (time cost of cargo, container cost and safety stock), inland/feeder transportation cost between original/final points and loading/unloading ports, and CO_2 cost (generated by ship operation, port operation and inland /feeder transportation).

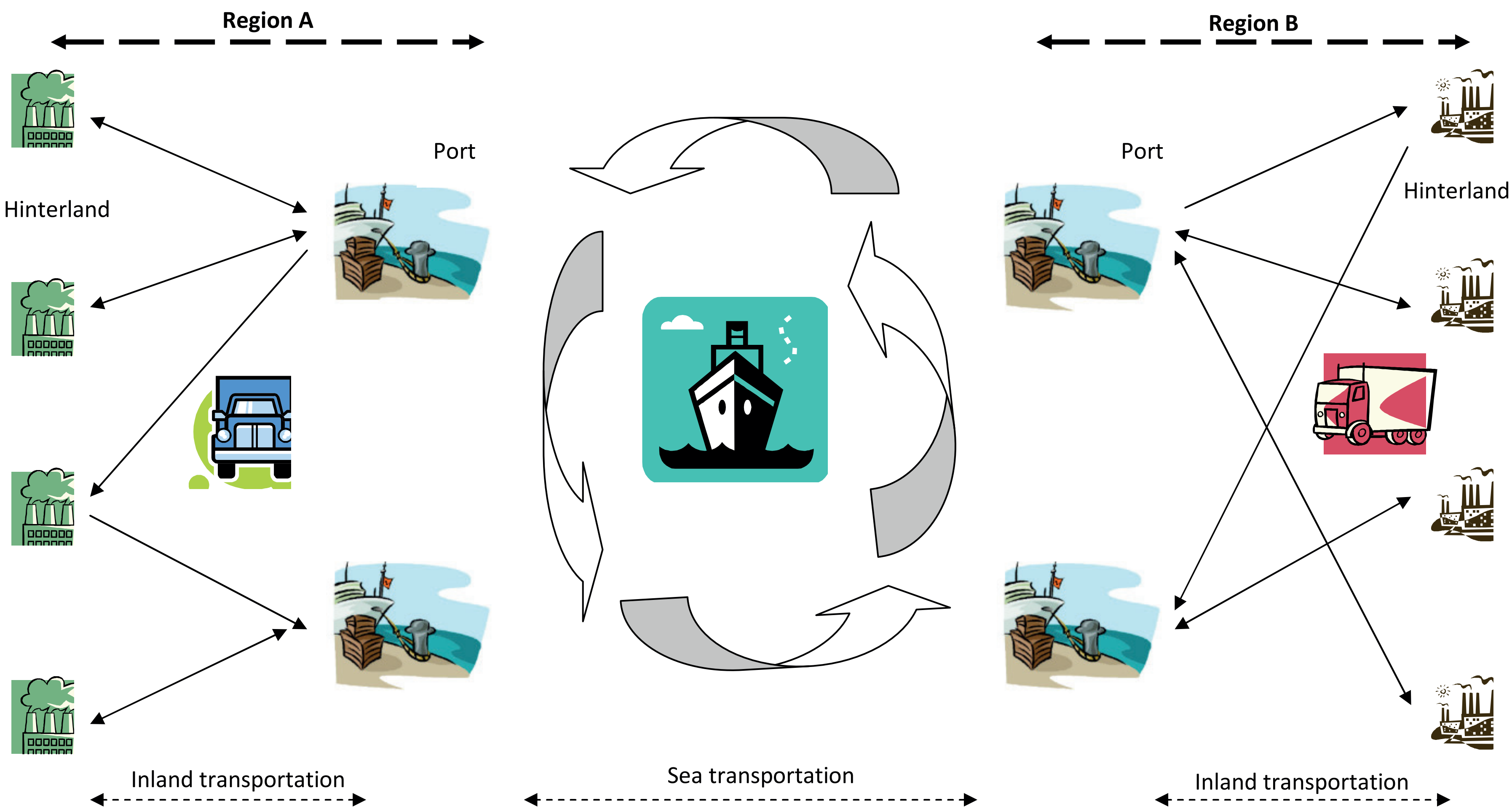

Figure 7-1: Transportation network

7.2.2 Model variables

Input variables:

N: the number of hinterlands in region A

M: the number of hinterlands in region B

Hinterlands in A are numbered from 1 to N, hinterlands in B from $N+1$ to $N+M$

$$lh_i = 0 \; if \; 1 \leq i \leq N; or \; else \; lh_i = 1$$

K: the number of candidate ports in region A

T: the number of candidate ports in region B

Ports in A are numbered from 1 to K, ports in B from $K+1$ to $K+T$

$$lp_\alpha = 0 \; if \; 1 \leq \alpha \leq K; or \; else \; lp_\alpha = 1$$

$teu_{i,j}$: the number of TEUs from hinterland i to hinterland j (TEU)

$box_{i,j}$: the number of boxes from i to j (container)

$value_{i,j}$: cargo value from i to j (USD)

TP: time period (day)

$size$: ship capacity (TEU)

uti: ship utilisation on the main leg (%)

voy: the number of round voyages in the time period

$$voy = max\left\{\frac{\sum_{i=1}^{N}\sum_{j=N+1}^{N+M} teu_{i,j}}{uti*size}; \frac{\sum_{i=N+1}^{N+M}\sum_{j=1}^{N} teu_{i,j}}{uti*size}\right\}$$

$freq$: the interval between two consecutive services (day) $\quad freq = \frac{TP}{voy}$

inv: inventory cost rate as percentage of cargo value (%/day)

v: ship speed (knot/day)

cc: daily container cost per TEU (USD)

due_α: port due (ship due, pilotage, towage …) per ship call in port α (USD/call)

thc_{α}: terminal handling charge in port α (USD/move)

pro_{α}: handling productivity in port α (move/day)

edt_{α}: dwell time of export cargo in port α before ship operation (day)

idt_{α}: dwell time of import cargo in port α after ship operation (day)

mt_{α}: manoeuvring time per entry/exit in port α (day)

$hCO2_{\alpha}$: CO_2 cost for serving one TEU in port α (USD)

$ic_{i,\alpha}$: inland/transhipment cost between hinterland i and port α (USD/TEU)

$it_{i,\alpha}$: inland/transhipment time between hinterland i and port α (day)

$iCO2_{i,\alpha}$: CO_2 cost between hinterland i and port α (USD/TEU)

$sd_{\alpha,\beta}$: nautical distance between port α and port β (mile)

ssc: daily ship cost at sea (USD)

spc: daily ship cost in port (USD)

$sCO2$: daily CO_2 cost generated by ship operation at sea (USD)

$pCO2$: daily CO_2 cost generated by ship operation in port (USD)

Decision variables:

$rt_{\alpha} = 1$: port α is selected on the route; or else $rt_{\alpha} = 0$

$lk_{\alpha,\beta} = 1$: port β is the subsequent port of α on the voyage; or else $lk_{\alpha,\beta} = 0$

$ld_{i,j,\alpha} = 1$: containers from i to j are loaded by port α; or else $ld_{i,j,\alpha} = 0$

$uld_{i,j,\alpha} = 1$: containers from i to j are unloaded by port α; or else $uld_{i,j,\alpha} = 0$

Intermediate variables:

HUB: set of selected ports

$HUBA$: set of selected ports in region A

HUBB: set of selected ports in region B

OD: set of cargo flow. $OD = \{(i,j) | 1 \leq i,j \leq N+M; teu_{i,j} > 0\}$

$r_{\alpha,\beta,\gamma}$=1: the ship passes through port γ on the voyage from α to β; or else $r_{\alpha,\beta,\gamma}$=0

pt_{α}: total time the ship spends in port α. It includes manoeuvring time and unloading and loading time (day)

$$pt_{\alpha} = 2 * mt_{\alpha} + \frac{\sum_{i=1}^{N+M}\sum_{j=1}^{N+M} box_{i,j}*ld_{i,j,\alpha}+\sum_{i=1}^{N+M}\sum_{j=1}^{N+M} box_{i,j}*uld_{i,j,\alpha}}{pro_{\alpha}*voy}$$

$tst_{\alpha,\beta}$: total sea time on the voyage from port α to port β (day)

$$tst_{\alpha,\beta} = \sum_{\gamma \in HUB}\sum_{\delta \in HUB} \frac{sd_{\gamma,\delta}*lk_{\gamma,\delta}*r_{\alpha,\beta,\gamma}*r_{\alpha,\beta,\delta}}{v}$$

$tpt_{\alpha,\beta}$: total port time on the voyage from port α to port β (day)

$$tpt_{\alpha,\beta} = \sum_{\gamma \in HUB} pt_{\gamma} * r_{\alpha,\beta,\gamma}$$

$time_{i,j}$: total transit time from hinterland i to hinterland j (day). It includes (i) transit time from the original point to the loading port, (ii) dwell time in the loading port before ship operation, (iii) time from the ship arrives the loading port until it leaves the unloading port, (iv) dwell time in the unloading port after ship operation and (v) transit time from the unloading port to the final destination.

$$time_{i,j} = \sum_{\alpha \in HUB} it_{i,\alpha} * ld_{i,j,\alpha} + \sum_{\alpha \in HUB} edt_{\alpha} * ld_{i,j,\alpha} + \sum_{\alpha,\beta \in HUB}(st_{\alpha,\beta} + pt_{\alpha,\beta}) * ld_{i,j,\alpha} * uld_{i,j,\beta} + \sum_{\beta \in HUB} idt_{\beta} * uld_{i,j,\beta} + \sum_{\beta \in HUB} it_{j,\beta} * uld_{i,j,\beta}$$

TSC: total ship cost at sea and in port (USD)

$$TSC = \sum_{\alpha,\beta \in HUB} \frac{sd_{\alpha,\beta}*lk_{\alpha,\beta}*ssc}{v} + \sum_{\alpha \in HUB} pt_{\alpha} * spc$$

TPC: total port due and terminal handling charge (USD)

$$TPC = \sum_{\alpha \in HUB} due_{\alpha} + \sum_{\alpha \in HUB} thc_{\alpha} * \sum_{i=1}^{N+M}\sum_{j=1}^{N+M} \frac{box_{i,j}(ld_{i,j,\alpha}+uld_{i,j,\alpha})}{vo}$$

TCC: total CO_2 cost (USD). It includes CO_2 cost at sea and in port generated by ship operation, CO_2 cost generated by cargo operation in port, and CO_2 cost generated by inland /feeder transportation.

$$TCC = \sum_{\alpha,\beta \in HUB} \frac{sd_{\alpha,\beta} * lk_{\alpha,\beta}}{v} * sCO2 + \sum_{\alpha \in HUB} pt_{\alpha} * pCO2 + \sum_{\alpha \in HUB} \sum_{i=1}^{N+M} \sum_{j=1}^{N+M} \frac{teu_{i,j}\left(ld_{i,j,\alpha} + uld_{i,j,\alpha}\right)}{voy} * hCO2_{\alpha} + \sum_{\alpha \in HUB} \sum_{i=1}^{N+M} \sum_{j=1}^{N+M} \frac{teu_{i,j}\left(iCO2_{i,\alpha} * ld_{i,j,\alpha} + iCO2_{j,\alpha} * uld_{i,j,\alpha}\right)}{voy}$$

TIC: total inventory carrying cost, container cost and safety stock (USD). Inventory carrying cost is dependent on cargo value and transit time from the origin to destination. Container cost is paid for the use of containers. Safety stock is to prevent the out of stock between two consecutive trips and determined by service frequency. It is calculated by the formula taken from Jansson and Shneerson (1987) without consideration of storage cost.

$$TIC = \sum_{i=1}^{N+M} \sum_{j=1}^{N+M} \frac{value_{i,j}}{voy} * time_{i,j} * inv + \sum_{i=1}^{N+M} \sum_{j=1}^{N+M} \frac{teu_{i,j}}{voy} * time_{i,j} * cc + \sum_{i=1}^{N+M} \sum_{j=1}^{N+M} \frac{value_{i,j}}{TP} * \frac{freq}{2} * inv$$

$TILC$: total inland/feeder transportation cost (USD)

$$TILC = \sum_{\alpha \in HUB} \sum_{i=1}^{N+M} \sum_{j=1}^{N+M} \frac{teu_{i,j}(ld_{i,j,\alpha} * ic_{i,\alpha} + uld_{i,j,\alpha} * ic_{j,\alpha})}{voy}$$

7.2.3 Mathematical model

Objective: to minimise total cost $TC = TSC + TPC + TILC + TIC + TCC$

By changing *binary* variables:

$ld_{i,j,\alpha}$ $\quad i = \overline{1, N+M}; j = \overline{1, N+M}; \alpha = \overline{1, K+T}$

$uld_{i,j,\alpha}$ $\quad i = \overline{1, N+M}; j = \overline{1, N+M}; \alpha = \overline{1, K+T}$

rt_{α} $\quad \alpha = \overline{1, K+T}$

$lk_{\alpha,\beta}$ $\quad \alpha = \overline{1, K+T}; \beta = \overline{1, K+T}$

Constraints:

$$\forall \boldsymbol{\alpha} \in \boldsymbol{HUB} \qquad \sum_{\boldsymbol{\beta} \in \boldsymbol{HUB}} \boldsymbol{lk_{\alpha,\beta}} = \mathbf{1} \tag{1}$$

/ each selected port has exactly one previous port and one subsequent port on the voyage.*

$$\forall \boldsymbol{\alpha} \in \boldsymbol{HUB} \qquad \boldsymbol{lk_{\alpha,\beta}} = \mathbf{0} \tag{2}$$

*/*no self- connection from a port to itself.*

$$\forall \boldsymbol{\alpha} \notin \boldsymbol{HUB} \qquad \sum_{\boldsymbol{\beta}=\mathbf{1}}^{\boldsymbol{K}+\boldsymbol{T}} \boldsymbol{lk_{\alpha,\beta}} = \mathbf{0} \tag{3}$$

/ non-selected port has no one-way sea connection with other ports.*

$\forall \alpha \notin HUB \qquad \sum_{\beta=1}^{K+T} lk_{\beta,\alpha} = 0$ (4)

/ no port has one-way sea connection with non-selected ports.*

$\sum_{\alpha \in HUBA} \sum_{\beta \in HUBA} lk_{\alpha,\beta} = \sum_{\alpha \in HUBA} rt_\alpha - 1$ (5)

$\sum_{\alpha \in HUBB} \sum_{\beta \in HUBB} lk_{\alpha,\beta} = \sum_{\alpha \in HUBB} rt_\alpha - 1$

/ the ship calls all selected ports in a region, then travels to another region*

$\forall (i,j) \in OD \qquad \sum_{\alpha \in HUB} ld_{i,j,\alpha} * (1 - |lh_i - lp_\alpha|) = 1$ (6)

/ cargo from i to j is loaded by exactly one port, loading port α is in the same region with hinterland i.*

$\forall (i,j) \in OD \qquad \sum_{\alpha \in HUB} uld_{i,j,\alpha} * \left(1 - \left|lh_j - lp_\alpha\right|\right) = 1$ (7)

/ cargo from i to j is unloaded by exactly one port, unloading port α is in the same region with hinterland j.*

$\forall (i,j) \in OD \qquad \sum_{\alpha \notin HUB} ld_{i,j,\alpha} = 0 \qquad \sum_{\alpha \notin HUB} uld_{i,j,\alpha} = 0$ (8)

/ non-selected ports are not loading and unloading ports for any shipment.*

$\forall (i,j) \notin OD \qquad \sum_{\alpha=1}^{K+T} ld_{i,j,\alpha} = 0 \quad \sum_{\alpha=1}^{K+T} uld_{i,j,\alpha} = 0$ (9)

/ there is no loading and unloading port for any pair (i, j) with no cargo transportation demand.*

7.2.4 Solution algorithm

Brute-force algorithm and greedy algorithm are used to solve the nondeterministic polynomial problem. The former algorithm generates all possible ship voyages. For each generated voyage, the latter algorithm is applied to allocate loading and unloading ports for each shipment. Based on ship voyage and inland transportation flows, total cost for each option is calculated. The option with minimum total cost will be selected as the solution.

There are five major steps in this approach:

Step 1: Port choice

Based on the list of candidate ports, all possibilities of port choice are created with $2^{\mathrm{K}} - 1$ options in region A, and $2^{\mathrm{T}} - 1$ options in region B. The total number of options is $(2^{\mathrm{K}} - 1) * (2^{\mathrm{T}} - 1)$. Table 1 illustrates the list of choices when each region has 4 candidate ports (15 cases per region). There are 225 (15*15) ways to select ports on the ship's voyage.

Table 7-1: List of port choices

Region A				Region B			
	Port choice		Port choice		Port choice		Port choice
1	1	9	2	1	5	9	6
2	1, 2	10	2, 3	2	5, 6	10	6, 7
3	1, 2, 3	11	2, 3, 4	3	5, 6, 7	11	6, 7, 8
4	1, 2, 3, 4	12	2, 4	4	5, 6, 7, 8	12	6, 8
5	1, 2, 4	13	3	5	5, 6, 8	13	7

6	1, 3	14	3, 4	6	5, 7	14	7, 8
7	1, 3, 4	15	4	7	5, 7, 8	15	8
8	1, 4			8	5, 8		

Step 2: Route generation

Corresponding to each state in step 1, different sequences of port calls are enumerated by generating all permutations of the selected ports in each region. Totally, there are $\sum_{i=1}^{K}\frac{K!}{(K-i)!} * \sum_{j=1}^{T}\frac{T!}{(T-i)!}$ Potential ship voyages. Table 7.2 displays possible voyages in case ports 1, 3 and 4 are chosen in region A, ports 5 and 8 in region B.

Table 7-2: A set of ship voyages

1	1→3 →4→5→8→1	7	3→4 →1→5→8→3
2	1→3 →4→8→5→1	8	3→4 →1→8→5→3
3	1→4 →3→5→8→1	9	4→3 →1→5→8→4
4	1→4 →3→8→5→1	10	4→3 →1→8→5→4
5	3→1 →4→5→8→3	11	4→1 →3→5→8→4
6	3→1 →4→8→5→3	12	4→1 →3→8→5→4

Step 3: Preliminary selection of loading and unloading ports

For each voyage generated in step 2, four corresponding costs are defined (Table 7.3): ship cost at sea (1), port due (3) and CO_2 cost at sea (11), and safety stock (8). Other costs will be determined when loading and unloading ports for all shipments are allocated. The optimal state of each voyage obviously depends on the choice of loading and unloading ports. Our greedy strategy is not to optimise all the undefined costs, but some of them. The greedy cost of a shipment corresponding with a pair of loading and unloading ports is defined as the sum of terminal handling charge (4), inventory cost at sea (5), inland/feeder transport cost (9), CO_2 cost generated by inland/feeder transport (12) and handling operation in port (13). The greedy idea is based on the fact that greedy cost of each shipment is independent from the choice of loading and unloading ports of other shipments. Therefore, instead of solving a huge problem for all shipments, we try to find a local optimum for each shipment by choosing the loading and unloading ports with minimum greedy cost. Ship cost (2) and inventory cost (6) and CO_2 cost (11) in port are out of consideration and can be referred to as model error.

Table 7-3: Total cost breakdown

	Cost	Stage	Defined
1	Ship cost	At sea	No
2		In port	Yes
3	Port cost	Port due	Yes
4		THC	No
5	Inventory cost	At sea	No

6		In port	No
7		Inland/feeder	No
8		Safety stock	Yes
9	Inland /feeder transport cost		No
10	CO_2 cost (ship)	At sea	Yes
11		In port	No
12	CO_2 cost (cargo)	Inland/feeder	No
13		In port	No

The greedy cost for the shipment from i to j with loading port α and unloading port β

$$gc_{i,j,\alpha,\beta} = \left(ic_{i,\alpha} + ic_{j,\beta}\right) * \frac{teu_{i,j}}{voy} + \left(iCO2_{i,\alpha} + iCO2_{j,\beta} + hCO2_{\alpha} + hCO2_{\beta}\right) * \frac{teu_{i,j}}{voy} +$$

$$\left(\frac{value_{i,j}}{voy} * inv + \frac{teu_{i,j}}{voy} * cc\right) * \left(it_{i,\alpha} + edt_{\alpha} + tst_{\alpha,\beta} + idt_{\beta} + it_{j,\beta}\right)$$

$$+\left(thc_{\alpha} + thc_{\beta}\right) * \frac{box_{i,j}}{voy}$$

Step 4: Cost estimation. Based on the ship route and loading and unloading ports for shipments, total cost for a voyage is calculated.

Step 5: Update. If the total cost is smaller than the recorded result, the new option will be updated.

7.3 Data description

7.3.1 Cargo flow

Raw data are provided by the the Port Import Export Reporting Service (PIERS). They include 108,847 monthly seaborne trade profiles between the USA and European countries (France, United Kingdom, Netherlands, Germany, Belgium, Norway, Sweden and Denmark). Each profile provides basic information of a shipment: origin, destination, the number of TEUs and containers and value. Original or ultimate point of a shipment is a city in Europe and a state in the USA. Based on the origins and destinations, 3,179 hinterlands are classified in Europe (on the basis of city) and 46 in the USA (on the basis of state). Shipments with similar origin and destination are integrated into a single one. Totally, there are 4,365 combined flows from Europe to the USA and 2,911 from the USA to Europe.

Table 7-4: Hinterland allocation

Country	Hinterlands	Country	Hinterlands
Belgium	181	Norway	45
Denmark	100	Sweden	114
Germany	1,019	UK	835
France	653	The USA	46
Netherlands	232		

7.3.2 Candidate ports

Twelve ports are selected as candidate ports on the ship voyage: Rotterdam, Antwerp, Hamburg, Bremerhaven, Le Havre & Felixstowe (Europe); New York, Charleston, Houston, Norfolk, Savannah and Baltimore (the USA). They are main ports on the Trans-Atlantic trade. Connections between hinterlands and candidate ports are demonstrated in Table 7.5.

Table 7-5: Connection between hinterlands and ports

Hinterland	Port	Connection mode
The USA	US ports	Truck and rail
Continental Europe	Rotterdam, Bremerhaven, Hamburg, Antwerp, Le Havre	Truck and rail
Continental Europe	Felixstowe	Feeder via one of continental ports
UK	Rotterdam, Bremerhaven, Hamburg, Antwerp, Le Havre	Feeder via the port of Felixstowe
Norway	Rotterdam, Bremerhaven, Hamburg, Antwerp, Le Havre, Felixstowe	Feeder via the port of Oslo
Denmark	Rotterdam, Bremerhaven, Hamburg, Antwerp, Le Havre, Felixstowe	Feeder via the port of Aarhus
Sweden	Rotterdam, Bremerhaven, Hamburg, Antwerp, Le Havre, Felixstowe	Feeder via the port of Gothenburg

7.3.3 Sea distance (mile)

Nautical distances between ports are retrieved from the database of Dataloy [8]

7.3.4 Inland distance (km)

Distances between hinterlands and ports are calculated from the online tool of Google Map[9]. It is assumed that rail distance and road distance are similar. Inland transport speed is 70 kilometres per hour.

7.3.5 Ship cost

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[8] (http://www.dataloy.com/).

[9] (https://maps.google.com/)

It includes capital cost, operational cost and bunker cost (adapted from chapter 5).

Daily capital cost (USD): $cost = 22.89 * (ship\ size)^{0.70}$

Daily operating cost (USD): $cost = 267 * (ship\ size)^{0.40}$

Daily bunker consumption at sea (tonne): $cost = 1.21 * (ship\ size)^{0.51}$

Bunker consumption in port (tonne): is assumed to be 5% of the level at sea (adapted from Cariou, 2011).

Fuel price: $400 per tonne.

7.3.6 Port cost

Port due (USD per ship call): is retrieved from the database of ENERPLAN, a joint project of Maersk Line, DTU Management Engineering and the IT University of Copenhagen (Brouer et al., 2014). It includes fixed cost per call and variable cost based on ship capacity.

Terminal handling charge (USD per movement): is retrieved from the online calculation of Hamburg Süd. [10]

7.3.7 Inland transport cost

Table 7-6: Inland transport cost

	Road ($/tonne-km) (1)	Rail ($/tonne-km) (2)	Road – Rail ratio (3)	Inland transport cost ($/tonne-km) (4)	Tonne per TEU (5)	Inland transport cost ($/ TEU-km) (6)
EU	0.1792	0.1408	4:1	0.174	10	1.74
US	0.256	0.0128	4:3	0.155	10	1.55

(1), (2): adapted from Schade et al. (2006) and converted from Euro to USD (exchange rate of 1.28). (3): Based on the ratios between road transport and rail transport (by tonne-km) from EU Statistics and US Department of Energy (2013). (5): According to UNCTAD (2013), the global volume was 155m TEUs, in correspondence with 1.578m tonnes, so one TEU is roughly equal to 10 tonnes.

7.3.8 Inventory cost

Inventory rate: 25% per year

Container cost: 0.8$/day (adapted from chapter 5)

7.3.9 CO_2 cost

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[10] https://ecom.hamburgsud.com/ecom/de/ecommerce_portal/tarifs_and_surcharges/thc_calc/ep_thc_calculator.xhtml

CO_2 tax: $32 per emission tonne (adapted from Schrote et al., 2011 and converted from Euro to USD)

For ship operation, CO_2 emission is computed by multiplying fuel consumption by a factor of 3.17 (adapted from Psaraftis & Kontovas, 2009).

For cargo operation in port: CO_2 emission is 17.29 kg per TEU (adapted from Veidenheimer, 2011).

For inland transportation: according to Cefic and ECTA (2011), road CO_2 emission is 62 g/tonne-km, rail CO_2 emission is 22 g/tonne-km. Based on the ratio between road and rail transportation in US and EU and average weight per TEU (Table), CO_2 emission is calculated to be 0.54 kg/TEU-km in EU and 0.45 kg/TEU-km in US.

7.3.10 Other operational parameters

Ship speed: 20 knots per hour

Handling productivity: 180 moves per hour (in all ports, 6 cranes with the productivity of 30 moves per hours are deployed to serve mainline ships)

Ship utilisation on the main leg: 80%

Manoeuvring time in ports: 3 hours per entry/exit (adapted from Wijnolst et al, 2000)

Export/import dwell time in ports: 3 days (adapted from Rankine, 2003)

7.4 Computational results and analysis

7.4.1 Results

The model is tried with various ship sizes from 2,000 TEUs to 18,000 TEUs. The solutions are found by specifically tailored computer programs written in the language of Freepascal. Some key outcomes of the experiment are presented in Table 7.7. The cheapest total cost per TEU falls in the option of a 9,000 TEU ship ($2,369), whereas the most expensive one in the option of a 2,000 TEU ship ($2,523). Ships operate optimally in two different routes embracing 12 ports of call. Of the five main cost components, inland transport costs accounts for the biggest part with more than 35% of the total cost. CO_2 cost contributes the smallest percentage with less than 2.5%. Inventory cost and shipping cost (ship cost and port cost) each play around one third of the total cost. The model error is calculated by the ratio between the bypassed costs in the greedy algorithm (ship cost, CO_2 cost and inventory cost in port) and total cost. The indicator is less than 7.5% in all cases.

Table 7-7: Summary of computational experiments

Size (TEU)	Route	Time (day)		Unit cost (USD per TEU)						Error
		At sea	In port	Ship cost	Port cost	Inventory cost	CO_2 cost	Inland transport cost	Total cost	
2,000	(1)	25.39	3.75	327	520	694	66	917	2,523	3.2%
3,000	(1)	25.39	4.13	270	504	705	56	917	2,451	3.5%
4,000	(1)	25.39	4.51	237	495	715	50	917	2,414	3.8%
5,000	(2)	25.47	4.88	215	491	723	46	919	2,393	4.0%
6,000	(2)	25.47	5.26	198	488	733	43	919	2,381	4.3%
7,000	(2)	25.47	5.63	185	485	744	40	919	2,373	4.5%
8,000	(2)	25.47	6.01	174	484	754	39	919	2,370	4.8%
9,000	(2)	25.47	6.39	166	482	765	37	919	2,369	5.1%
10,000	(2)	25.47	6.76	159	481	775	36	919	2,370	5.4%
11,000	(2)	25.47	7.14	152	480	786	35	919	2,372	5.6%
12,000	(2)	25.47	7.52	147	480	796	34	919	2,375	5.9%
13,000	(2)	25.47	7.89	142	479	807	33	919	2,380	6.2%
14,000	(2)	25.47	8.27	138	478	817	32	919	2,385	6.4%
15,000	(2)	25.47	8.65	135	478	828	31	919	2,390	6.7%
16,000	(2)	25.47	9.02	131	477	838	31	919	2,397	7%
17,000	(2)	25.47	9.40	128	477	849	30	919	2,403	7.2%
18,000	(2)	25.47	9.77	125	477	859	29	919	2,410	7.5%

Route (1): Antwerp -> Bremerhaven -> Hamburg -> Rotterdam -> Felixstowe -> Le Havre -> New York -> Norfolk -> Charleston -> Houston -> Savannah -> Baltimore -> Antwerp (12,189 miles)

Route (2): Antwerp -> Felixstowe -> Bremerhaven -> Hamburg -> Rotterdam -> Le Havre -> New York -> Norfolk -> Charleston -> Houston -> Savannah -> Baltimore -> Antwerp (12,225 miles)

The use of a 9,000 TEU ship brings about the smallest total unit cost. Figure 7.2 illustrates its voyage embracing 25.47 days at sea and 6.39 days in ports. Table 7.8 shows the breakdown of the total unit cost based on cost item and supply chain stage. Table 7.9 demonstrates cargo flows going through the visited ports on the route. Import containers tend to be unloaded more in the first regional ports (Antwerp and Felixstowe in Europe, New York in the USA) whereas export containers loaded in the last ones (Rotterdam, Le Havre in Europe; Savannah and Baltimore in the USA). To decrease inventory cost, it is reasonable to unload containers as soon as possible whereas load them as late as possible. Studies of Lago et al. (2001) and Malchow (2001) in the US ports also indicate that a port's market share increases for (i) export when it is called last, (ii) import when it is called first, in a service.

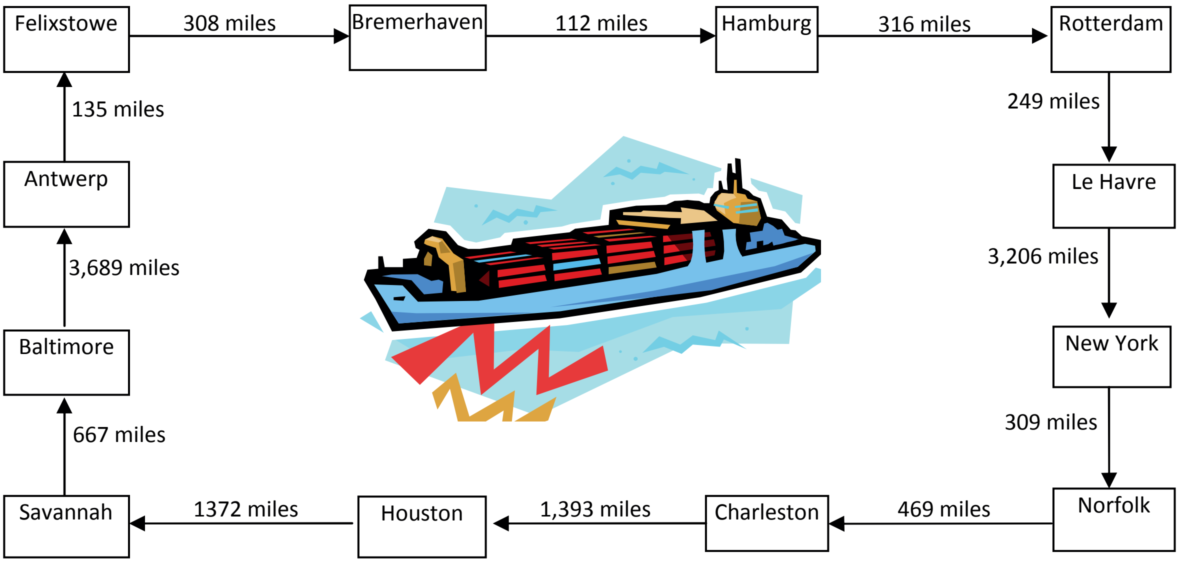

Figure 7-2: The optimal voyage of a 9,000 TEU ship

Table 7-8: Cargo flows through ports

Port	Loading				Unloading			
	Shipments	TEUs	Boxes	Value ($)	Shipments	TEUs	Boxes	Value ($)
Antwerp	849	1,460	869	57,063,018	919	1,857	1,068	110,177,163
Felixstowe	1,455	1,223	755	65,151,558	1,455	1,457	812	67,238,511
Bremerhaven	110	885	559	57,870,343	88	563	313	35,844,783
Hamburg	428	872	504	50,743,249	132	281	168	14,355,064
Rotterdam	714	1,670	996	97,195,814	135	783	449	32,422,156
Le Havre	809	1,088	667	70,426,954	182	276	155	12,108,330
New York	285	652	374	31,444,503	1,470	2,908	1,766	163,961,954
Norfolk	152	76	42	1,403,393	547	962	567	58,462,269
Charleston	103	127	66	2,230,505	996	1,679	1,022	109,120,142
Houston	664	1,219	725	60,402,341	806	1,098	687	50,482,041
Savannah	531	1,419	800	64,400,271	222	250	141	7,951,256
Baltimore	1,176	1,725	958	112,264,994	324	302	165	8,473,273

Table 7-9: Breakdown of total unit cost (9,000 TEU ship)

Cost item	Sub-component	Value ($ per TEU)	Percentage
Ship cost	Capital cost at sea	27.51	1.16%
	Operating cost at sea	20.9	0.88%
	Bunker cost at sea	103.99	4.39%
	Capital cost in port	26.37	1.11%
	Operating cost in port	371.91	15.70%
	Bunker cost in port	6.9	0.29%
Port cost	Port due and Terminal handling charge	5.24	0.22%
Inventory cost	Inventory cost at sea	1.3	0.05%
	Inventory cost in port (during ship operation)	482.31	20.36%
	Inventory cost in port (during dwell time)	0.33	0.01%
	Inventory cost during inland transport	1.11	0.05%
	Safety stock	106.94	4.51%
Inland transport cost	Inland transport	226.77	9.57%
CO_2 cost	CO_2 cost at sea	919.17	38.80%

	CO2 cost in port (by ship operation)	9.17	0.39%
	CO2 cost in port (by cargo operation)	22.03	0.93%
	CO2 cost during inland transport	36.91	1.56%

7.4.2 Analysis

Ship cost and port cost are the most conventional factors in network optimization problems. In fact, they only represent less than one third of the door-to-door cost. The deployment of mega vessels naturally drives down unit ship cost and port cost. According to our model, doubling vessel capacity will lower them by \$11.77 and \$59.55, respectively.

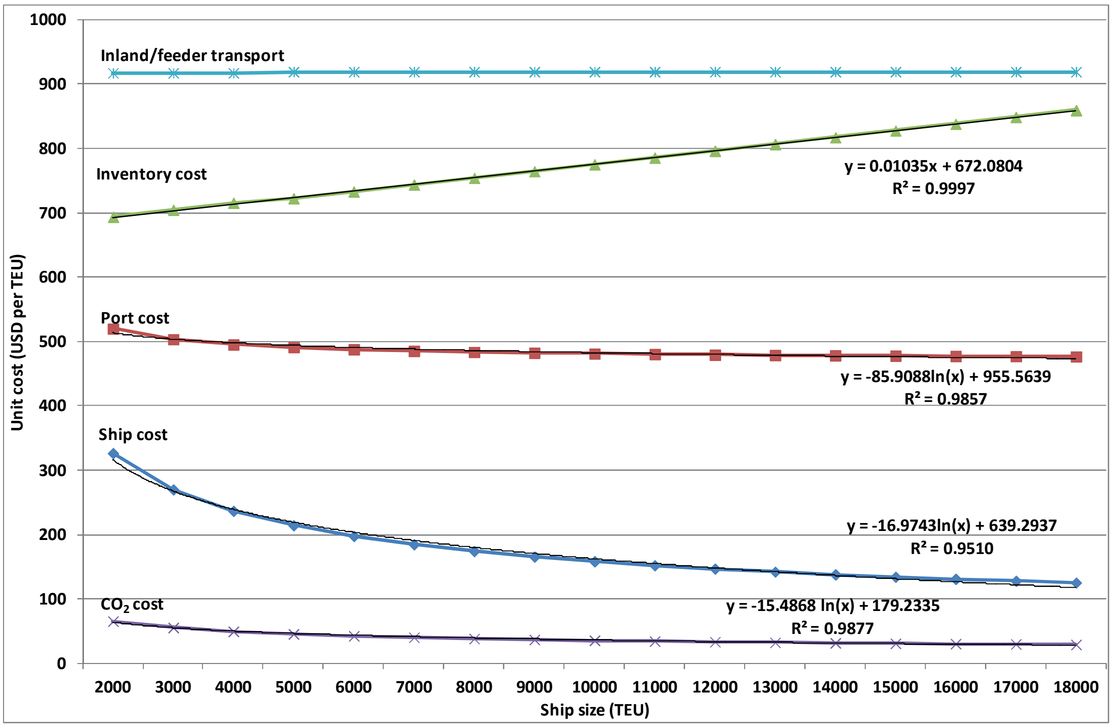

Figure 7-3: Ship size and unit cost

In contrast to such positive effect on the shipping cost, mega vessels lead to higher inventory cost. If ship size goes up by 1,000 TEUs, the cost moves up by \$10.35. Inventory cost is a hidden factor and often out of consideration in optimal models. Nevertheless, it accounts for a significant portion in the total cost and increase as ship capacity becomes bigger (27.5% with a 2,000 TEU vessel, 32.2% with 10,000 TEU and 35.7% with 18,000 TEU). Optimal ship size is evidently a trade-offs between the shipping cost and inventory cost.

The largest inventory costs are incurred during transit time at sea and dwell time in ports. The former is determined by ship speed whereas the latter by port policy and operational characteristics. However, major barriers of bigger vessels come from inventory cost generated during ship operation in ports and safety stock. On the one hand, bigger vessels require longer operating time in ports. On the other hand, they make longer the interval between two consecutive trips to ports, which means that shippers must keep higher stock to prevent the lack of inventory. Total port time is 6.4 days for a 9,000 TEU ship, in comparison with 9.8 days for an 18,000 TEU ship. Consequently, unit inventory cost in the port time increases from $107 to $165. Service frequency is 2 days for the former option and 4 days for the latter, which is equivalent to safety stock costs of $36.91 and $73.82 per TEU, correspondingly.

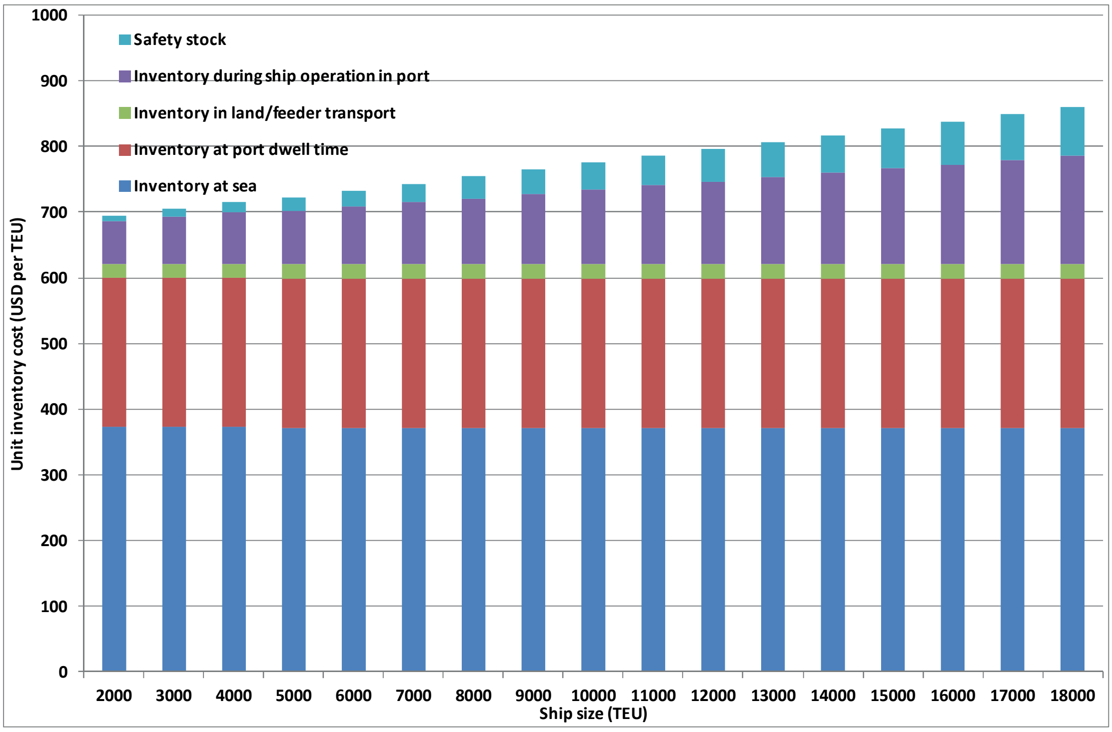

Figure 7-4: Ship size and unit inventory cost

Although inland/feeder time plays only a small part in the total transit time, inland/feeder transport cost is the most expensive item in the door-to-door cost with the portion of over 35%. The cost is naturally impacted by the choice of ports on shipping routes. The more port calls, the closer the service to the final market. Consequently, transport cost between hinterlands and visited ports declines. As illustrated in Figure 5, unit inland/feeder transport cost is $2,082 on the route with 2 port calls, the respective costs on the routes with 7 and 12 port calls are $1,033 and $919. High distribution cost is obviously a weakness of routes with a few visits, although they are beneficial from cheaper shipping cost due to short travelling distance as well as the smaller number of visited ports.

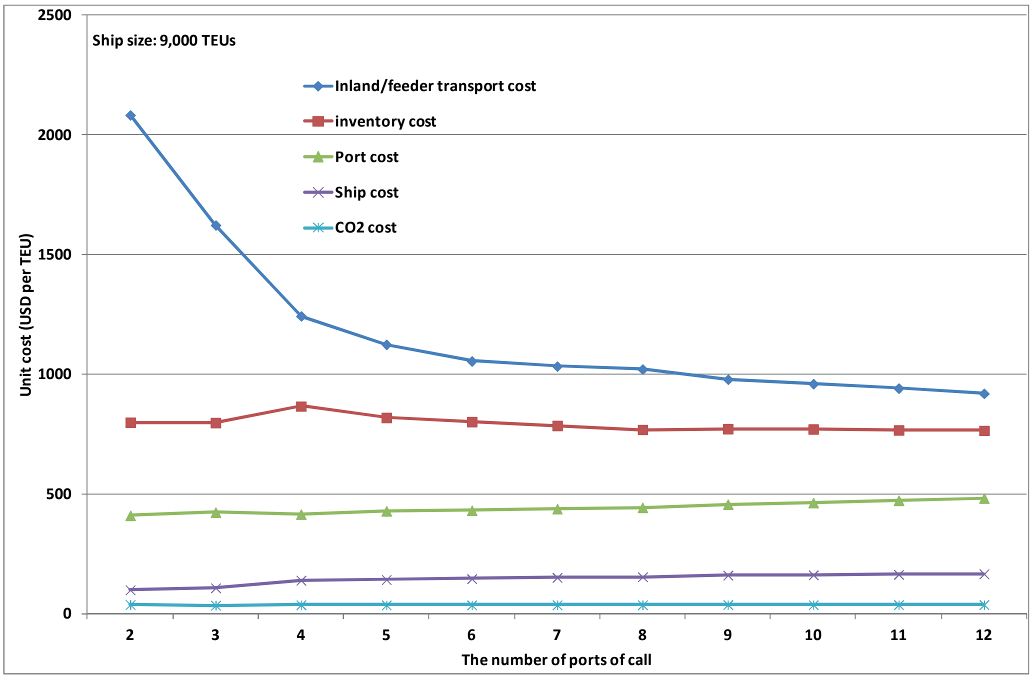

Figure 7-5: The number of ports of call and unit cost

Environmental effect of shipping has become growing concern in recent years (Balland et al., 2012; Cariou, 2011; Eide et al., 2011; Song & Xu, 2012; Wo & Moon, 2014). Our model takes account of CO_2 cost through bunker consumption and CO_2 tax. Actually, the cost merely contributes a marginal portion to the total cost with 2.6% ($65.57) in case of a 2,000 TEU ship, and 1.2% ($29.42) of an 18,000 TEU ship. It can be realised that the unit environment cost goes down as ship capacity increases. The largest part of CO_2 cost in the supply chain is generated by ship operation. Therefore, cheaper environmental cost could be a good argument to launch mega ships. It has been claimed by Maersk Line that CO_2 emission of its Triple-E ships is 50% less than the industry average on the Asia-Europe trade lane.

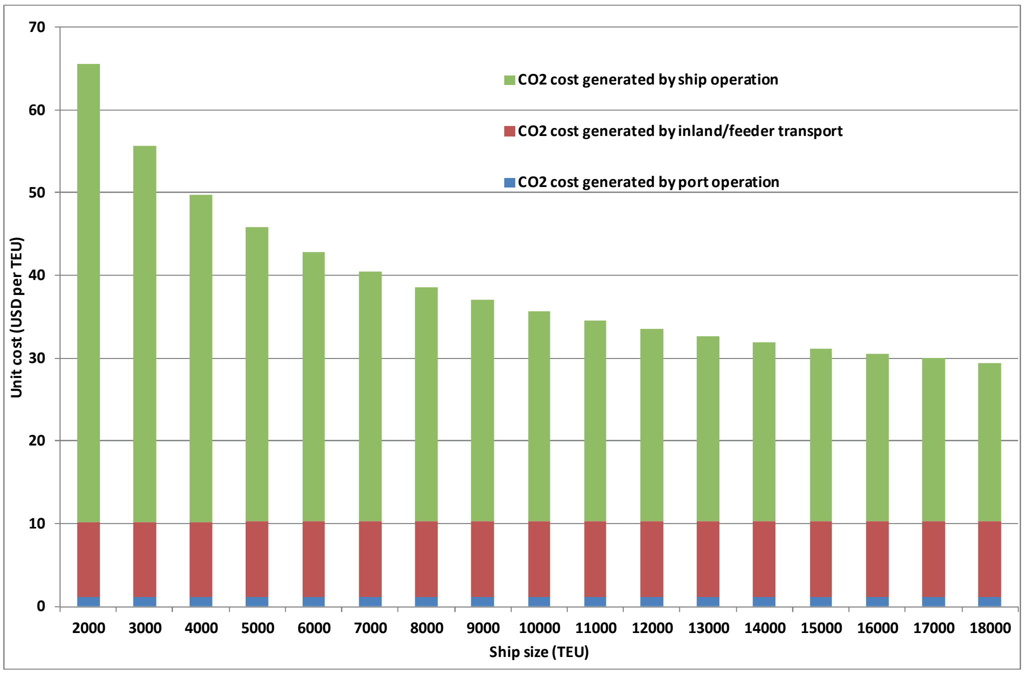

Figure 7-6: Ship size and unit CO_2 cost

7.5 Conclusions

This chapter proposes a model to optimise transportation flows between two regions through and end-to-end service. The major difference from other models is the inclusion of inland transport cost, inventory cost and CO_2 cost, in addition to ship cost and port cost. The model not only takes account of expense of operators but also shippers and society. In terms of supply chain stage, it integrates both maritime and inland legs.

The application is carried out using trade flows between the USA and Europe. The outcome reveals that inland transport cost is the most expensive one among the supply chain costs. It is influenced much by the selection of ports. The greater the number of port calls, the cheaper the cost is. Often treated as hidden cost, but inventory cost contributes a considerable portion to the total cost. The raise of this cost is a major barrier for the deployment of mega vessels as consequences of longer operation in ports which make higher the inventory captured during port time and longer waiting time between two successive trips which results in higher safety stock.

Chapter 8: CONCLUSIONS

8.1 Findings

Network design is obviously an important topic in the research on container liner shipping. Four research questions are placed in this thesis to investigate network design in container liner shipping. The first three ones are related to empirical research whereas the last one is related to optimization research.

Research question 1: How were operational patterns deployed in route design?

Route records in the years 1995-2011 of the top shipping lines were employed to find out key operational parameters of end-to-end, pendulum and round-the-world as well as their deployment in practice. The majority of routes operated under the end-to-end pattern. The pendulum was most deployed at the beginning of the 2000s, but the use went down afterwards. The round-the-world was employed limitedly, only Evergreen could operate it efficiently in a long period. A major advantage of the two latter patterns was the capability to serve multiple trades on a single route. On the other hand, traffic imbalance between trade legs prevented shipping lines from launching big vessels on pendulum and round-the-world routes. Consequently, they became disadvantageous over end-to-end routes in terms of scale economies of ship size.

Research question 2: How was container shipping network developed?

The second research issue employed the same data as the first one to analyze topological structure of the East-West shipping network. Through network indicators, some key results can be indicated: (i) expansion of the shipping system; (ii) features of arcs to link ports; (iii) the most central ports on the network; (iv) scale-free distribution of port calls; (v) positive relationship between the number of port calls and throughput; (vi) de-concentration trend in calling behavior. Dynamics of different regional networks can be seen, in that a striking feature was strong growth of secondary ports to capture calling share of leading regional ports.

Research question 3: How efficient were fleet expansion and mega vessel deployment?

Effects of operational factors on total (and unit) revenue and cost were measured via multiple linear regression models. There is no statistical evidence about impact of ship size on operators' financial performance. In terms of cost, total cost grew at lower level than capacity; consequently unit cost becomes smaller. Total revenue increased in line with added capacity, but with lower pace. As a result, unit revenue tended to decline as the fleet became bigger. Through the models, it can be recognized positive impact of slot usage and market freight rate as well as negative impact of oil price on financial results. A noticeable implication of the outcome is to highlight the importance of slot utilisation in ensuring the economics of fleet expansion and bigger vessel deployment in the industry.

Research question 4: How do operational factors influence on route design?

Research question 4 involves with route optimization. In addition to ship cost and port cost, the model takes account of inland/feeder transport cost, inventory cost and environmental cost. It can be realized that ship cost and port cost is only a part of the total door-to-door cost. Inland/feeder transport cost plays the biggest portion in the total cost and determined much by port choice strategy. Inventory cost is often treated as hidden cost, but it can be comparable to maritime cost and become more expensive as ship size goes up. The outcome of the forth research question implies the necessity to integrate logistics costs in optimizing shipping routes. Otherwise, the final result can be one-sided.

8.2 Limitation and future research

This research mainly concentrates on the deployment of the operational patterns in the industry. Therefore it is more descriptive in nature. It could be developed by taking account of cost models to efficiently compare different patterns as well as their viability in operation.

Regarding network analysis, route data are integrated from different shipping lines to study general features of the global shipping network, so this research cannot approach their individual strategies in organizing service. Network effects of strategic alliances and co-operation between carriers are not evaluated. The interaction between East-West and North-South or feeder routes is also out of the scope of our thesis. Such issues are topics in the next steps.

The data recruited to analyse fleet deployment is limited in the period of 1997-2012 with 224 samples. The inclusion of a greater number of observations can bring about better results for the analysis. Only five explanatory variables are employed in the models. Other ones such as charter fleet, alliance routes, empty container repositioning and operational trades may also added to explain more clearly financial performance of shipping lines.

In the optimization model, key data are recruited from official statistics as well as port industries. Some missing ones must take the assumption based on other researches, for instance manoeuvring time and dwell time in port. Therefore, there are some gaps with practice operation. The model is applied on end-to-end route between two markets. It can be expanded to serve multiple markets by the patterns of pendulum and round the world. The model is mainly concerned with the economic view, does not deal with port technical problems. Draught restrictions can prevent some large ships visiting a port. Serving a large number of containers in a short time can influence on transfer, yard operations, and receipt/delivery. We assume that there is no limitation with inland connection. However congestion may emerge as a result of a large number of vehicles. Only a few ports are selected as feeder ports. In fact, many ports can be used to take this function. Due to the lack of information, containers between port and origin/destination of shipments are assumed to be transported by rail and road; yet they are also used by inland waterway.

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DECLARATION

I hereby declare that:

- The doctoral dissertation is my own work without recourse to any unauthorised aids.

- I used only such sources and aids as are included in the references.

- I made due reference to all the works either quoted or used as the basis for ideas.

Best regards

Nguyen Khoi Tran