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Cascading Effects and Optimal Network Configuration Design for Liner Shipping

by

Rafiazka Millanida Hilman

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Lieve het leven van mij,
Ik heb gezegd.

Ik ben tot de tanden gewapend.
Doe maar gewoon, dan doe je al genoeg.

Abstract

Container liner shipping gains it centrality in the maritime transportation research along with the growth of seaborne trade. Global trade performance at higher speed brings twofold impact. The attractiveness of economies of scale captures the attention of major container liner as lower shipping cost per TEU may allow thicker profit margin. The deployment of Ultra Large Container Vessel (ULCV) afterwards is motivated by the aforementioned assumption. Consequently, persistent entrance of ULCV could exacerbate overcapacity condition. Falling transportation cost per TEU and tightening competition among shipping liners are the critical implication to which container liner should deal with.

Most of ULCV are phased into Asia-Europe route due to demand hike within this trade lane. A swing in preference of the container liners towards ULCV triggers reallocation of ship assignment. The previously dominant medium size vessels are allocated to smaller routes, widely known as cascading phenomenon. It serves the main focus of this thesis to examine the subtle point to challenge: Is that a strategic decision to make given the presence of ULCV? Does ULCV guarantee economies of scale such that profit can be maximized? What is strategic response that may lead to optimum solution for container liner in this setting?

The objective of this thesis is to construct a model for the situation where cascading phenomena driven by the deployment of ULCV exist in container liner shipping and propose a network design as a strategic response to the current situation such that profit is maximized. At first, network structure is analyzed based on network properties in graph theory such as degree centrality and betweenness centrality. Using a mix integer programming formulation, combined ship-scheduling and cargo-routing problem is solved by conducting two-phase problem namely Regional Route Network Design (RRND) and Route Construction and Ship Allocation (RCSA) are solved. In order to reduce the problem size, clustering algorithms of PAM and DBSCAN are performed to ports located along Asia and Europe trade lane.

This thesis highlights the implication of ULCV deployment on profitability of liner shipping in which Maersk is used as a case study. To capture the cascading phenomena, two consecutive periods are selected based on the development of ULCV namely 2010 and 2018. Maersk original routes in Asia-Europe service network are used as a reference network. There are 1,935 OD pair demand observed between 58 ports for both year, while demand in 2018 is projected by 34% growth from the initial period in 2010.

This thesis finds that highly centralized and connected ports can be regarded as candidates of additional port to be called on route, among others are Shanghai, Hong Kong, Rotterdam, and Singapore. On the clustering part, PAM clustering is upper hand than DBSCAN as it results in shorter distance and larger demand concentration at hub ports. Overall, the proposed network CBN A with 10 clusters is the best to compare to reference network because both are performed under slow steaming practice at 15 knots with demand volume in 2010. It allows higher profit by 30 with cost efficiency of 12%. This finding indicates that more competitive financial performance can be induced by properly adjusted network design with combination of maximized cargo flow between ports given minimized distance.

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Chapter 1 Introduction

Container liner shipping gains it centrality in the maritime transportation research along with the growth of seaborne trade. UNCTAD (2017) reports that 10.3 billion tons in seaborne trade volumes reached in 2016. Among others, containerized trade accounts for 1,720 million tons approximately 16.7% of seaborne trade by volume and 60% by value. Furthermore, the projected trade volume growth at 2.8% in 2017 allows over 260 million tons more loaded on the vessels than in the previous year.

This positive expectation brings back the market optimism after the prolonged depressed demand triggered by global economic contraction at the moment the US hit financial crisis in 2008. Shipping industry was severely affected by global recession at its shipping cycle peak. Subsequent staggering effect was created by an imminent downfall in demand for container shipping slightly after a significant capacity upgrade. At that point, orderbook was six times higher than the average orders placed between 1980 and 2006 (Haralambides and Thanopoulou, 2014).

Global trade performance at higher speed brings twofold impact. Heaver (2002) observe that an increasing vessel size is could be a blatant consequence of the growing seaborne trade. Causation between volume of goods traded across oceans and size of ship deployed on services holds, assuming the characteristics of container shipping as derived demand of international trade. Unsurprisingly, the attractiveness of economies of scale captures the attention of major container liner as lower shipping cost per TEU may allow thicker profit margin. However, less cautious decision on vessel order placement with respect to business cycle may have more harm to the industry. Container shipping, for instance, is still under the shadow of an oversupply to the upcoming years because expected delivery from preceding orderbook that has been made before global crisis put idle capacity on a longer list.

Persistent entrance of ultra large container vessels (ULCV) both before and after economic downturn such as Emma Maersk (14,770 TEU) in 2006 and MSC Oscar (19,224 TEU) in 2015 could exacerbate overcapacity condition. The trend towards pronounced increase in container ship size is estimated to sustain as reflected by the delivery of newbuilding in 2017 such as MOL Triumph (20,150 TEU), Maersk Madrid (20,568 TEU), and OOCL Hong Kong (21,413 TEU). Larger size vessel does present in orderbook, including CMA CMG expecting 9 units of 22,000 TEU vessel in 2019 (Hand, 2017). Falling transportation cost per TEU and tightening competition among shipping liners are the critical implication to which container liner should deal with.

Most of ULCV are phased into Asia-Europe route for being expanded to 23% of containerized trade in 2016 (UNCTAD, 2017). Nevertheless, World Maritime News (2018) citing SeaIntel Maritime Analysis asserts that the annual capacity that can be adsorbed within this trade lane does not exceed 5%. Consequently, the previously dominant medium size vessels are allocated to smaller routes because scrapping is too early to consider. Otherwise stated, container liner attempts to push excess capacity to other markets, thus, taking the cascading effects into accounts. There is subtle point to challenge: Is that a strategic decision to make given the presence of ULCV? Does ULCV guarantee economies of scale such that profit can be maximized?

What is strategic response that may lead to optimum solution for container liner in this setting?

1.1. Problem Description and Complexity

The presence of ULCV inevitably affects the network structure of container shipping. Smaller number of port of calls and more tendencies towards indirect from direct service in order to maximize the volume of cargo carried in a voyage are likely to be the pattern if the trend continues. Another complexity brought by ULCV is on the adequacy of port specification as not all ports are capable in handling such a large container ship. Either way, it is financially unsound for liner shipping company to call at a port with low demand. As it is the case, the shifting from the predominant circular, pendulum, and butterfly routes to hub-and-spoke route with transshipment option is expected.

1.2. Research Problem

The objective of this thesis is to construct a model for the situation where cascading phenomena driven by the deployment of ULCV exist in container liner shipping and propose a network design as a strategic response to the current situation such that profit is maximized. Furthermore, the optimization method discussed in the model is tested on the empirical case of Asia-Europe Container shipping route in which Maersk network in 2010 used as a reference network.

This results in the main research question as follows:
To what extent the optimality of network configuration design can be guaranteed under cascading phenomena driven by the deployment of ULCV?
In order to adequately address the main research question, number of issues and sub research questions should be clarified as follows:

1. How does the trend of ULCV deployment drive cascading phenomena in container liner shipping network?
2. How does the shifting in structure of hub and regional network of container liner shipping between 2010 and 2018 take place?
3. Which model can be used to design container liner shipping networks for liner shipping in response to cascading phenomena?
4. Which mathematical programming technique can be used to solve combined decision making on fleet-design, ship-scheduling and cargo-routing problem?
5. Which proposed network is the best to compare to reference network?

1.3. Contribution

This thesis contributes to the use of mathematical programming technique in designing efficient route network for container liner. A model for simultaneous network design and vessel deployment with multiple hubs and regions is presented. A more realistic setting is adopted in the problem formulation concerning on the ULCV deployment with weekly service window and flexible demand fulfilment. This thesis differs from the major literatures in this field by initializing the principle of network theory derived from graph theory where connectivity (edge) between points (node) matters. Ports are treated as nodes under directed network while number of trade links and cargo flows to other ports are represented by edge so that port call and transshipment can be strategically determined by referring to port with high connectivity and throughput as well as route or sea leg with considerable amount of demand. Insight from this particular aspect could improve the performance of the widely recognized three level of decision making comprising fleet-design, cargo-routing, and ship-scheduling problem. Furthermore, this thesis offers an alternative perspective by looking at optimal solution for profit maximization under recent uncertainty faced by container liner namely cascading effect.

1.4. Structure

This thesis is organized as follows. Chapter 2 reviews relevant literatures related to network design and decision making in container liner shipping comprising strategic planning level, tactical planning level and operational planning level. Sub-question 3 is addressed in this part. Chapter 3 discusses methodology including problem formulation of fleet-design, cargo-routing, and ship-scheduling along with iterative and clustering algorithm as solution algorithm, assumptions, and scenarios. Chapter 4 provides available data required in this thesis research. Both chapters are dedicated to establish foundation for a rigorous mathematical programming technique raised on sub-question 4.

Analytical parts are delivered from Chapter 5 to Chapter 10. Chapter 5 provides theoretical proof for the feasibility of economies of scale assumption in the case of ULCV. It aims to mathematically justify the significance of ULCV deployment that drives cascading phenomena in container liner shipping network. Chapter 6 identifies the cascading phenomena in the container liner shipping as a result of the ULCV deployment that may affect the network structure. It attempts to answer sub-question 1 and 2. Chapter 7 delivers the estimation of profitability regarding to the deployment of ULCV. This serves as an empirical case to theoretical proof established in Chapter 5 as well as a benchmark to optimal solution presented in Chapter 9.

Chapter 8 presents the result of clustering algorithm for various k-centroids (PAM Clustering) and density-based approach (DBSCAN Clustering). It is necessary to run these algorithms in order to: i) simplify the large and complex problem in container liner decision making; and ii) ruminate over set of ports into two classes namely hub and feeder. The first reason falls into sub-question 4 on the congruity of mixed integer program while the second makes a point in regards to sub-question 3 where hub-and-spoke design is the case. Chapter 9 reports comparative performance of proposed network design over the reference network design in pursuant to sub-question 5. Last but not least, discussion and main findings in this thesis are summed up in Chapter 10 as a stepping stone to further research direction in the future.

Chapter 2 Literature Review

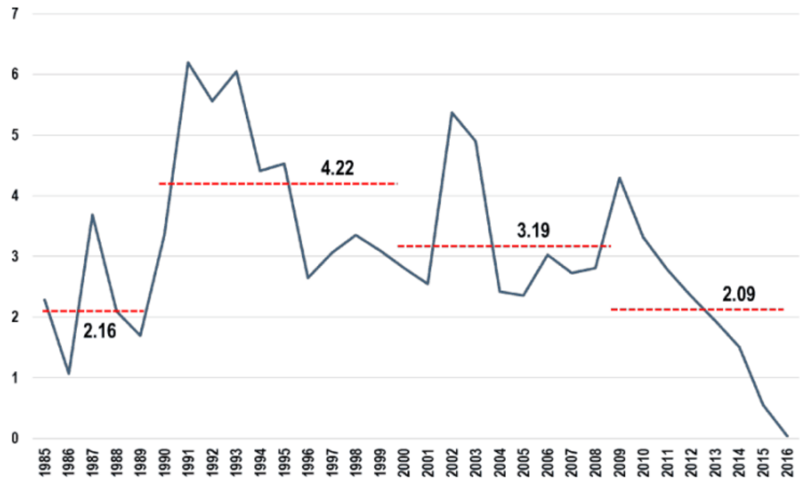
Container shipping operation is a complex decision making that counts each individual problem solution and joint decision making between respected problems in the model. An increasing complexity is found as heavy swing towards ULCV is getting bold in practice. Consequently, overcapacity on supply side presses down freight rate generating lower profit. It shows that despite global trade bounces back to positively firm growth, number of uncertainties and ambiguities still exist. Container shipping liner are battling with conflicting ideas especially on cargo routing such that profit can be maximized: Whether fewer port availability for ULCV leads to fewer port calls? Whether slow steaming option taken by ULCV leads to fuel cost efficiency? Whether the spacious dimension of ULCV leads to hub-and-spoke system?

This chapter highlights these issues by reviewing the previous works related liner network design and decision-making level in the context of ULCV. At first, this chapter highlights the emergence of ULCV as an attempt to exploit economies of scale (Section 2.1). Continuous deployment of ULCV in particular route ultimately results in cascading effects in other routes. Section 2.2 provides numbers of network design in container liner namely hub and spoke, butterfly, pendulum, and circular route as previously discussed in Mulder (2016). Last but not least, decision-making level is available in Section 2.3 where individual and combined problem are addressed.

2.1. ULCV Economies of Scale

The scope of ULCV deployment is not limited to the extent container shipbuilding takes place, but also alters the very central maritime infrastructure which is container port and terminal. As the workhouse of global economy, container vessel should be able to timely adapt to the market dynamics. Prior to the crisis in 2008, container volume growth was above Gross Domestic Product (GDP) growth rate. Multiplier of 2.5 GDP, for instance, can be interpreted as for 1% of GDP growth, container volume grows at 2.5%. The robust growth for quite a long period triggers continual upgrade in ship size so does container volume loaded into it.

Figure 2.1. TEU to GDP Multiplier, 1985-2016



Source: Rodrigue, Notteboom, and Slack (2017)

Figure 2.3 illustrates the relational state expressed in multiplier between container volume and GDP from 1985 to 2016. Container volume is represented by total handing volumes at ports. Rodrigue, Notteboom, and Slack (2017) suggests that there are four phases to identify. Firstly, initial speed up process of containerization along with globalization and trade liberalization took place between 1960s and 1990 resulting in multipliers within 2 to 2.5. The second phases occurred from 1990 to 1999 marked by surging multiplier up to 4 due to the expansion of service network among liners and port development worldwide. Slightly corrected from the previous phase, the multiplier stood still at peak growth of 3 between 2000 and 2008 given hefty growth of container port volume in China and major ports across hemisphere. Notwithstanding, massive wave of global economic contraction actuated by the US financial crisis in 2008 shifted the multiplier to tumultuous downward. It unceasingly is weakened from the range of 2 in the initial years of the fourth phase to the value less than 1 in 2015 and ended up at 0 by 2016.

A positive sign towards global economic recovery in 2017 brought a better prospect for container shipping industry. Alphaliner quoted by World Maritime News (2018) states that TEU to GDP multiplier could be lifted to 1.7 in 2017 considering the growth of global container throughput at 6.7% with Chinese ports on the frontier at 9.1%. Even though less multiplying effects exist at the present, Rodrigue, Notteboom, and Slack (2017) argues that this ratio is still relevant to anticipate container volume in port traffic forecasting because it captures the interaction between trade performance and container liner decision: the flow of empty containers (trade imbalance) and transshipment (service network).

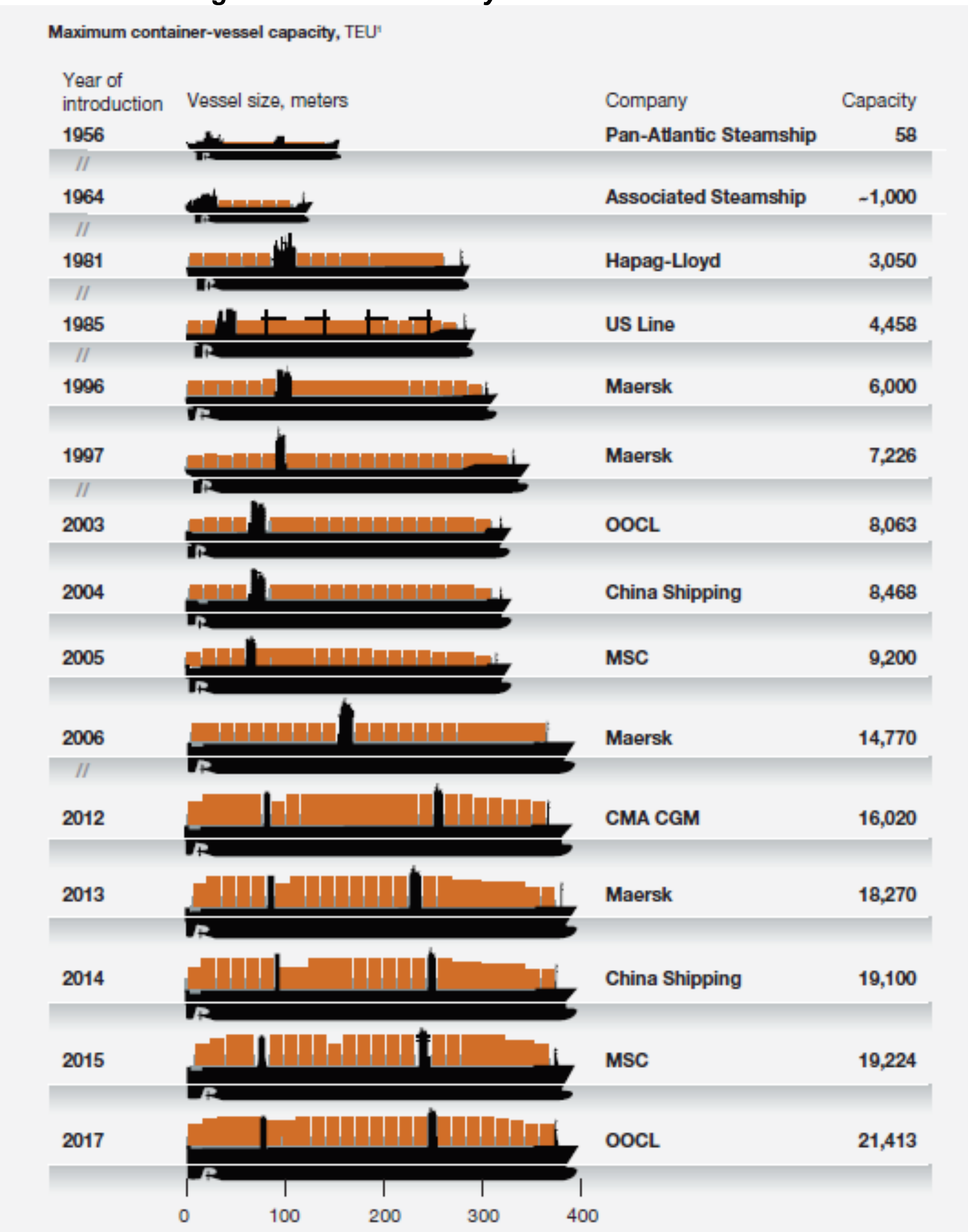
A captivating concept of economies of scale evolves under particular expectation that lower transportation cost per TEU could be sustained due to cost saving at sea leg. Moreover, the tight competition among container shipping liners leave a narrow choice for another option besides looking at size factor to secure their competitiveness in the market. Lim (1998) argues that according to incontrovertible basic theory of scale economies, there are two types of cost consideration. Firstly, an increase in cargo capacity does not linearly relates to building costs. Secondly, the lower unit cost per TEU during the sailing period offers higher earning per TEU given a steady freight rate. He recognizes the prospect for alliances in container shipping industry to optimize the scale power.

In consonance with this point, McKinsey (2017) asserts that cost efficiencies in crew, emission, and fuel are the primary logics behind the search for scale. Structural consolidations that have been on the air for more than a decade justify Lim (1998). Operating a single ship jointly between two liners on a route is financially more plausible than running two small vessels independently.

2.1.1. Container Fleet Development

Since its pioneering step after taking a transformation from a World War II oil tanker to the 58 TEU SS Ideal X, a dramatic increase in size of container vessel capacity is clearly seen (McKinsey, 2017). The presence of containerization in shipping business changes the embedded nature of cargo handling and port activities that previously was characterized by employment irregularity, lack of coordination, and extemporaneousness of schedule.

Figure 2.2. Evolutionary Size of Container Vessel



Source: McKinsey (2017)

The definition of large vessels, not to mention ULCV, changes over times. Figure 2.2 illustrates the development of container vessel size since its introduction in 1956 until 2017. The sequence of capacities and requirements imposed are as follows:

- The first generation accommodates the largest at capacity closer to 1,000 TEU (with LOA <175 m and draught <9 m).
- The second generation loads maximum 2,000 TEU to 3,000 TEU (with LOA <175 m and draught <9 m).
- The third generation allows capacity at most 3,000 TEU to 5,000 TEU (with LOA <270 m and draught <11.5 m).

- The fourth generation known as Panamax contains up to 6,800 TEU (with LOA <300 m and draught <13.6 m).
- The fifth generation known as Post-Panamax carries maximum 6,000 TEU to 8,000 TEU (with LOA <350 m and draught <14 m).
- The sixth generation has space for maximum 10,000 TEU to 13,600 TEU (with LOA <405 m and draught <16.5 m).
- The seventh generation allows containers to be loaded maximum 14,000 TEU to 22,000 TEU (with LOA <405 m and draught <16.5 m).

Classifying container vessels with the immense wave of larger vessels in the recent time could be varied because of the absence of common denominator that refers to particular types of container vessel. Category evaluation based on capability of Panama Canal and Suez Canal to accommodate such vessels comes more often than others, therefore, the third and fourth generation are named after. In the context of contemporary largest container vessels, Prokopowicz and Berg-Andreassen (2016) highlight that vague definition stumbles upon Very Large Container Ships (VLCS) and Ultra Large Container Ships (ULCS). The consider VLCS for vessel size all 10,000 TEU and 20,000 TEU and ULCS for vessel size above 20,000 TEU. In this matter, VLCS and ULCS correspond to VLCV and ULCV because the term of ship is interchangeable with vessel.

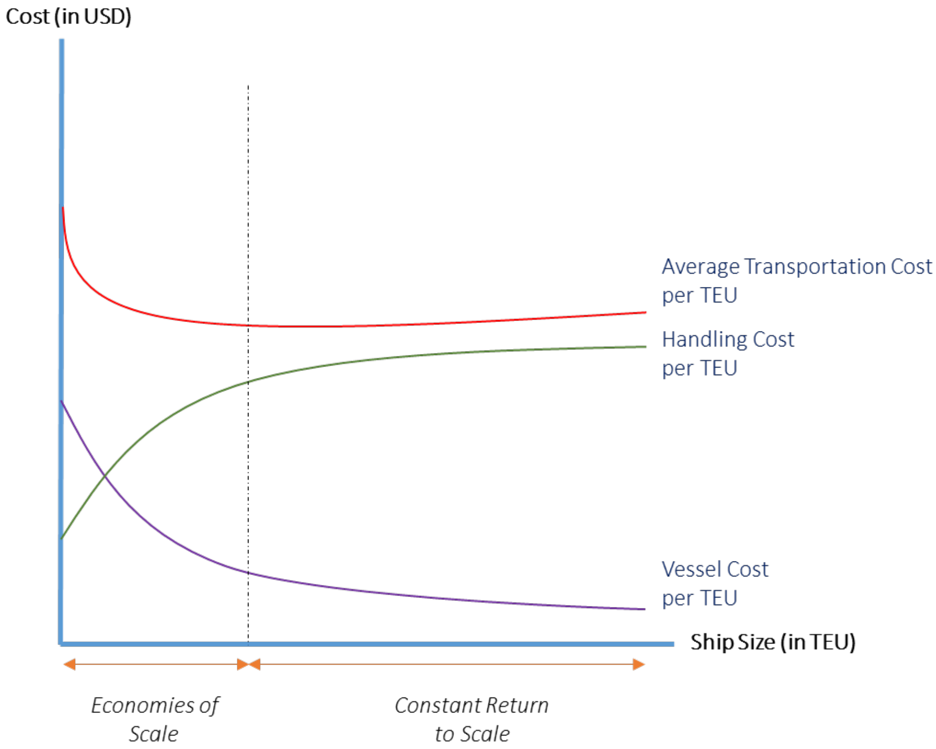
Considering the period of observation in this thesis is between 2010 and 2018, ULCV is defined as a container vessel with maximum design capacity starting from 14,000 TEU to 22,000 TEU. Consequently, the availability of ships that is discussed in Chapter 3 should fall into this range and port selection is subject to draft restriction at 16.5 m.

2.1.2. Container Port and Terminal Development

Handling ULCV requires more advance technique and waterside infrastructure at port. McKinsey (2017) discusses the physical constraints including the narrowness of waterways. Number of port to visit is limited due to draft restriction. The today largest vessel OOCL Hong Kong with 21,413 TEU capacity needs a clearance for its 16 m draught. It is a challenge for Hamburg where restricted draft is 15.1 m during high tide and even does not exceed 12.8 m during low tide (Prokopowicz and Berg-Andreassen, 2016). Furthermore, it raises an issue on the provision of adjusted port infrastructure. Port operators and terminal are strained in cash due to heavy investment on upgrading quay cranes and dredging equipment, building quay walls, and extending berth length.

The lineup of largest container vessel in the mid-1990s, Regina Maersk (7,500 TEU), put upstream seaports such as Antwerp and Hamburg into discourse. Baird (1996) convince that as scale increases, more harms to competitiveness of these ports are more likely to be the case. The fact that the container market shares of Hamburg-Le Havre range increase instead, as argued by Notteboom et al. (1997), is by the means of artificial extension of the lifecycle motivated by political forces, according to Baird (1997). He projects that calling at ports located in narrow inland waterways will not prolong in the future.

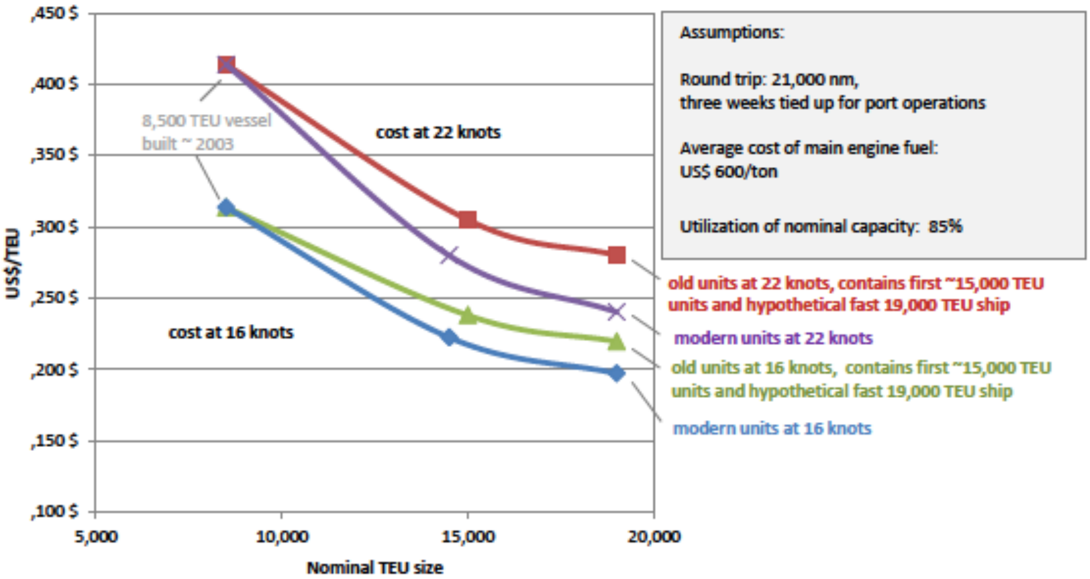
Figure 2.3. Vessel Costs and Transportation Costs



Source: Author's illustration based on OECD (2015)

Number of studies investigate the validity of economies of scale notion in the case of larger container vessels in the contest of optimal ship size (Chen and Zhang, 2008; Sys et al. 2008; and Tran and Haasis, 2014). It is widely believed that the search of size upgrade is motivated by cost saving as discussed previously in Section 2.1. However, a contrasting point of view from OECD (2015) shows a negative relation between ship size and handling costs. Decreasing vessel cost per TEU is actually followed by increasing handling costs per TEU, making even higher total transportation cost per TEU. This standpoint seems quite pessimistic in viewing the prospect of economies of scale in the case of ULCV. The stated argument holds only if the utilization rate of ULCV is high due to fixed handling charge imposed by terminal operator. To this point, yet to be found that terminal operator levies higher handling charge for ULCV. Therefore, it could not be fully taken as granted. The critical insight from theoretical perspective is made in Chapter 5 while empirical figures are presented in Chapter 7 and Chapter 9.

Figure 2.4. Simulation of Cost Savings



Source: OECD (2015)

Misleading path regarding to the interpretation of economies of scale could be triggered by less materialized fact that cost savings decrease as ships get bigger. Figure 2.4 indicates that a large proportion of cost savings generated when a vessel is upsized from 8,500 TEU to 15,000 TEU, meanwhile, a larger ship being introduced leads to a lower proportion of cost savings (15,000 TEU to 20,000 TEU). An incremental size upgrading as seen in the first shifting from an old ship with smaller size to a new ship with larger size account for this finding supports Sys et al. (2008) and Veldman (2011).

2.1.3. Cascading Effects

OECD (2015) observes that ULCV deployment on particular trade lane, such as Asia-Europe may affect the condition and infrastructure requirement in other regions where other routes remain. These larger newbuilds may replace the existing fleet design and become redundant. Alternatively, container shipping liner assigns the displaced ships to another route where those smaller ships may serve smaller trade volume. As the trickle-down-phenomenon prevails on the trade lane with the smallest trade volume and set of ships, cascading effects hold. Thus, the massive impact of ULCV and a seemingly boundless future for the development of larger ships, may bring continuously changing configuration of maritime transport chain.

An empirical study proposed by Cariou and Cheaitou (2014) exhibit cascading pattern of medium-size ships coming from or sailing to South America, for instance North Europe-South America trade. Build on the premises that the potential overcapacity would likely be responded by container shipping liner through adding transshipment hubs, they compare the profit outcomes between direct service and indirect service using 2 sets of ships: 4,000 TEU and 6,000 TEU of which constitutes 7 vessels each. Tangier and Algeciras are selected as transshipment hubs. It is found that an additional call at transshipment hub is conditional upon the sizeable cargo collected there especially after substituting 6,000 TEU vessels for 4,000 TEU vessels.

Figure 2.5. Cascading Effects in Container Shipping Trade Lane

	2011	2013	2015	2017
Asia-North Europe	16,000	16,000	19,000	21,000
Asia-Med	14,000	14,000	16,000	16,000
Transpacific	10,000	13,000	14,000	14,000
Transatlantic	7,000	8,000	9,000	9,000
Asia-South America	9,000	10,000	11,000	13,000
Asia-W Africa	4,000	4,000	8,000	13,000

Source: Drewry (2018)

Figure 2.5 reveals the cascading patterns in container shipping. Vessels with capacities 16,000 TEU that in 2011 and 2013 served Asia-North Europe is on routes from Asia to Mediterranean in 2015 and 2017 as a subsequent decision to deploying larger vessels with capacities 19,000 TEU in 2015 and 21,000 TEU in 2017. Similar phenomena are apparent during the period on other trade lanes such as between Transpacific and Asia-South America, Transatlantic and Asia-West Africa, as well as Transpacific and Asia-West Africa.

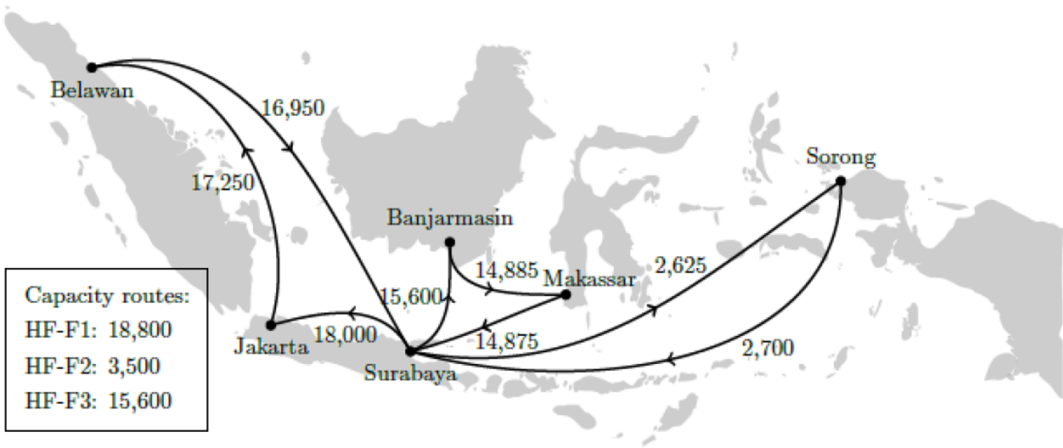
2.2. Liner Network Design

In liner network design, there are four route systems that are generally examined: Hub and spoke, Butterfly, Pendulum, and Circular. This section is adopted from Mulder (2016) where shipping lines in Indonesia being a central point in the case study. The six main ports are presented and properties of liner shipping including economies of scale and route efficiency based of route system. Demand imbalances between regions where each port located occur. Sorong, for instance, is the farthest port in the east with relatively away smaller demand comparing to the western counterparts such as Jakarta and Surabaya where cargos are densely centralized. Thereupon, as transporting cargo from Surabaya to Sorong is more expensive than to elsewhere, a container liner should build a pricing strategy in order to maintain the attractiveness of sailing to Sorong.

2.2.1. Hub and Spoke

Surabaya serves as a hub in this route system where the rest of ports namely Jakarta, Belawan, Banjarmasin, Makassar, and Sorong are the spokes. There are three routes determined: F1, F2, and F3. The first route connects Surabaya-Jakarta-Belawan-and Surabaya on the go. The second route offers a direct feeder service between Surabaya and Sorong. The third route sails along Surabaya-Banjarmasin-Makasar-Surabaya. As a hub is connected to various feeder ports, container liner can allocate different ships that fit to different routes by taking demands into account.

Figure 2.6. Hub and Spoke Route

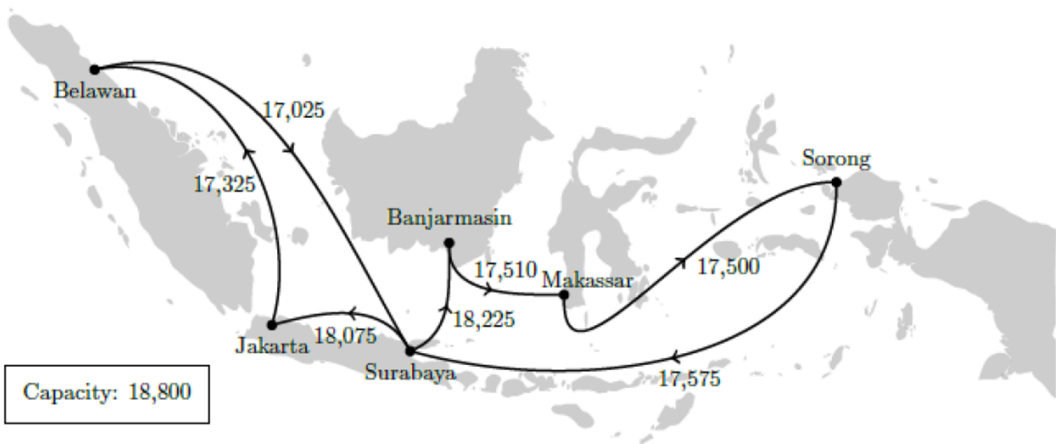


Source: Mulder (2016)

2.2.2. Butterfly

Butterfly route system allows hub port to be called twice in a sailing period. In this case, the order of port visit is Belawan-Surabaya-Banjarmasin-Makassar-Sorong-Surabaya-Jakarta-Belawan. Comparing to Circular route system, Butterfly route system performs better in term of capacity utilization. As Surabaya is called twice on route and Jakarta is called directly after, a cargo from Jakarta to Surabaya only spends one sea leg.

Figure 2.7. Butterfly Route

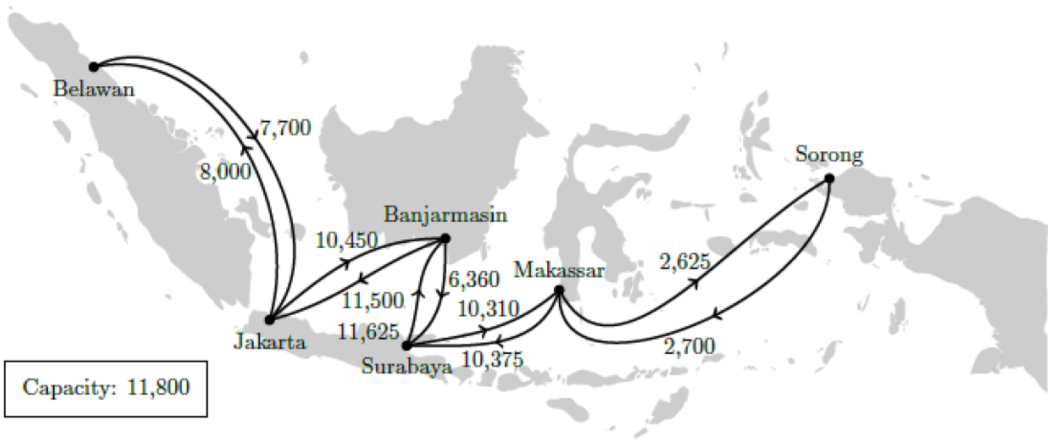


Source: Mulder (2016)

2.2.3. Pendulum

Multiple calls at one port are made in the Pendulum route system. It shows that each port is visited twice in a reversed order. This route system requires the lowest capacity because all ports are called twice. It has less flexibility on the fleet size deployment comparing to hub and spoke because a single type of ship sails to every port during a journey without considering demands and port restrictions.

Figure 2.8. Pendulum Rou

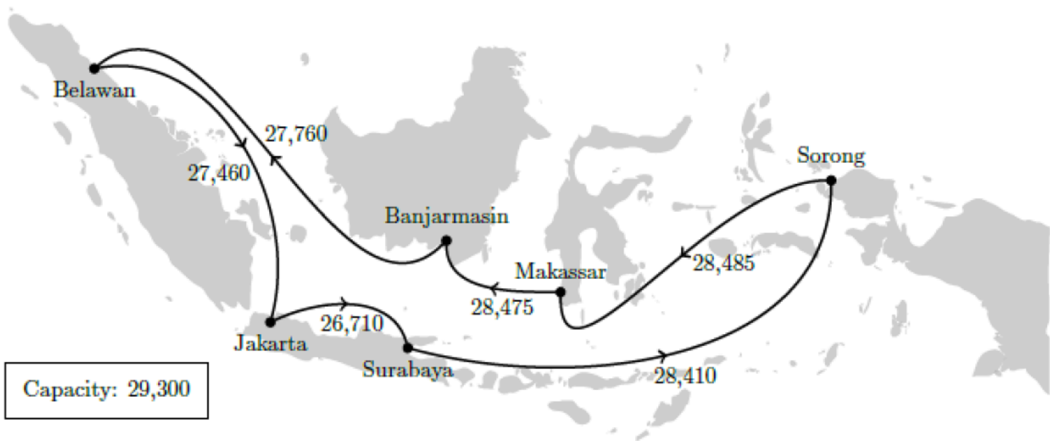


Source: Mulder (2016)

2.2.4. Circular

In the circular route, every port is visited once in a round. The journey starts from Surabaya to Sorong, Makassar, Banjarmasin, Belawan, Jakarta, and returns to Surabaya. This results in longer period spent in on sea leg so that efficient capacity utilization cannot be obtained. Surabaya and Jakarta that is close by distance requires considerable time to transport a cargo because a cargo from Surabaya are on the round tour visiting all ports on route before retrieving Jakarta that is at the end of the route.

Figure 2.9. Circular Route



Source: Mulder (2016)

2.3. Decision-making Level

Transformation brought by containerized shipping in the market in the following year does affect the types of operations. Lawrence (1972) outlines three types of operations namely tramp shipping, industrial shipping, and liner shipping. The first refers to the on-demand assignment of ship so that a fixed schedule is not required and a supernormal profit can be generated due to a higher freight rate. The second represents a shipping operation directly controlled by cargo owner expecting the lowest shipping cost. The later mentioned illustrates a shipping practice attached to regularity in term of both route and schedule. Container liner afterwards falls into this category.

Today, container liner deals with an integrated approach in maintaining its operational standard. Agarwal and Ergun (2008) specify decision making level of liner shipping into three constituting strategic planning level, tactical planning level, and operational planning level. The strategic planning level involves selection of fleet based on number of vessel and vessel size such that the optimal fleet design can be determined. Furthermore, tactical planning level aims to solve the ship-scheduling problem by designing service network. It consists of routes creation and ship allocation to the respective routes. The subsequent stage which is the operational planning level copes with the cargo-routing problem by choosing the cargo on board and the route used to transport the cargo.

2.3.1. Fleet-design

The optimal fleet size is determined by Fagerhold (1999) using an integrated solution approach that consists of 3 phases. At first, the largest fleets are deployed to the routes where demands do not always as large as capacities. Ship size can be scaled down upon the evaluation and the ships serving each route with least cost are selected. The second phase creates routes combination with a week sailing period is imposed. The ship size of the new route should not exceed the largest ship on the previous routes that are combined. Last phase is set as a partitioning problem where larger problems need longer computational time to solve following exponential increase in time.

Powell and Perakis (1997) prefers an integer programming to solve the optimality of fleet size. However, as frequently perceived as a challenge for an integer programming, integer solutions should be fulfilled. Result manipulations generate suboptimal solutions. Moreover, larger problems turn to be time consuming.

2.3.2. Ship-scheduling

Ronen (1983) is among the first providing literature review ship routing and scheduling. An updated version can be found in Ronen (1993) after observing the development of maritime transport literate within a decade. Similar objective is retrieved by Christiansen, Fagerholt, and Ronen (2004) for observation period from 1994 to 2004.

Ting and Tzeng (2003) apply dynamic programming algorithm to manage minimal total expected variation of time window in a set of preferred port sequence. They suggest various options to control the ship-scheduling, among other are speed adjustment and port visit order. The usual time window is set at weekly schedule. Agarwal and Ergun (2008) note that service offered by container liners mostly available once a week in order to bring certainty to customer with regularity in schedule.

2.3.3. Cargo-routing

Boffey et al. (1979) suggests a heuristics method to maintain optimal solution for cargo-routing problem such that maximizing profit is in parallel with maximize revenue under fixed costs environment. Demand is assumed to be independent to service so that transit time becomes a critical parameter. Thereupon the longer transit time than limit required, port pair selection should be reviewed.

Rana and Vickson (1991) in which later instigated by Reinhardt et al. (2007) underlines the relevance of loops in routing where it is perceived as connected routes because it mirrors the industry. Choosing particular cargo instead of loading all available cargo is possible. Reinhardt et al. (2007) applies one route per ship during the planning horizon with an insertion of optimal ports for transshipment, meanwhile Fagerholt (2004) set a ship to sail at least one route. Although cargo selection is feasible, the unassigned cargo volume should be minimized in keeping with service. Song et al. (2007) introduce two objectives namely unassigned cargo minimization and minimize total costs minimization corresponding under minimal assigned cargo and use heuristics approach to solve the problem.

Multi-port calling, and hub-and-spoke networks is tested by Imai et al. (2009) to achieve least-cost combination among routing scenarios. To minimize distance with respect to demands, a genetic algorithm is employed. Chuang et al. (2010) also use a genetic algorithm to find the fittest route under circular design where pre-determined port at starting point is the same at end point.

2.3.4. Combined Ship-scheduling and cargo-routing problem

Fagerholt (2004) comes up with two-phase solution method for a multi-trip vehicle routing problem (VRP) in the case of real liner shipping problem. At first, route generation out of 120 ports is conducted for all feasible solutions in which later is used as input to an integer programming to deal with the combined problem of ship-scheduling and cargo-routing. This approach works for a small and well-constrained problem where the proportion of demand at each port to ship capacity, so the ratio between voyage times and maximum time available is. Meanwhile, he suggests heuristics to assure optimal solution within a reasonable amount of time for a larger problem, so does for not well-constrained structure of problem.

Alternatively, Álvarez (2009) present comparative performance of three algorithms namely a greedy heuristic, column generation, and Benders decomposition as a strategy to maintain the quality of solution in short computational time. This methodological approach is derived from the combination of mathematical programming and meta-heuristics mechanism. The joint routing and ship deployment problem is formulated as a mixed integer program (MIP) and is solved separately using the previously stated method. In term of solution quality, the column generation and Benders decomposition do not differ. Contrastingly, Benders decomposition allows faster computational time. Gelareh and Pisinger (2011) impose similar decomposition technique particularly a branch-and-cut to the fleet deployment on hub and spoke network (FDHSN). Nonetheless, challenge faced by a larger problem remains the same: exponential growth of time required to have an optimal solution. On this point, heuristics can be considered.

Chapter 3 Methodology

This part of the thesis aims to provide a systematic overview of the problem formulation that has been introduced in Chapter 1. In the beginning, network structure is introduced to lay a theoretical foundation of port call selection. It relates to the second sub-research question on the shifting in structure of container liner shipping network. These centrality measures are calculated in Chapter 6 using Cytoscape. It is followed by the problem description for both independent and combined decision making in the following sections in order to respond the third, fourth, and fifth sub research question respectively on model, mathematical programming, and proposed network. A solution algorithm is proposed along with assumptions and scenarios. In the independent decision making, three individual problems namely fleet-design, cargo-routing, and ship-scheduling problem are given before formulating the combined ship-scheduling and cargo routing problem. The later mentioned problem is executed software program developed by Mulder (2016) with some adjustment made by author to fit the model specification in this thesis.

3.1. Network Structure

Centrality is one of the focal point in the network study because the centrality of a node in a network captures a number of ideas relating to the prominence of a node in a network. There are two main centrality measurements used in this thesis namely degree centrality (C_D) and betweenness centrality ($C_B(N)$). Degree centrality captures the relative prominence of a node comparing to other nodes in the form of the degree. A node with degree $n-1$ (the maximum possible degree) would be directly connected to all other nodes, hence this node is quite central to the network. Therefore, a node that has 2 edges or simply said that a node is connected to only 2 other nodes within a network that consists of large number of *n* is considered to be less central. Thus, degree centrality can be computed as,

$$C_D = d_i(g) = \#\left(i;\ g_{ij} = 1\right) = \sum_{j \neq i}^{N} g_{ij} \tag{3.1}$$

The representation of a network as specified in De Benedictis et. al. (2013) is a graph that consists of a set of nodes $N = \{1, 2, 3, .., n\}$ and edges $g \in \{0, 1\}$ where all possible networks on *n* nodes is denoted by g as described by an *N x N* adjacency matrix $g = \left[g_{ij}\right]$. The binary value of g_{ij} shows the existence of relationship between node *i* and *j* in which the value of 1 signifies the presence of link between two nodes and 0 otherwise. Let $N_i(g) = \left\{j\ \in N \text{ I }\ g_{ij} = 1\right\}$ denote the nodes with which node *i* has a link, thus this set will be referred to as the neighbors of *i.* The terminology of node in this thesis refers to port that are called in container shipping network, while edge is interchangeable to cargo demand flow between ports. That being so, neighbor is in parallel with other ports that a particular port is connected to through cargo flow.

Since the measure of degree centrality depends on the number of nodes in the network, it is impractical to make a comparison between networks with different size of node. On that account degree centrality can be transformed into the normalized form by putting normalized factor $N-1$ of the total number of possible neighbors excluding self,

$$C_D^N = d_i(g) = \#(i;\ g_{ij} = 1) = \frac{\sum_{j\neq i}^{N} g_{ij}}{N-1} \tag{3.2}$$

If the edge is directed, the degree centrality of node has two components namely the out-degree centrality and in-degree centrality. The first corresponds to the number of outgoing link, meanwhile, the second represents the number of ingoing link. The value of this parameter ranges from 0 to 1. The closer the degree centrality to 1 indicates the more a node is directly connected to the other edges in the network.

$$C_{D\_out}^N = \frac{\sum_{j\neq i}^{N} g_{ij}}{N-1} \tag{3.3}$$

$$C_{D\_in}^N = \frac{\sum_{j\neq i}^{N} g_{ji}}{N-1} \tag{3.4}$$

Betweenness centrality amplitudes the superior position of a node concerning on the flow of information between node pairs in the network. It captures degree of the shortest paths to reach a node such that the one lies on the central has a potential to exploit the flow of information. The measurement of this type of centrality is defined as

$$C_B(N) = \sum_{x\neq n\neq y} \frac{\sigma_{xy}(N)}{\sigma_{xy}} \tag{3.5}$$

where the number of shortest paths in the network ranging from node x and y is denoted by σ_{xy} so that $\sigma_{xy}(N)$ constitutes the number of shortest paths that are characterized by the inclusion of node n. Therefore, higher value of betweenness centrality value indicates signaling pathways of information. In shipping route and network design, a node with high betweenness centrality is perceived as an intersection of cargo flows such as in the case of transshipment.

3.2. Problem Formulation

Agarwal and Ergun (2008) specifies the scope of individual decision making in liner shipping namely fleet design problem (Section 3.2.1), ship-scheduling and network design problem (Section 3.2.2), and cargo routing problem (Section 3.2.3). In order to formulate problem closer to the real liner shipping problem as suggested by Fagerholt (2004), a joint problem between ship-scheduling and cargo routing is proposed in Section 3.2.4.

3.2.1. Fleet-Design Problem

Fleet-design problem stands on the objective of setting fleet composition in terms of number and size optimally. This problem should be solved due to high costs barrier identified as fixed costs arising from capital expenditure and variable costs resurging from operating expenditure. The preference towards ULCV is commonly driven by economies of scale. Lower transportation cost per TEU, however, is followed by higher fixed costs. Therefore, proper demand estimation in selected route should be made.

3.2.2. Ship-Scheduling and Network Design Problem

Ship-scheduling problem focuses on the design of service network where routes and ship allocation to the designated routes are determined given a certain fleet. The restricted nature of ship allocation to specific routes is due to the limitation of port specification, given the particular ship type. This is the case in which not all ports can be visited by ULCV recalling the issues on depth of harbor, width of harbor entrance, quay length, and crane dimension. Regarding to port call and transshipment, hub and spoke network design is constructed.

3.2.3. Cargo-Routing Problem
Cargo-routing problem sets the demand volume that should be accepted and determine the route to transport this cargo given a fleet and a fleet schedule. Costs incur during the sailing between origin and destination port in parallel with revenue collected based on freight rate. For the purpose of profit maximization setting, only demand pair that satisfies or partly satisfies is taken.

3.2.4. Combined Ship-Scheduling and Cargo-Routing Problem
A combinatorial approach between ship-scheduling and cargo routing problem is motivated by the contingency characteristics of the aforementioned problems. Inadequate decision related to service network on ship-scheduling may result in sub-optimum profit on cargo routing. Accordingly, it is justified to formulate simultaneous decision making where service network is constructed with routes set in order to transport cargo from origin to destination such that profit maximization holds.

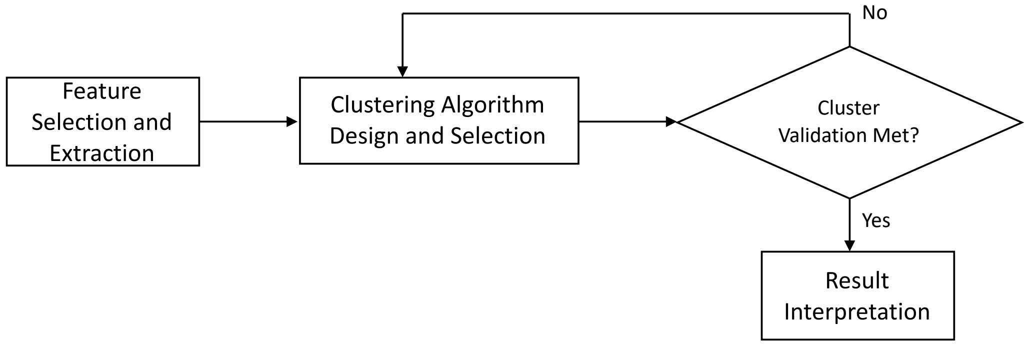
3.3. Solution Algorithm
As a means to design a network that satisfies the hub-and-spoke specification, an iterative solution algorithm based on a MIP is applied. It is more preferred to a genetic algorithm-based approach because the improvement in network by iteration can be guaranteed (Mulder and Dekker, 2016). Hub and regional routes are iteratively updated while other routes remain the same.

- Potential hub ports are selected from the data.
- Port clustering is designed using clustering algorithm.
- Route network consists of hub and regional routes.
- A string of ports is a directed network denoting the order of port visit.
- Optimization of connecting hub routes is made given set of regional routes.
- Optimal design for regional routes can be generated under satisfied demand obtained with fixed hub routes.
- Initial regional route network is obtained by solving the regional route network design (RRND) problem considering initial demand between each OD-pair.
- Ship allocation and cargo routing (SACR) problem is solved in which satisfied demand is later used as a new input in the RRND problem.

3.3.1. Initial Cluster Set Up
Clustering algorithms are applied to reduce the size of problems in RRND and SACR. These algorithms assign data objects into clusters based on shared characteristics. Cluster in itself, according to Everitt (1980), can be defined as “an aggregate of points in the test space such that the distance between any point in the cluster is less than the distance between any point not in it”. This serves as a basis of the first type of clustering algorithm used in this thesis which is partitional model such as Partitioning Around Medoids (PAM) clustering algorithm (Kaufman and Rousseeuw, 1990).

In conjunction with this concept, Everitt et. al. (1980) discussed another operational definition of cluster which is "continuous regions of this space (d-dimensional feature space) containing a relatively high density of points separated from other such regions by regions containing a relatively low density of points". The later mentioned represents density model of clustering algorithm such as Density-based (DBSCAN) clustering algorithm (Ester et al., 1996). Collectively, these definitions outline the presence of internal homogeneity and external separation (Gordon, 1999).

Figure 3.1. Schematic Overview of Clustering Procedure



In constructing port clusters $C = \{C_1, \ldots, C_K\}$ given a set of ports $\boldsymbol{P} = \{p_1, \ldots, p_N\}$, the procedure follows Figure 3.1. Feature selection suggests a particular characteristic that could be used to distinguish a subset from other subsets, while feature extraction attempts to do data transformation in order to extract a novel feature (Jain et. al., 2000). Both terminologies are somehow interchangeably in a large and growing body of clustering literature as the two are in search of a salient feature p_{ji}.

<u>Feature Selection and Extraction</u>
Assessing clustering tendency aims to check whether the dataset contains any inherent clusters with non-random structures. A salient feature is extracted using visual and statistical determination of clustering tendency namely Visual Analysis for Cluster Tendency Assessment (VAT) and Hopkins Statistic. Hathaway and Bezdek (2002) originally propose VAT to examine the clustering tendency of a set of data by virtual means. A matrix of pairwise objects in the dataset are reordered based on dissimilarities as in this case is distance. Distribution of clusters is indicated by the dark and intense block images along pairwise diagonal.

Algorithm 1: Visual Analysis for Cluster Tendency Assessment (VAT)

1. For each pairwise object in the dataset, compute the dissimilarity matrix (DM) using Euclidean distance.
2. Construct an ordered dissimilarity matrix (ODM) based on reordered DM where similar objects are located next to each other, *vice versa*.
3. Display visual illustration of ODM as an ordered dissimilarity image (ODI).

Implementation of VAT in R uses the combination of three R packages: *factoextra, clustertend, and seriation*. It reveals that the white shade is proportional to the value of the dissimilarity between objects as pure red plotted if $dist(p_i, p_j) = 0$ and pure blue plotted if $dist(p_i, p_j) = 1$. The square shaped dark blocks along the diagonal line indicates the number of clusters. In the case of Asia-Europe trade lane, it appears that three well-formed red blocks presented implying three main port clusters comprising Asia, Mediterranean, and Europe. Further clustering algorithms in the next stage are performed to generate reasonable number of cluster that may minimize distance and maximize cargo carrying capacity within a respected route.

Algorithm 2: Hopkins Statistic

1. Set a sample of n points $(p_1, \ldots, p_n)$ from the dataset D under uniform distribution.
2. Find the nearest neighbor p_j for each point $p_i \in D$ with distance function between p_i and p_j defined as $x_i = dist(p_i, p_j)$.
3. Construct a simulated dataset $rand_D$under random uniform distribution that consists of a sample of n points $(q_1, \ldots, q_n)$ with the same variance as the dataset D.
4. Find the nearest neighbor q_j for each point $q_i \in rand_D$ with distance function between q_i and q_j defined as $x_i = dist(q_i, q_j)$.
5. Measure the Hopkin Statistics $H = \frac{\sum_{i=1}^{n} y_i}{\sum_{i=1}^{n} x_i + \sum_{i=1}^{n} y_i}$ as the ratio between the mean of the nearest neighbor distance in dataset $rand_D$ and the summation over the mean nearest neighbor distances in both dataset.

In addition to visual representation of clustering tendency using VAT, Hopkins Statistic detects spatial randomness in the dataset that may hinder the accuracy of clustering. Hopkins and Skellam (1954) proposed H estimator as probability that a dataset under a uniform data distribution. The null hypothesis states that the dataset D is uniformly distributed where no meaningful clusters found, meanwhile, the alternative hypothesis states otherwise implying the existence of meaningful clusters in the dataset. Hopkins Statistic is computed in R with *clustertend* package. In the dataset of 58 ports along Asia-Europe trade network retrieved from Lachner and Boskamp (2011), H value is 0.19. As H value closer to 0 (or far below the cutting point of 0.5), it suggests the rejection of null hypothesis and it can be concluded that this dataset contains clusters.

Clustering Algorithm Design and Selection

In constructing a route, port call should be determined beforehand. As a port has a unique location, the exclusivity of port in a single cluster should be guaranteed by $C_i \cap C_n = \emptyset$, where $i, j = 1, \ldots, K$ and $i \neq j$ recalling that $C_i \neq \emptyset \; i = i, \ldots, K$ and $\cup_{i=1}^{K} C_i = \boldsymbol{P}$. Thereupon, hard clustering is preferred with two variations: strict partitioning clustering and strict partitioning clustering with outliers. The first enforces singularity membership of an object into one cluster using PAM. The second allows outlier objects belong to no cluster using DBSCAN.

Algorithm 3: PAM Clustering Algorithm

1. Assign k ports as the initial medoids.
2. Construct a distance matrix between each origin and destination (OD) pair where $\exists i: \{p \in P: p \in \; C_i\}$ using Euclidean distance function $d(\boldsymbol{i}, \boldsymbol{j}) = d(\boldsymbol{i}, \boldsymbol{j}) = \sqrt{(j_1 - i_1)^2 - (j_2 - i_2)^2}$.
3. Determine initial hubs using k largest ports with regards to demand criteria.

4. Search non-hub ports that close to particulars hubs such that lower average distance obtained.
5. Assign those ports to the closest hub ports.

Initial clusters are determined by applying k-medoids clustering algorithm with k potential hub port attached to it. The rest of ports are allocated to the closest hub port using Euclidean distance function with regards to demand between ports. It generates number of clusters that minimizes average distance between ports within respected cluster. PAM clustering algorithm is performed in R with *factoextra* package.

Algorithm 4: DBSCAN Clustering Algorithm

1. Assign k ports as the initial medoids.
2. Construct a distance matrix between each origin and destination (OD) pair where $\exists i: \{p \in P: p \in C_i\}$ using Euclidean distance function $d(\boldsymbol{i},\boldsymbol{j}) = d(\boldsymbol{i},\boldsymbol{j}) = \sqrt{(j_1 - i_1)^2 - (j_2 - i_2)^2}$.
3. Determine initial hubs using k largest ports with regards to demand criteria.
4. Search non-hub ports that close to particulars hubs such that lower average distance obtained.
5. Assign those ports to the closest hub ports.

Comparing to PAM clustering algorithm that requires distinctively separated clusters, DBSCAN clustering algorithm accommodates clusters of arbitrary shape. On that account, PAM clustering algorithm fits to spherical-shaped distribution of objects or convex clusters, while DBSCAN clustering algorithm deals with non-convex clusters and outliers. In order to find the proper cluster for ports across Asia and Europe, DBSCAN clustering algorithm is conducted in R under *factoextra* package.

DBSCAN operates in order to generate a density estimate over the data space. The density around a point is estimated by using the concept of ϵ-neighborhood. This algorithm sets value for $N_\epsilon(p)$ and a $minPts$ to indicate density of a region and to categorize the points in a dataset under core, border, or noise points. $N_\epsilon(p)$ sets the closeness among points and to be considered a part of a cluster, meanwhile $minPts$ keeps the number of neighbors that belongs to a point should to be included into a cluster.

<u>Cluster Validation</u>
Cluster validation comes in to verify whether a particular structure in the data exists in the partition or scanning produced by clustering algorithm. It incorporates two approaches: internal validation and external validation. According to Xu and Wunsch (2009), internal validation is independent of prior information as direct examination on the original data regarding to clustering structure is taken, for instance Silhouette Method. On contrary, external validation depends on prespecified structure of data, such as Corrected Rand Index.

Algorithm 5: Silhouette Method

1. Compute PAM clustering algorithm for different values of k.
2. For each k, calculate the average silhouette of observations using $s(i) = \frac{b(i)-a(i)}{max\{a(i),b(i)\}}$ and it results in respective category:
   a. A strong cluster structure (0.71-1.0)
   b. A reasonable cluster structure (0.51-0.70)
   c. An artificially weak cluster structure (0.26-0.50)
   d. No substantial cluster structure (<0.25)
3. Plot the curve of average silhouette according to the number of clusters k.
4. The location of the maximum average silhouette is considered as the appropriate number of clusters.

Silhouette method computes the average silhouette of observations for different values of k. The optimal number of clusters k is the one that maximize the average silhouette over a range of possible values for k (Kaufman and Rousseeuw, 1990). The formal expression of Silhouette method is stated in Algorithm 5 where $a(i)$ the average distance between port i and all other ports within the same cluster meanwhile $b(i)$ is the lowest average distance of port i to all points in any other cluster, of which port i is not a member. Taking $a(i)$ as a measurement of dissimilarity of port i to its own cluster and $b(i)$ represents a poor matching to its neighboring cluster, a small value of $a(i)$ and a large value of $b(i)$ are expected to have a well-matched port i to cluster k.

On the external validation, Rand Index is computed to examine whether k-medoids clustering suits to the original structure of the data (Rand, 1971). Corrected Rand Index takes the similarity measurement between two clustering. It yields a value within 0 (no agreement) and +1 (perfect agreement) range. In dataset collected from Lachner and Boskamp (2011) on Asia-Europe container flows, the probability of pair of ports are clustered similarly in the subset X and Y is at 0.80. Thus, the agreement between the X and Y clustering regarding to the port pairs is 80% asserting high validity of cluster.

3.3.2. Hub Selection

The new hub is selected based on shortest average distance. In Equation 3.1, demand between clusters is represented by d_c and the present hub of cluster c' is indicated by h'_c.

$$\Delta_{hc} = c^{nm} \sum_{c \in C} \Delta_{hh_{c'}} (d_{cc'} + d_{c'c}) \qquad (3.1)$$

$$\Delta_h^c = \frac{\sum p \in P \Delta_{ph}}{|P|} + \alpha \Delta_{hc} \qquad (3.2)$$

The first requirement mentioned above is similar to Mulder and Dekker (2016) stipulating a hub to be located at the central of the cluster. The second requirement is derived from Koning (2018) where factor α is added to augment attractiveness of hub location as seen in Equation 3.2. The iterative process takes places until steady state is reached for every cluster.

3.3.3. Regional Route Network Design

Regional network represents a set of ports that could be visited in each cluster where number of feeder ports are connected to a hub. On a journey, feeder ports only can be visited once. Vessel speed is assumed to be constant as the existing average speed is considered as optimal, while Mulder and Dekker (2016) allows speed optimization in the problem formulation. It aims to satisfy weekly demand of each port under similar setting to vehicle routing problem with heterogeneous fleet where deliveries and pickups are simultaneous.
The following sets are introduced.

Sets

P^c Set of all ports in the particular cluster (excluding the hub port)
R Set of routes
R_p Set of routes which contain port $p \in P^c$
S^c Set of available ships in the particular cluster

The notation above is used in the following parameters.

Parameters

c_{rs}^r Weekly route cost of route $r \in R$ using ship $s \in S^c$
c_r^t Transshipment cost of route $r \in R$ for transporting demand for cargo between ports in the same cluster
t_{rs} Duration of route $r \in R$ using ship $s \in S^c$ at existing average speed and number of required ships to be allocated for weekly frequency
n_s Number of available ships of type $s \in S^c$
q_{prs} Fraction of satisfied demand of port $p \in P^c$ due to weekly sailing on route $r \in R$ using ship $s \in S^c$
k Constant denominates number of available ships

The model decision variables thusly are

Decision variables

y_{rs} Number of weekly port calls on route $r \in R$ using ship $s \in S^c$
z_r Binary variable representing the preference towards route $r \in R$ where $z_r = 1\, if\ the\ route\ is\ used\ and\ z_r = 0\, if\ otherwise$

The problem can be expressed as a MIP with the objective function minimizing the total costs incur on the selected route.

Problem Formulation

$$\min \sum_{r \in R} \sum_{s \in S^c} c_{rs}^r t_{rs} y_{rs} + \sum_{r \in R} c_r^t z_r \tag{3.4}$$

$$s.t. \sum_{s \in S^c} \frac{1}{k} y_{rs} \leq z_r \qquad \forall r \in R,\, s \in S^c \tag{3.5}$$

$$\sum_{r \in R} \sum_{s \in S^c} q_{prs} y_{rs} \geq 1 \qquad \forall p \in P^c \tag{3.6}$$

$$\sum_{r \in R_p} z_r = 1 \qquad \forall p \in P^c \tag{3.7}$$

$$\sum_{r \in R} t_{rs} y_{rs} \leq n_s \qquad \forall s \in S^c \ (3.8)$$

$$y_{rs} \in \mathbb{Z} \qquad \forall r \in R, \forall s \in S^c \ (3.9)$$

$$z_r \in \{0.1\} \qquad \forall r \in R (3.10)$$

In the direction of obtaining an optimal solution to stated problem in the objective function 3.4, number of constraints are bounded. Constraints (3.5) ensure the value of $z_r = 1$ if a ship sails on a route $r \in R$. To have all demand satisfied, Constraints (3.6) is applied. In addition to the demand requirement, Constraints (3.7) make sure that each port in the cluster could only be visited once. Number of ships used per ship type is limited by Constraints (3.8). Meanwhile, binary and integrality conditions of aforementioned variables are enforced by Constraints (3.9) and (3.10).

3.3.4. Route Construction and Ship Allocation

Section 3.2.3 on Regional Route Network Design provided regional network as the input for route construction. Another input left is regarding to ship allocation to each of those routes. Recalling that all possible routes only visit some of the hub ports, decision on which routes to sail should be made. The model specifications in this section is in parallel with Mulder and Dekker (2016) except the existing average speed is considered as optimal.

The following sets are admitted.

Sets

L	Set of legs
D	Sets of origin-destination demand pairs (OD-pairs)
Q	Sets of paths
Q_l	Set of paths that accounts for leg $l \in L$
Q_{od}	Set of paths that satisfied demand $od \in D$
R_l	Set of routes that accounts for leg $l \in L$

The above-mentioned notation implies in the following parameters.

Parameters

c_q^q	Cost of transporting one TEU along path $q \in Q$
b_s	Maximum TEU capacity of ship type $s \in S$
d_{od}	Demand of OD pair $od \in D$

The model decision variables are as follows.

Decision variables

x_q	TEU amount of satisfied demand that is transported along path $q \in Q$

The problem can be expressed as a MIP with the objective function minimizing the total costs minus revenue. In another word, it is a total profit maximization model where negative values resulted from the objective function reflect the positive profit.

Problem Formulation

$$\min \sum_{r \in R} \sum_{s \in S^c} c_{rs}^r t_{rs} y_{rs} + \sum_{q \in Q} c_q^q x_q$$

$$s.t. \sum_{q \in Q_{od}} x_q = d_{od} \quad (3.11)$$

$$\sum_{q \in Q_l} x_q \leq \sum_{r \in R} \sum_{s \in S^c} b_s y_{rs} \quad \forall od \in D \quad (3.12)$$

$$\sum_{r \in R} t_{rs} y_{rs} \leq n_s \quad \forall l \in L \quad (3.13)$$

$$x_q \geq 0 \quad \forall s \in S^c \quad (3.14)$$

$$q \in Q \quad (3.15)$$

$$y_{rs} \in \mathbb{Z} \quad \forall r \in R, \forall s \in S^c \quad (3.16)$$

There are three types of costs entitled to the model 3.11: (un)loading and transshipment costs, penalties due to unsatisfied demands, and total route costs. The later mentioned costs include fixed ship cots, port call costs, berthing costs, and fuel costs. Constraints (3.12) is used to restrict partially satisfied demands because demands should be either fully satisfied using one of the OD-paths or unsatisfied (as it is counted as lost sales). Leg capacity constraints in the network are introduced by Constraints (3.13). Number of ships used per ship type is limited as stated under Constraints (3.14). Thoroughly, non-negativity and integrality conditions of the path flows, and number of allocated ships are enforced by Constraints (3.15) and (3.16).

3.4. Assumptions

There are number of assumptions made related to fleet-design problem, ship-scheduling problem, and cargo-routing problem as discussed above.

- Initial fleet is given.
- Availability of all ships has been made since the initial planning period.
- Once a ship is assigned to a particular route, it will serve the route during time horizon stated in planning.
- Demand is assumed to be constant across planning horizon.
- Port restrictions are imposed on the size of ships.
- Weekly service window is applied.
- Multiple visit to port in a route is allowed.
- Hub and feeder networks are generated simultaneously.

3.5. Conclusions

Assumptions stipulated in Section 3.4 enables the model to illustrate and construct the ideal condition for container liner in designing ship-scheduling and cargo-routing. Regarding to fleet availability, instead of specifying the ships at individual level using IMO number, this thesis defines the ship class by size ranging from 10,000 TEU to 22,000 TEU for hub service and from and 1,200 TEU to 9,600 TEU for feeder service. This specification results in a prescriptive analysis to the extent that preference over ship size should be made to reach optimal profitability. Moreover, ships are allocated to certain route based on cargo demand since the beginning of planning period and remain on operation within time horizon. These first three assumptions are enforced under particular consideration namely limited access to AIS database. However, it still fits to the objective of this thesis in examining the impact of vessel size on optimal profit level.

On demand side, this thesis assumes a limitation of constant demand level across planning timeline to simplify the model. In fact, container liner faces volatility across the period due to higher demand in Christmas and Chinese New Year. Port restrictions in term of draft is considered for the feasibility of ULCV deployment on hub routes. Meanwhile, weekly service window is necessary to maintain regularity of service. Multiple port visits respond high demand in larger ports such that high demand delivered and high profitability could be obtained. Last assumption is taken into account to guarantee the synchronized pickup and delivery between hub and feeder ports.

Chapter 4 Data

This part of the thesis specifies data generating process that is used in the thesis. The new dataset is created notwithstanding to represent the reality with an actual decision making. It consists of two separate datasets with identical structure of variables with different timeframe: 2010 and 2018. Running multiple datasets simultaneously is motivated by the shifted preference over larger ship size within the period. Maersk service network on the Asia-Europe trade route is used including port of call, ship, and speed. Demand matrix in 2010 is based on Lachner and Boskamp (2011) with updating for forecasted data in 2018. The cost data are from Linerlib (2012) in addition to distance matrix is retrieved from Lachner and Boskamp (2011). Moreover, the distances used in clustering are composed based on cartesian coordinate information gathered from Marine Traffic (2018).

4.1. Port

Port dataset are developed based on ports located along the main Asia-Europe trade lane that are visited by Maersk container vessels in 2010 and 2018. In the first period of observation Mulder (2011), there were 58 hub ports but in the second phase (Maersk, 2018), there are only 39 ports left. Less port of call phenomena is analyzed in the context of cascading effect in container shipping in Chapter 6. In Appendix A, the list of hub ports, countries and regions can be found in Table A.1.

4.2. Distance

The distances between ports are estimated in reference to sea distance collected from Lachner and Boskamp (2011) as provided in Appendix A in Table A.2. On clustering section, Euclidian distance between port $\boldsymbol{i}$ and $\boldsymbol{j}$ is formulated as an approximation to sea distance. Such distance is translated into the line segment length between the two $\overline{(\boldsymbol{ij})}$ that exists in Euclidean 2-space with Cartesian coordinates collected from Marine Traffic (2018). Using Pythagorean formula, the distance is computed in *R* program as

$$d(\boldsymbol{i},\boldsymbol{j}) = d(\boldsymbol{i},\boldsymbol{j}) = \sqrt{(j_1 - i_1)^2 - (j_2 - i_2)^2} \tag{4.1}$$

The use of Euclidean distance in the case of maritime transportation should be made cautiously and carefully to prevent misdirection caused by straightline connection. In order to improve the quality of distance data among ports, the results of clustering are validated by the sea distance in Lachner and Boskamp (2011). The one that results in minimum distant is chosen. As such clustering generate shortest average distance between ports in a cluster, this value remains valid.

4.3. Ship and Network

Ships deployed by Maersk Asia-Europe network in 2010 and 2018 become a reference that is compared with the best network proposed in this thesis. Maersk ships and capacities in that are assigned to each of 9 routes in 2010 can be retrieved in Appendix B in Table B.2. Moreover, the similar information for 2018 network are made available in Table B.3. The average capacity of ships operated in 2018 is 17,804

TEU, two times larger than the size of 2010 capacity. It leads to an indication that the preference of container shipping liners such as Maersk towards ULCV may drive the cascading effect. This issue is discussed in Chapter 6. The comparison on Maersk route capacities in 2010 and 2018 can be found in the aforementioned appendix in Table B.4.

Pertaining to the network, the shifting from a more complex route structure to a leaner design is captured in Chapter 7 in conjunction with the direction settling in hub and spoke network structure. Maersk decides to reduce the number of routes within Asia-Europe trade lanes from 8 in 2010 to 6 in 2018 as shown in Table B.4, Table B.5, and Table B.6 in Appendix B.

4.4. Speed

Notteboom (2006) observes that the speed variation of container vessel ranges from 18 to 26 nautical miles per hour. This could be the case for 2010 observation when the operational speed was close to the design speed at 24 nautical miles per hour on average (Appendix B in Table B.5). However, the introduction of slow streaming obviously reduces the speed rate to 61% in 2018 (Appendix B in Table B.6). Therefore, constant speed at 15 nautical miles per hour is considered for ships deployed in 2018 (Appendix B in Table B.7).

4.5. Demand

Demand matrix for 2010 refers to data supplied by Lachner and Boskamp (2011) in Appendix A (Table A.3) with 1,935 OD demand pairs, meanwhile the dataset for 2018 is estimated using global average forecasting at 34% growth between 2010 and 2018 (World Bank, 2017). Aggregation method for non-selected hub ports in the same clusters is accommodated to make use of flow concentration in a way that economies of scale can be obtained on the hub network. Demands from and to non-selected hub ports are then served via the closest selected hub ports using feeder network service. Consequently, cost saving from sea leg activities is expected to improve the profitability of liner service.

4.6. Port Tariff

Following Mulder and Dekker (2013) and Koning (2018), terminal handling cost for unloading and transshipment are assumed to be constant per route type. Port cost incurs at fixed rate USD 25,000 for hub ports, meanwhile, USD 15,000 is imposed on feeder route. On top of that, variable costs are subject to vessel size in the case of unloading and transshipment. The amount of USD 170/TEU should be paid by the container carriers for cargo handling at hub ports, meanwhile USD 85/TEU is charged at feeder ports. This rate is based on the average handling charge provided in K-Line (2017) for Asian ports at USD 144 per TEU and European ports at USD 171 per TEU.

4.7. Cost

Fleet costs can be specified into three cost categories: capital cost, operating cost, and fuel cost. Capital cost is related to ship size and purchase price of ship. Operating cost consists of general overhead cost, crew cost, and maintenance cost. Linerlib

(2012) present the operating cost as the summation of 5% of the newbuilding purchase price and the 1.5 times of crew cost. Fuel cost is calculated based on IFO180 global average price assumption USD 500 per ton (Ship and Bunker, 2018).

4.8. Revenue

Revenue per unit is represented by container freight rate for Far East-Europe market in UNCTAD (2018). On Shanghai–Northern Europe trade bound during the period of observation which is between 2010 and 2018, the freight rates are strikingly fluctuated. In 2010, the peak was at USD 1,789 per TEU, however, it was halted by half to USD 881 per TEU a year after due to global economic crisis. Until 2015, the figures were higher than USD 1,000 per TEU. Slowing down in container shipping market in the following years due to simultaneous delivery of newbuilding especially on the ULCV class pushes freight rate into USD 700 per TEU. This latter figure is used in this thesis as a basis of revenue. On feeder route, it is about USD 105 per TEU.

4.9. Conclusion

This thesis refers to routes served by Maersk in 2010 to test the model performance for both observation periods which are 2010 and 2018. Consequently, demand between ports visited on Maersk routes as available in Lachner and Boskamp (2011) is used to indicate demand size in 2010 and the forecasted demand by 34% growth based on that initial level is assumed to measure demand in 2018. This approach is set down because of limited access to real time data. Comparing routes in both years, less than 50% demand between port pairs matched because of expansion of recent port pairs within the new network that are not available previously. As this measurement is taken, quality of data shall not affect the reliability of model constructed because this thesis primarily focuses on methodological part in looking at ship-scheduling and cargo-routing problem.

Chapter 5 Theoretical Proof of Economies of Scale on ULCV

The model set up used in this thesis has been presented in Chapter 3. This thesis focuses on finding an optimal solution for a combined ship-scheduling and cargo routing problem given the presence of ULCV. A profit maximization model is constructed with the objective function minimizing the total costs minus revenue. Accordingly, two sub-problems are studied: i) Regional Route Network Design (RRND); and ii) Route Construction and Ship Allocation (SACR).

Notwithstanding the above-mentioned problem formulation in Chapter 3, the formal theoretical insight is not yet properly addressed. In complement to an introductory discussion in Chapter 2 by comparing and contrasting the economies of scale arguments between Chen and Zhang (2008), Sys et al. (2008), Tran and Haasis (2014), and OECD (2015), this chapter derives theoretical proof into the problems in the direction of sub-research question 1: "How does the trend of ULCV deployment drive cascading phenomena in container liner shipping network?" Later in this data-independent chapter, it shows that the strict preference towards ULCV assignment on main network such as Asia-Europe trade lane is triggered by economies of scale concept. It is expected that deploying a larger ship on route with higher demand will induce: i) revenue-increment per route and ii) cost-saving per TEU on route in such way that the profitability can be improved in the network.

5.1. The Model

On the Route Construction and Ship Allocation problem, a ship is assigned on a route for V round voyages within T time units, therefore, VT is found to be a planned time window of the ship assignment. As $V \to \infty$, the long run average cost $c^*(s)$ becomes the main consideration as the development of ULCV is motivated by the decreasing cost per TEU. In the round tour, $P = \{1, \dots, |P|\}$ with $p \in P$ are the ports visited and the number of port calls is $N = V|P| + 1$ with $n \in \{1, \dots, N\}$ due to the cyclic voyage setting. Therefore, it implies that the first port call turns to be the last port call as well. The route cost (bunker cost and fleet cost) incurs during sailing time at sea leg between ports $p[n]$ and $p[n+1]$ is denoted by $c^v_{p[n],p[n+1]}(s)$ with a ship size s TEU. Let $c^p_{p[n]s}(s)$ be the port cost (port tariff, transshipment cost, and handling cost) charged to ship s. Thus, the long run average cost is

$$c^*(s) := \lim_{V\to\infty} \frac{c^v_{p[n],p[n+1]}(s) + c^p_{p[n]s}(s)}{V}, \forall s \in S \tag{5.1}$$

where $s = \left\{S \in V^{|P|}_{\geq 0} \mid \sum_{p \in P} S_p = \bar{S}\right\}$ is the set of feasible ship size.

5.2. Proofs of Cost

Lemma 5.1. The route cost function $c^v_{p[n],p[n+1]}(s)$ is convex in the ship size of s for $1 \leq n < N$ and $T \in \tau$.

Definition 5.1. A function $f: M \to \mathbb{R}$ is convex if it has a convex domain M for any $x, y \in M$ and every $\lambda \in [0,1]$ it holds that $\lambda f(x) + (1-\lambda) f(y) \geq f(\lambda x + (1-\lambda) y)$.

Proof 5.1. $c_{p[n],p[n+1]}^{v}\ (s)$ is convex if and only if sub-additivity property holds where $\lambda c_{p[n],p[n+1]}^{v}\ (s) + (1-\lambda)c_{p[n],p[n+1]}^{v}\ (s') \geq c_{p[n],p[n+1]}^{v}\ (\lambda s + (1-\lambda)s')$.

Lemma 5.2. The port cost function $c_{p[n]s}^{p}(s)$ is convex in the ship size of s for $1 \leq n < N$ and $T \in \tau$.

Proof 5.2. $c_{p[n]s}^{p}(s)$ is convex if and only if sub-additivity property holds where $\lambda c_{p[n]s}^{p}(s) + (1-\lambda)c_{p[n]s}^{p}(s') \geq f(\lambda c_{p[n]s}^{p}(s) + (1-\lambda)c_{p[n]s}^{p}(s'))$.

Theorem 5.1. The optimal long-term average cost per TEU $c^{*}(s)$ is joint convex in $s \in S$ given that $c^{*}(s)$ exists in $\mathbb{R}$ for $s \in S$.

Definition 5.3. The composition of $h \cdot g$ is convex if function $h: \mathbb{R} \rightarrow \mathbb{R}$ is convex and function $g: \mathbb{R}^{n} \rightarrow \mathbb{R}$ is linear.

Proof 5.3. The existence of $\lim_{V \to \infty} \frac{c_{1,V|P|+1}^{v}\ (s) + c_{1,V|P|+1}^{p}(s)}{V}$ holds by assumption. As convexity in $c_{p[n]s}^{p}(s)$ is proved by Lemma 5.2 so does convexity in $c_{p[n],p[n+1]}^{v}\ (s)$ is preserved by Lemma 5.1, joint convex in s holds in this limit.

ULCV is expected to call at less port since the availability of ports that are suitable for larger vessels is lower in number. As slow steaming persists, low bunker cost is expected after counting on high vehicle efficiency of the recent technology installed in the latest generation of ULCV.

5.3. Proofs of Economies of Scale

Corollary 5.1. Revenue per TEU increase with increment of vessel size.

Corollary 5.2. Profit per TEU rises linearly with increment of vessel size.

Corollary 5.3. Marginal saving in cost per TEU reduces progressively with increment of vessel size.

Jannson and Shneerson (1987) indicates the tradeoff between economies of scale achieve during voyage at sea (line-haul operation) and diseconomies of scale in port (handling operation) given the varying size of ship. Cullinane and Khanna (1999) conform the diseconomies of scale in port for large container. Therefore, as proposed in this thesis, diseconomies of scale in port is outweighed by economies of scale at sea at large distance, making larger vessel still possible to exploit the economies of scale in general.

Chapter 6 Cascading Effects on Existing Maersk Network

This chapter delivers two scopes of discussion related to the cascading phenomena in Maersk Asia-Europe Network between two periods of observation: 2010 and 2018. At first the structure of network in both years are examined using network properties such as degree centrality and betweenness centrality. Changes in network structure between 2010 and 2018 lay a foundation for further investigation on the presence of cascading effects in respected network. Moreover, as highly centralized and connected ports are identified, these ports can be regarded as candidates of additional port to be called on route after measuring weighted factors of the annual throughput and technical restrictions. It aims to improve service profitability as examined further in Chapter 9 on network configuration design.

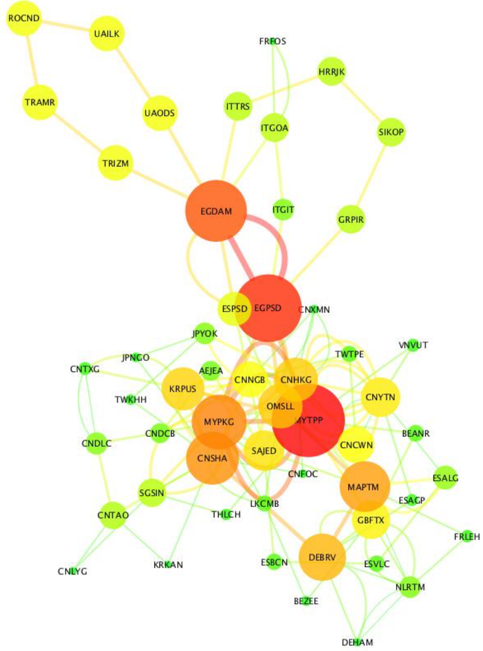
6.1. Original Route Network

This section reports an observation on the structure of Maersk route network serving trade between Asia and Europe. Ports called along the route are structured as a paired and directed network since a port is visited before and after another. Moreover, it implies that that the calling order and frequency of such pair are important to be investigated. The first part of this section is illustrated based on the non-weighted port call pairs using the original network of Maersk in 2010 (Section 5.1.2) and 2018 (Section 5.2.2) to examine whether structural change as indicated by cascading phenomena occur given the fact that ULCVs are extensively deployed within the period. The discussion is later followed by the weighted port call pairs with respect to origin and destination demand flows in the second part of this section based on demand for container transportation in 2010 from Lachner and Boskamp (2011). A weighted network analysis in 2018 is not specified because demand is assumed to be analogous to 2010 in term of flow between ports with scale growth in demand size by 34%.

6.1.1. Maersk Asia-Europe Network in 2010

In 2010, there were 58 port calls across 8 routes in Maersk Asia-Europe network. It made 24 multi-edge node pairs. Aggregating all available paths, 27 ports were visited after another, creating a category of ports with 1 in-degree connectivity and out-degree connectivity. It can be seen that by far in Appendix C in Table C.1, less ports have higher in-degree connectivity: 10 ports with 2 in-degree connectivity, 5 ports with 3 in-degree connectivity, 7 ports with 4 in-degree connectivity, 3 ports with 7 in-degree connectivity, and 1 port each with 8 and 9 in-degree connectivity.

Figure 6.1. Maersk Port Call Network, 2010



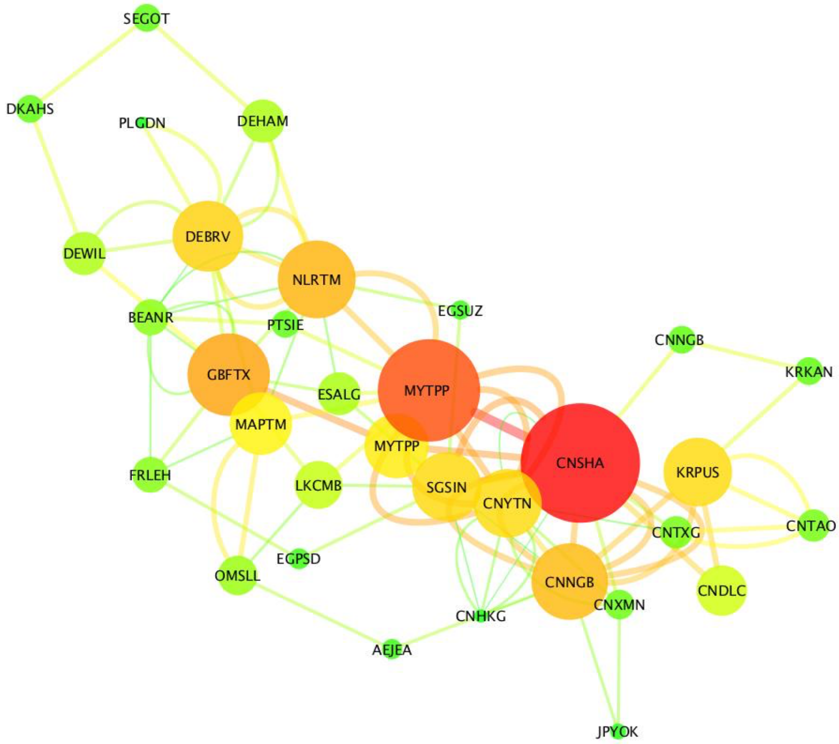
Source: Author's illustration based on Maersk Network in 2010 in Mulder (2011)
Note: Network structure is designed and illustrated by Cytoscape.

Figure 6.1 provides the structure of Maersk Asia-Europe Network in 2010. A bigger size and darker color node represent a higher betweenness centrality attached to that port. It is apparent from the figure that 5 ports could be proposed as candidates for additional port calls: Tanjung Pelepas (0.41), Port Said (0.36), Damietta (0.31), Port Klang (0.24), Shanghai (0.22), Tangier (0.20), Bremerhaven (0.18), Salalah (0.15), Hongkong (0.14), and Pusan (0.13).

6.1.2. Maersk Asia-Europe Network in 2018

In 2018, there were 39 port calls across 6 routes in Maersk Asia-Europe network. It made 17 multi-edge node pairs. Aggregating all available paths, 24 ports were visited after another, creating a category of ports with 1 in-degree connectivity and out-degree connectivity. It can be seen in Appendix C in Table C.2 that by far, less ports have higher in-degree connectivity: 9 ports with 2 in-degree connectivity, 3 ports with 3 in-degree connectivity, 2 ports with 4 in-degree connectivity, 4 ports with 6 in-degree connectivity, and 1 port each with 5, 7, and 8 in-degree connectivity.

Figure 6.2. Maersk Port Call Network, 2018



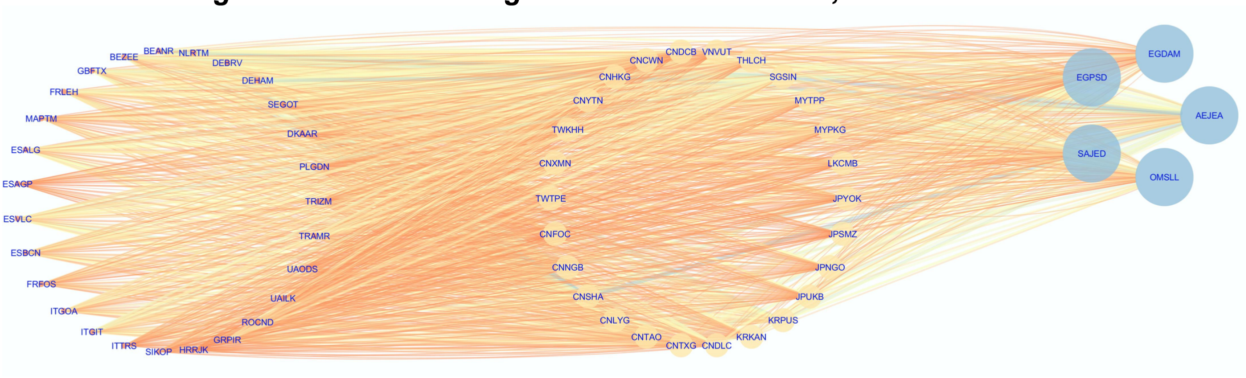
Source: Author's illustration based on Maersk Network in 2010 in Maersk (2018)
Note: Network structure is designed and illustrated by Cytoscape.

Figure 6.2 provides the structure of Maersk Asia-Europe Network in 2018. A bigger size and darker color node represent a higher betweenness centrality attached to that port ranging from 0 to 1. It is apparent from the figure that the top 10 ports could be proposed as candidates for additional port calls are: Shanghai (0.46), Tanjung Pelepas (0.36), Felixtowe (0.23), Rotterdam (0.20), and Ningbo (0.19), Bremerhaven (0.16), Singapore (0.15), Pusan (0.14), Yantian (0.13), and Tangier (0.11).

6.2. Weighted Demand Network

A decision to call at particular port is not solely driven by the factor related to connectivity as illustrated in Section 6.1 but is also motivated by the volume of demand represented by cargo flow from and to that port. In this respect, network analysis fits to the particular feature of connectivity as it is mainly extracted from graph theory. Tran and Hassis (2014) employ network analysis in container shipping case to seek for transshipment option. Ports with higher betweenness centrality and more intensive cargo handling activities are more likely to facilitate interlining demand paths through transshipment.

Figure 6.3. Maersk Weighted Demand Network, 2010



Source: Author's illustration based on Maersk OD Matrix in 2010 in Lachner and Boskamp(2011)
Note: Network structure is designed and illustrated by Cytoscape

Figure 6.3 depicts the port positioning in the Maersk Asia-Europe Network in 2010. Using group attribute layout algorithm executed in Cytoscape, ports with the same degree are clustered into a circle based on two network properties namely closeness centrality and degree centrality. These attributes are computed to categorize the role of port in the network structure. Taking demand flows across ports into account, three circles are positioned into a grid in the network: Asia, East Mediterranean /Middle East, and Europe.

It shows that the East Mediterranean and the Middle East ports namely Port Said, Damietta, Jebel Ali, Salalah, and Jeddah serve as a gateway of container flows from Asia to Europe and vice versa as signified by the highest closeness centrality at 0.93 and degree centrality of 53 indegree and outdegree each (Appendix C.3). This finding is in line with Tran and Hassis (2014) stating that the five aforementioned ports are large in transshipment incidence, led by Port Said at 92.5% in 2011. In addition, as the containers on the westbound exceed the eastbound, closeness centrality of Asian ports (0.70) are higher than the European Port (0.60). Meanwhile, degree centrality does not strictly imbalance where Asian ports are connected to 32 ports in the network and European ports are entitled to the rest 31 ports.

6.3. Cascading Phenomena

Continuous newbuilding deliveries in container shipping sustain in 2018. Knowler (2018) presents HIS Markit data showing that the additional capacities driven by newbuilding deliveries in 2018 will be around 1.3 million TEU. This figure is lower than 2017 notably at 1.7 million TEU but is higher still comparing to 2016 at 0.8 million TEU. Fluctuated figures are driven by the pick-up stage in the global economy amidst recovery at 3.1% annual growth for the last three years. Apart from that, ULCV segment prevails as vessels larger than 18,000 TEU comprises 30% of the orders due. Doubling figures of that ULCV is predicted to come by the end of 2021 considering the existing orderbooks for 57 ULCV. There are 24 vessels will be on the market no later than 2018 while the rest 32 will join the operations in 2019 and 2020.

A stiff competition among container liners still presents. The latest generations of ULCV are being pushed into Asia-Europe trade lane. In January 2018, OOCL received the last of 6 vessels in 21,413 TEU series: OOCL Hongkong, OOCL

Germany, OOCL Japan, OOCL United Kingdom, OOCL Scandinavia, and OOCL Indonesia. These ships are deployed to Asia-Europe trade lane as part of LL1 service sailing a 77 days round trip with port rotation: Shanghai – Ningbo – Xiamen – Yantian – Singapore - via Suez Canal – Felixstowe – Rotterdam – Gdansk – Wilhelmshaven – Felixstowe - via Suez Canal – Singapore – Yantian - Shanghai.

Similar decision is taken by Maersk concerning on the route selection of its ULCV. Taking the Maersk newbuilding deliveries for ULCV class in 2017 and 2018, there are 8 vessels with capacity 20,568 TEU received of which all are destined to strengthen Asia-Europe network: Madrid Maersk, Munich Maersk, Moscow Maersk, Milan Maersk, Monaco Maersk, Marseille Maersk, Manchester Maersk, and Murcia Maersk. Looking at this pattern, the prediction stating that Asia-Europe trade lane will be capacitated with vessels larger than 14,000 TEU by the end of 2020 is without reservation.

6.3.1. Routes

Table 6.1 shows the reallocation of previously deployed ships on Asia-Europe route to other regions due to the emergence of ULCV. Sofie Maersk, for example, used to serve A1 route connecting Asia and Europe via Hamburg now is assigned to Asia-South America Route via Lazaro Cardenas in Mexico. Some other vessels provide intercontinental service from Asia to Mediterranean and intracontinental service cross America and Mediterranean.

Table 6.1. Cascading Ship on Route between 2010 and 2018

Route	Vessel	Vessel Capacity (TEU)	2010	2018	Cascading Region
A1	Sofie Maersk	8,160	JPYOK-DEHAM-JPYOK	CNNGB-MXLZC-CNNGB	Asia-South America
A2	Maersk Seville	8,478	KRPUS-DEHAM-KRPUS	PAPCN-USMIA-PAPCN	Intra-America
A3	Maersk Kinloss	6,500	CNDLC-EGDAM-CNDLC	USCHS-MXVER-USCHS	Intra-America
A6	Gudrun Maersk	9,074	JPYOK-ESALG-JPYOK	EGPSD-CNTAO-EGPSD	Asia-Mediterranean
A7	Gjertrud Maersk	9,074	CNSHA-DEBRV-CNSHA	USEWR-TWKHH-USEWR	Asia-South America
A9	Maersk Sebarok	6,478	THLCH-NLRTM-THLCH	EGPSD-AEJEA-EGPSD	Intra-Mediterranean
A10	Sally Maersk	8,160	CNYTN-DKAHS-CNYTN	MXZLO-PECLL-MXZLO	Asia-South America
A11	Maersk Surabaya	8,400	CNTAO-ITGOA-CNTAO	EGSUZ-CNSHA-EGSUZ	Asia-Mediterranean

A12	Maersk Kyrenia	6,978	CNSHA-HRRJK-CBSHA	AEJEA-TRIZM-AEJEA	Intra-Mediterranean

Source: Mulder (2011) and Maersk (2018)

As previously discussed in Section 2.1.3 on the implication of cascading phenomena on cargo routing and vessel assignment, Maersk should adjust the deployment of the prior vessels serving between Asia and Europe. Earlier this year in January 2018, Maersk introduced supplementary Asia – Latin America/West Coast South America services that was effectively on operation starting from April 2018 (Maersk, 2018). This fourth loops is AC5 connecting Asia to Colombia, the Caribbean and Pecem. The expanded trade lane within this network provides weekly services by using vessels that in the past were sailing from Asia to Europe such as Charlotte Maersk, Sine Maersk, and Susan Maersk.

6.3.2. Ships

Upon the deployment of ULCV, the average vessel capacity serving Asia-Europe route increases by 104% from 8,690 TEU in 2010 to 17,804 TEU in 2018. The largest vessel size with capacity 13,000 TEU in 2010 served AE7 route sailing from Dalian to Europe via Damietta. At the moment, it is replaced by a vessel with 40% larger space with capacity up to 19,130 TEU.

Table 6.2. Route Capacities in 2010 and 2018

2010		2018	
Route	**Average (TEU)**	**Route**	**Average (TEU)**
AE1	8,365	AE1	19,029
AE2	8,444	AE2	17,583
AE3	6,504		
		AE5	19,083
AE6	9,086	AE6	13,430
AE7	13,643	AE7	19,130
AE9	6,474		
AE10	8,316	AE10	18,568
AE12	6,621		
AE11	8,231		
Average	**8,690**	**Average**	**17,804**

Source: Mulder (2011) and Maersk (2018)

6.4. Conclusion

This chapter highlights two salient points regarding to the relevance of network analysis prominently derived from graph theory on the optimal network design of container shipping. Firstly, the non-weighted port call pairs represent ports with relatively high betweenness centrality. Secondly, the weighted port call pairs with respect to origin and destination demand flows exhibit considerably high closeness centrality and degree centrality. Therefore, it provides useful insights for the optimal network design in Chapter 9 by considering hub-and-spoke setting network design that consists of hub routes and feeder network.

Chapter 7 Estimated Profitability of the ULCV Deployment

Chapter 6 delivers the estimation of profitability regarding to the deployment of ULCV. As specified in the previous chapters, the scope of ULCV in this chapter includes a range of container ships: 14,000 TEU; 16,000 TEU; 18,000 TEU; 20,000 TEU; and 22,000 TEU. In furtherance of detail figures, numbers of cost structure are introduced namely capital cost, operating cost, and fuel cost. These three categories make total cost that has been envisaged in Chapter 4. Profit is obtained subsequently after deducting total cost from revenue.

7.1. Capital Cost

Table 7.1. Capital Cost of ULCV

Capacity (in TEU)	14,000	16,000	18,000	20,000	22,000
Estimated newbuilding price (in million USD)	124	137	148	158	162
Capital cost (in USD per day) *	31,000	34,250	37,000	39,500	40,500
Capital cost (in million USD per year)	11.16	12.33	13.32	14.22	14.58
Capital cost per transported TEU (in USD)	83.04	80.27	77.08	74.06	69.03

Source: Author estimation based on OECD (2015)
Note: *5% depreciation rate and 4% interest rate

Table 7.1 recaps the capital cost components of ULCV. OECD (2015) releases estimated newbuilding price for container ship sizes ranging from 4,000 TEU to 20,000 TEU. Extrapolation is considered to appraise larger vessels, so does interpolation for the size in between categories. Assuming depreciation rate at factor of 5% and interest rate at 4%, yearly capital cost by vessel size is varied from USD 11 million to USD 15 million. Considering 80% of utilization rate for 60 days round tour for each of 12 voyages annually, capital cost per TEU decreases by 17% from USD 83 for 14,000 TEU ship to USD 69 for 22,000 TEU ship.

7.2. Operating Cost

Table 7.2. Operating Cost of ULCV

Capacity (TEU)	14,000	16,000	18,000	20,000	22,000
Crew cost (in million USD per year)	1.15	1.15	1.20	1.20	1.25
Overhead and maintenance cost (in million USD per year)	6.78	7.43	8.00	8.50	8.73
Operating cost (in million USD per year)	7.93	8.58	9.20	9.70	9.98
Operating cost (in USD per day)	22,014	23,819	25,556	26,944	27,708
Operating cost per transported TEU (in USD)	58.97	55.83	53.24	50.52	47.23

Source: Author estimation based on Linerlib (2012) and OECD (2015)

Operating cost in Table 7.2 consists of two main parts: i) crew cost; and ii) overhead and maintenance cost. In details, overhead and maintenance cost can be disaggregated into: insurance; stores; spare parts; lubricating oils; repairs and maintenance; dry docking; and management and administration. A vessel in 18,000 TEU class such as Maersk McKinney Moller is commonly manned by 13 to 21 crew.

As explained in Chapter 4, the estimation of operating cost follows Linerlib (2012). It is the summation of depreciation value and 1.5 times of crew cost. The first is estimated based on 360 voyage days. The figure does not differ much from one size to another because the number of crew required to operate the vessel are about the same. The proportion of overhead and maintenance cost, therefore, is the difference between operating cost and crew cost. Operating per TEU cost is lower as ship capacity becomes bigger as indicated by reduce in operating cost per TEU.

7.3. Fuel Cost

Table 7.3. Fuel Cost of ULCV

Capacity (in TEU)	14,000	16,000	18,000	20,000	22,000
Estimated fuel consumption (in ton per day)	98	110	122	135	148
Fuel cost (in USD per day)	81,993	92,033	102,073	112,950	123,827
Fuel cost (in million USD per year)	29.52	33.13	36.75	40.66	44.58
Fuel cost per transported TEU (in USD)	219.63	215.70	212.65	211.78	211.07

Source: Author estimation based on Notteboom and Carriou (2009) and OECD (2015)

Fuel cost estimated in Table 7.3 is based on constant speed at 15 knots and bunker price USD 500 per ton. Recalling that a round tour our takes 60 days in which 46 days are spent on sea leg while 14 days are allocated to port related activities such as loading and unloading, fuel consumption at port is assumed at 30% of estimated fuel consumption. Under slow steaming practice, increase in capacity by 57% from 14,000 TEU to 22,000 TEU results in higher fuel cost by 51%. New generation vessel most prominently ULCV, is equipped by more efficient machine and propeller so that marginal fuel cost growth is lower than marginal capacity growth.

7.4. Movement Cost

Table 7.4. Movement Cost of ULCV

Capacity (in TEU)	14,000	16,000	18,000	20,000	22,000
Handling cost (in million USD per year)	22.85	26.11	29.38	32.64	35.90
Port charge (in million USD per year)	2.10	2.10	2.10	2.10	2.10
Movement cost (in million USD per year)	24.95	28.21	31.48	34.74	38.00
Movement cost per transported TEU (in USD)	185.63	183.67	182.15	180.94	179.94

Source: Author estimation based on K-Line (2017)

Table 7.4 specifies movement cost by taking two allocations into account namely handling cost and port charge. The first depends on TEU size at USD 170 per TEU, while the second is imposed per port visit at USD 25,000. In this scenario several assumptions imposed as follows: i) utility rate is at 80%; ii) 12 round tour voyages between Shanghai and Rotterdam are made a year (20,756 nmi for each round tour), and iii) 14 ports are called on average on a round tour. It is found that handling cost varies from USD 22.85 million (14,000 TEU) to USD 35.90 million (22,000 TEU). Even though, the movement cost both expressed in aggregate annual value and per TEU incrementally increase as vessel becomes larger, the movement cost per TEU shrinks in as more cargo capacity available in larger vessel.

7.5. Total Cost

Table 7.5. Total Cost of ULCV

Capacity (in TEU)	14,000	16,000	18,000	20,000	22,000
Capital cost (in million USD per year)	11.16	12.33	13.32	14.22	14.58
Operating cost (in million USD per year)	7.93	8.58	9.20	9.70	9.98
Fuel cost (in million USD per year)	29.52	33.13	36.75	40.66	44.58
Movement cost (in million USD)	24.95	28.21	31.48	34.74	38.00
Total cost (in million USD per year)	73.55	82.25	90.74	99.32	107.14
Cost per transported TEU (in USD)	547.25	535.48	525.13	517.30	507.28
Cost per nmi (in USD)	590.60	660.44	728.64	797.54	860.29

Source: Author estimation based on Notteboom and Carriou (2009) and OECD (2015)

The aggregation over four aforementioned costs presented in Table 7.1 to Table 7.4 can be retrieved in Table 7.5. The two most cost intensive are movement cost and fuel cost. Fuel cost is slightly lower than movement cost in this regard due to slow steaming at constant speed of 15 knots. On top of the rest, fuel cost comprises 40% (14,000 TEU) to 42% (22,000 TEU) of total cost. Meanwhile, movement cost makes up for 34% (14,000 TEU) to 35% (22,000 TEU) of total cost. Moreover, it also indicates that cost incurs at sea leg outweighs port cost. Economies of scale on ULCV case is still relevant to this stage as cost per transported TEU is lower for larger vessel deployment. This is the turning point for the argument of economies of scale as presented in Figure 2.3.

7.6. Revenue and Profit

Table 7.6. Revenue and Profit of ULCV

Capacity (in TEU)	14,000	16,000	18,000	20,000	22,000
Revenue (in USD million per year)	94.08	107.52	120.96	134.40	147.84
Total cost (in USD million per year)	73.55	82.25	90.74	99.32	107.14
Profit (in USD million per year)	20.53	25.27	30.22	35.08	40.70
Profit per transported TEU (in USD)	152.75	164.52	174.87	182.70	192.72

Source: Author estimation based on Notteboom and Carriou (2009) and OECD (2015)

Table 7.6 shows the revenue and profit that Maersk could potentially generate by assigning a larger vessel in the ULCV class. Load factor is assumed at 80% with constant ship speed at 15 knots. As cyclic voyage spends 60 days, there are 12 voyages in a year. Profit grows up to 12% (USD 72.74 million to USD 85.30 million) when the size of ship is upgraded from 14,000 TEU to 16,000 TEU. However, further deployment of upgraded size from 20,000 TEU to 22,000 TEU generates lower profit growth respectively at 9% (USD 110.54 million to USD 123.34 million). It shows that the operation of ULCV may generate higher profit under a considerably high load factor in order to exploit the economies of scale. This preliminary estimation will be compared to the performance of optimal network design in Chapter 9.

7.7. Conclusion

This chapter shows that economies of scale holds for larger vessel deployment in general because the bigger cargo size as denominator contributes to less cost per TEU. Nonetheless, an interesting observation is found. Marginal cost per transported TEU is flattening as the ship size reaches 20,000 TEU. Cost saving per TEU from 16,000 TEU to 18,000 is USD 10.35 while further size increment to 20,000 TEU only retains USD 7.83. It affects the profitability at equitable level. It could be the case that high operational cost incurs in operating larger vessels so that higher utilization rate should be attained to compensate that.

Chapter 8 PAM and DBSCAN Clustering Algorithm

This part of the thesis examines results of clustering algorithms namely PAM and DBSCAN that theoretically has been explained in Chapter 3. The adequate port cluster is constructed based on minimum distance between ports in a cluster and maximize demand at a selected hub port in a cluster. The output of this chapter is used as input for route construction in the case of Maersk container shipping for Asia-Europe route. Later in the discussion of optimal network with the presence of ULCC, the results are discussed in term of which hub port should be called on the eastbound and westbound voyage to generate a hub-and-spoke design. The comprehensive enumeration of hub network in this chapter is constructed based on Euclidean distance.

8.1. PAM Clustering Algorithm

In this setting, clustering of maximum spacing is applied in order to obtain minimum spanning trees. Given a P set of n ports labeled $p_1, \dots, p_n$, each pair of p_i and p_j have a numerical distance $d(p_i, p_j)$. The distance is symmetric for $d(p_i, p_j) > 0$ where $d(p_i, p_j) = d(p_j, p_i)$. Therefore, $k - clustering$ of P is a partition of P into k non-empty sets $C_1, \dots, C_k$. A simple swap neighborhood operation drives this continuous process. Experiments from combination of $k = \{10,13,15\}$ are reported below using *fpc* and *cluster* package with visualization generated by *RgoogleMaps* in R environment. Hub ports are selected according to criteria postulated on Equation 3.1 and Equation 3.2.

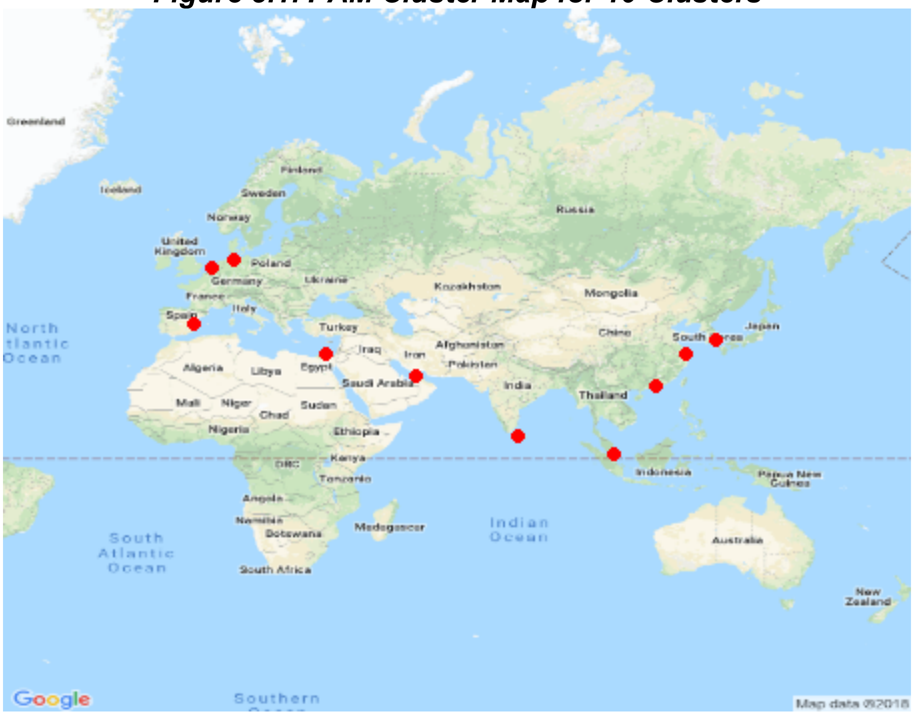
PAM Clustering is considered in this thesis due to the fact that in shipping liner, distance travelled is positively correlated with bunker cost. Notteboom and Vernimmen (2009) simulate a cost model to capture the impact of bunker cost on operational cost in the case of North Europe–East Asia loop and find the presence of higher cost per TEU even for larger and more efficient vessel such as Post-Panamax class. In order to minimize distance travel such that reasonable cost structure and timely arrival window hold, decision on which port to call should be made. Classification is made over ports: hub and feeder. Hub in each cluster, known as medoid in PAM, is selected at first out of an empty set of medoids based on the objective function of distance minimization to other objects. Search phase take places by adding ports serving as hub to the set until the optimal distance is achieved.

Table 8.1. PAM Clustering for 10 Clusters

Pusan	**Shanghai**	**Hong Kong**	**Singapore**	**Colombo**
Kwangyang	Ningbo	Chiwan	Laem Cha Bang	
Nagoya	Qingdao	Da Chan Bay	Vung Tau	
Shimizu	Dalian	Kaohsiung	Port Klang	
Kobe	Tianjin	Yantian	Tanjung Pelepas	
Yokohama	Lianyungang	Xiamen		
		Fuzhou		
		Taipei		
Jebel Ali	**Port Said**	**Valencia**	**Rotterdam**	**Hamburg**
Salalah	Damietta	Genoa	Felixtowe	Bremerhaven
	Jeddah	Fos Sur Mer	Antwerp	Goteborg
	Ambarli	Tangier	Zeebrugge	Gdansk
	Izmir	Algeciras	Le Havre	Aarhus
	Chornomorsk	Barcelona		
	Odessa	Malaga		
	Piraeus	Gioia Tauro		
	Constanta	Trieste		
		Koper		
		Rijeka		

Note: Hub ports are printed in bold red.

Figure 8.1. PAM Cluster Map for 10 Clusters



Note: Hub ports are indicated by the red spots.

Table 8.1 and Figure 8.1 present clustering result based on PAM algorithm for 10 hub ports. The shortest within cluster distance of 142 nmi is found in Cluster 9 with

Rotterdam serving as hub, while the farthest distance of 894 nmi is in Cluster 6 where distance from port in this cluster to Jebel Ali is measured. Number of ports connected to hub are varied from a single standing port of Colombo to 11 ports in Mediterranean area feeding cargo to Valencia. On average, 6 ports in each cluster are 491 nmi apart to the respected hub.

Table 8.2. PAM Clustering for 13 Clusters

Pusan	**Qingdao**	**Shanghai**	**Hong Kong**	**Singapore**	**Colombo**	**Jebel Ali**
Kwangyang	Dalian	Ningbo	Chiwan	Laem Cha Bang		Salalah
Nagoya	Tianjin		Da Chan Bay	Vung Tau		
Shimizu	Lianyungang		Kaohsiung	Port Klang		
Kobe			Yantian	Tanjung Pelepas		
Yokohama			Xiamen			
			Fuzhou			
			Taipei			

Port Said	**Ambarli**	**Valencia**	**Antwerp**	**Rotterdam**	**Hamburg**
Damietta	Izmir	Genoa	Zeebrugge	Felixtowe	Bremerhaven
Jeddah	Chornomorsk	Fos Sur Mer	Le Havre		Goteborg
	Odessa	Tangier			Gdansk
	Piraeus	Algeciras			Aarhus
	Constanta	Barcelona			
		Malaga			
		Gioia Tauro			
		Trieste			
		Koper			
		Rijeka			

Note: Hub ports are printed in bold red.

Figure 8.2. PAM Cluster Map for 13 Clusters

Note: Hub ports are indicated by the red spots.

Table 8.2 and Figure 8.2 provide clustering result based on PAM algorithm for 13 hub ports. The shortest within cluster distance of 101 nmi is found in Cluster 3 with Shanghai serving as hub, while the farthest distance of 894 nmi is in Cluster 7 where distance from port in this cluster to Jebel Ali is measured. Number of ports connected to hub are varied from a single standing port of Colombo to 11 ports in Mediterranean area feeding cargo to Valencia. On average, 4 ports in each cluster are 369 nmi apart to the respected hub.

Table 8.3. PAM Clustering for 15 Clusters

Pusan	**Qingdao**	**Shanghai**	**Yantian**	**Hong Kong**	**Singapore**	**Colombo**	**Jebel Ali**
Kwangyang	Dalian	Ningbo	Xiamen	Chiwan	Laem Cha Bang		Salalah
Nagoya	Tianjin		Fuzhou	Da Chan Bay	Vung Tau		
Shimizu	Lianyungang			Kaohsiung	Port Klang		
Kobe				Taipei	Tanjung Pelepas		
Yokohama							

Port Said	**Ambarli**	**Gioia Tauro**	**Valencia**	**Antwerp**	**Rotterdam**	**Hamburg**
Damietta	Izmir	Trieste	Genoa	Zeebrugge	Felixtowe	Bremerhaven
Jeddah	Chornomorsk	Koper	Fos Sur Mer	Le Havre		Goteborg
	Odessa	Rijeka	Tangier			Gdansk
	Constanta		Algeciras			Aarhus
	Piraeus		Barcelona			
			Malaga			

Note: Hub ports are printed in bold red.

Figure 8.3. PAM Cluster Map for 15 Clusters

Note: Hub ports are indicated by the red spots.

Table 8.3 and Figure 8.3 provide clustering result based on PAM algorithm for 13 hub ports. The shortest within cluster distance of 101 nmi is found in Cluster 3 with Shanghai serving as hub, while the farthest distance of 894 nmi is in Cluster 8 where distance from port in this cluster to Jebel Ali is measured. Number of ports connected to hub are varied from a single standing port of Colombo to 11 ports in Mediterranean area feeding cargo to Valencia. On average, 4 ports in each cluster are 358 nmi apart to the respected hub.

8.2. DBSCAN Clustering Algorithm

Evolving from the density-based perspective, DBSCAN assigns points a cluster if the condition of 'density reachable from each other' is fulfilled (Ester et al, 1996). A cluster C can be defined as a non-empty subset of D satisfying maximality and connectivity condition. The first condition holds if $p \in C$ and q is density-reachable from p, then $q \in C$. The second conditions refer to $\forall\, p, q \in C, p$ is density-connected to q. Given that o is the core point with p and q as neighbors, p and q are density reachable from o such that p and q are density connected.

Starting with an arbitrary point p, the DBSCAN algorithm retrieves its ϵ -neighborhood. All clusters are identified by determining all core points and extending each core point to density reachable points. The cluster is complete if no more core points are found. Cluster map is provided in R using *ggmap* library. Parameters used in running DBSCAN clustering algorithm is $Eps = \{0.25\}$ and $MinPts = \{3\}$ that generates 7 clusters at first. Unlike PAM Clustering, DBSCAN clustering does not require a trivial number of initial clusters. Herein, the optimal parameter Eps and $MinPts$ are obtained by running Algorithm 3 as asserted in Chapter 3. The result below reports DBSCAN clustering for 10 Clusters executed in R with *dbscan* package supported with script for mapping in *RgoogleMaps*.

Clustering by means of density as is applied in the case of port calls for container liner. Owing to the idea that ports located next to each other in a dense geographical neighbor should be allocated into a cluster in order to maintain robust scheduling and cost-efficient operation. Moreover, argument on economies of scale becomes an important point to make. As larger vessel including ULCV requires higher demand to reach higher utilization, cargo is likely to be concentrated on hub ports so that the cargo originally comes from smaller ports in the surrounding is transported to the most reachable hub in the region using feeder network. Therefore, density-based approach is relevant with the idea of hub-and-spoke design.

Table 8.4. DBSCAN Clustering for 10 Clusters

Pusan	**Shanghai**	**Hong Kong**	**Singapore**	**Jebel Ali**
Kwangyang	Ningbo	Chiwan	Laem Cha Bang	Salalah
Nagoya	Qingdao	Da Chan Bay	Vung Tau	Jeddah
Shimizu	Dalian	Kaohsiung	Port Klang	
Kobe	Tianjin	Yantian	Tanjung Pelepas	
Yokohama	Lianyungang	Xiamen	Colombo	
		Fuzhou		
		Taipei		
Constanta	**Gioia Tauro**	**Valencia**	**Rotterdam**	**Goteborg**
Chornomorsk	Port Said	Genoa	Felixtowe	Gdansk
Odessa	Damietta	Fos Sur Mer	Antwerp	Aarhus
Koper	Piraeus	Tangier	Zeebrugge	
	Ambarli	Algeciras	Le Havre	
	Izmir	Barcelona	Hamburg	
	Rijeka	Malaga	Bremerhaven	
	Trieste			

Note: Hub ports are printed in bold red.

Figure 8.4. DBSCAN Cluster Map for 10 Clusters

Note: Hub ports are indicated by the red spots.

Table 8.4 and Figure 8.4 provide clustering result based on DBSCAN algorithm for 10 hub ports. The shortest within cluster distance of 181 nmi is found in Cluster 9 with Rotterdam serving as hub, while the farthest distance of 1,523 nmi is in Cluster 5 where distance from ports in this cluster to Jebel Ali is measured. Number of ports connected to hub are varied from 3 ports in Middle East to 8 ports in Mediterranean feeding cargo to Gioia Tauro. On average, 6 ports in each cluster are 527 nmi apart to the respected hub.

8.3. Conclusion

Comparing the results of two clustering algorithms which are PAM and DBSCAN, PAM clustering with 15 hubs gives shortest distance between ports in a cluster at about 359 nmi with respect to demand. On the other hand, DBSCAN clustering results in 47% further distance that leads to significant increase in fuel cost. Moreover, directly calling at ports located in the enclaved region such as Constanta or the isolated area away from the main trade lane, for example Goteborg, could be not profitable for the container liner. Recalling the prior stated objectives of clustering namely minimum distance between ports in a cluster and maximize demand, port aggregation based on PAM clustering can be obtained efficiently. Therefore, the result given by PAM clustering for port strings along Asia-Europe trade lane will serve as inputs to hub route construction and network design in Chapter 9.

Comparing the performance of clustering above to network properties analyzed in Chapter 6, it shows that 4 of 10 ports already serve as hub nodes connecting one cluster to another across Asia and Europe respectively in Maersk Network 2010 (Figure 6.1) and Maersk Network 2018 (Figure 6.2). Those are Port Said, Shanghai, Hongkong, and Pusan in the first figure. In the second figure, Shanghai, Rotterdam, Singapore, Pusan, and Tangier make up the list.

Chapter 9 Network Configuration Design

This chapter is dedicated to report the findings with regards to sub research question 5: “Which proposed network is the best to compare to reference network?” The presence of ULCV in Maersk’s Asia-Europe Network affects the profitability of container shipping activity. In order to maximize profit with given vessels, route structure and network design should be simplified such that utilization rate is optimum. Input data such as demand, distance, and cost parameter can be retrieved in Chapter 4. The reference network has been data mined from Mulder (2011) while the optimized figure presented below is based on the mathematical model of Liner Shipping Network Design Problem formulated in Chapter 3. The implementation of such model is executed in the software program developed by Mulder (2016) with some adjustment made by author to fit the model specification in this thesis.

9.1. Reference Network Design

The original Maersk network in 2010 is used as the reference network. It consists of 8 routes namely AE1, AE2, AE3, AE6, AE7, AE9, AE11, and AE12 that are available in Appendix B in Table B.1. On average, there are 17 ports called on route as each varies from 13 to 21 ports. Westbound sails from Yokohama (AE1 and AE6), Pusan (AE2), Dalian (AE3), Shanghai (AE7 and AE12), Laem Cha Bang (AE9), and Qingdao (AE11). On the eastbound, voyage begins in Rotterdam, Hamburg, Bremenhaven, Felixtowe, and Antwerp. The characteristics of this network can be seen in detail in Table 9.1 and Table 9.2.

Table 9.1. Profitability of the Reference Network

Profit (in million USD)	1,088.79
Revenue (in million USD)	4,474.44
Total cost (in million USD)	3,385.01
Fleet cost (in million USD)	812.40
Bunker cost (in million USD)	885.47
Handling cost (in million USD)	1,197.58
Transshipment cost (in million USD)	313.13
Port cost (in million USD)	188.25

In the existing condition, running the network generates annual revenue at USD 4.5 billion in which amount close to USD 3.4 billion is allocated to cover costs incur during operational activities. Handling cost remain the largest among others up to 1.2 billion, followed by bunker cost of USD 885 million, fleet cost of USD 812 million, transshipment cost of USD 313 million and port cost of USD 188 million. In the end, Maersk makes profit around USD 1.1 billion.

Table 9.2. Operational Performance of the Reference Network

Number of routes	8
Average number of port per routes	17
Number of ships	82
Best average utilization (in %)	84.3
Worst average utilization (in %)	56.1
Average utilization (in %)	70.2
Percentage demand delivered (in %)	85.7
Percentage rejections (in %)	14.3

Considering demand schedule in 2010, operational performance of the reference network is assessed. In order to deliver demand, ships are deployed with capacities ranging from 10,000 TEU; 12,000 TEU; to 14,000 TEU. It results in the deployment of 82 vessels with average utilization 70.2% as 85.7% demand delivered within time window.

9.2. Optimal Hub Network Design

Clustering algorithm determined in Chapter 8 provides potential hubs using PAM clustering algorithm with distance and demand function considered. As results, three centroid based partition of ports formulated: 10, 13, and 15. It allows the exchange of ports between routes in the network. As no ports selected other than the one in existing network, feasibility of cargo allocation in the expanded route still hold. As no ports selected other than the one in existing network, feasibility of cargo allocation in the expanded route still hold.

The 10-centroid partition, the ports potentially visited by Maersk on its cyclic voyage from Asia to Europe can be determined by applying 10-centroid partition. The final hubs on a port string from Asia to Europe can be retrieved as follows: Pusan (KRPUS), Shanghai (CNSHA), Hong Kong (CNHKG), Singapore (SGSIN), Colombo (LKCMB), Jebel Ali (AEJEA), Port Said (EGPSD), Valencia (ESVLC), Rotterdam (NLRTM), and Hamburg (DEHAM).

Another alternative in the proposed routes is developed by following 13-centroid partition algorithm. As the westbound sails at first of the voyage, Asian ports are called prior to European ports consisting: Pusan (KRPUS), Qingdao (CNTAO), Shanghai (CNSHA), Hong Kong (CNHKG), Singapore (SGSIN), Colombo (LKCMB), Jebel Ali (AEJEA), Port Said (EGPSD), Ambarli (TRAMR), Valencia (ESVLC), Antwerp (BEANR), Rotterdam (NLRTM), and Hamburg (DEHAM).

In addition, the 15-hubs on a port string from Asia to Europe can be retrieved as follows: Pusan (KRPUS), Qingdao (CNTAO), Shanghai (CNSHA), Yantian (CNYTN), Hong Kong (CNHKG), Singapore (SGSIN), Colombo (LKCMB), Jebel Ali (AEJEA), Port Said (EGPSD), Ambarli (TRAMR), Giuoa Tauro (ITGIT), Valencia (ESVLC), Antwerp (BEANR), Rotterdam (NLRTM), and Hamburg (DEHAM). This port sequence serves as an initial route in the proposed network. In search of optimal routes, routes crossover method and roulette wheel method inspired by genetic algorithm is employed.

As stated earlier, this thesis aims to investigate the optimality condition under cascading effects triggered by the deployment of ULCV along Asia-Europe trade lane. The blocking treatment is imposed in the second part of experiment to reveal the impact of larger ship assignments. This phase generates 3 current best network (CBS) as comparatively presented below.

9.2.1. Current Best Hub Network A (CBHN A)

CBHN A is composed based on OD demand matrix in 2010 and ships deployed in 2010 (10,000 TEU, 12,000 TEU, and 14,000 TEU with speed closer to design speed at 24 knot). The optimal ship size in this network is 10,000 TEU and 12,000 TEU.

Table 9.3. Cost Structure of CBHN A

	10 Clusters	13 Clusters	15 Clusters
Total cost (in million USD)	2,760.85	2,863.69	2,876.69
Fleet cost (in million USD)	613.67	627.37	638.63
Bunker cost (in million USD)	811.94	832.72	847.01
Port cost (in million USD)	83.86	79.75	95.30
Handling cost (in million USD)	1,251.39	1,324.51	1,293.62
Transshipment cost (in million USD)	-	-	2.84

Table 9.4. Operational Performance of CBHN A

	10 clusters	13 clusters	15 clusters
Number of routes	7	6	5
Average number of port per route	10	13	15
Number of ships	65	63	60
Best average utilization (in %)	85.36	88.29	90.58
Worst average utilization (in %)	61.36	64.29	66.58
Average utilization (in %)	73.36	76.29	78.58

Table 9.3 presents cost structure of the Best Hub Network A. It shows that handling cost remains the largest spending regardless the size of clusters ranging from USD 1,251 million (10 clusters) to USD 1,324 million (13 clusters). Bunker cost follows afterwards for USD 812 million (10 clusters) to USD 847 million (10 clusters). In total, hub network that is grouped into 15 clusters has the highest cost (USD 2,877 million). Reasonably to this point, expanded number of hubs results in further costs. On the operational aspect, higher average utilization is found in 15 clusters comparing to the rest as more ports included to serve as hub as indicated in Table 9.4.

9.2.2. Current Best Hub Network B (CBHN B)

CBHN B refers to the scenario with OD demand matrix in 2018 and ships deployed in 2010 (10,000 TEU, 12,000 TEU, and 14,000 TEU with speed closer to design speed at 24 knot). The optimal ship size in this network is 12,000 TEU and 14,000 TEU.

Table 9.5. Cost Structure of CBHN B

	10 Clusters	13 Clusters	15 Clusters
Total cost (in million USD)	3,699.97	3,838.16	3,855.40
Fleet cost (in million USD)	822.41	840.85	855.91
Bunker cost (in million USD)	1,088.12	1,116.09	1,135.17
Port cost (in million USD)	112.38	106.89	127.72
Handling cost (in million USD)	1,677.05	1,775.23	1,733.74
Transshipment cost (in million USD)	-	-	3.81

Table 9.6. Operational Performance of CBHN B

	10 clusters	13 clusters	15 clusters
Number of routes	7	6	5
Average number of port per route	10	13	15
Number of ships	85	81	79
Best average utilization (in %)	89.79	92.98	90.94
Worst average utilization (in %)	69.79	72.98	70.94
Average utilization (in %)	79.79	82.98	80.94

Similar to Table 9.3, total cost incurs at the highest for 15 hub clusters network. In order sail in between hub ports, liner meets total cost as specified: USD 3,855.40 million (15 clusters), USD 3,838.16 million (13 clusters), and USD 3,699.97 million (10 cluster). Handling cost is on the top of rest cost allocation for all type of cluster respectively. It is varied from USD 1,677.05 million for 10 clusters to USD 1,775.23 million for 13 clusters. Comparing Table 9.6 to Table 9.4, average utilization for all clusters increases. It shows that more cargo demand flow within the network enhance the delivery on designated routes.

9.2.3. Current Best Hub Network C (CBHN C)

CBHN C is specified with OD demand matrix in 2018 and ships deployed in 2018 (16,000 TEU, 18,000 TEU, 20,000 TEU, and 22,000 TEU with slow steaming at 15 knot). The optimal ship size in this network is 16,000 TEU and 18,000 TEU.

Table 9.7. Cost Structure of CBHN C

	10 Clusters	13 Clusters	15 Clusters
Total cost (in million USD)	3,729.57	4,145.22	3,816.85
Fleet cost (in million USD)	828.99	908.12	847.35
Bunker cost (in million USD)	1,096.83	1,205.37	1,123.82
Port cost (in million USD)	113.28	115.44	126.44

Handling cost (in million USD)	1,690.47	1,917.25	1,716.40
Transshipment cost (in million USD)	-	-	3.77

Table 9.8. Operational Performance of CBHN C

	10 clusters	13 clusters	15 clusters
Number of routes	7	6	5
Average number of port per route	10	13	15
Number of ships	76	71	65
Best average utilization (in %)	86.20	94.30	96.89
Worst average utilization (in %)	70.20	78.30	80.89
Average utilization (in %)	78.20	86.30	88.89

Table 9.7 exhibits similar pattern to Table 9.5 and Table 9.3. Handling cost becomes the most cost intensive spending while bunker cost comes definitely after. Total cost figure in this network is the highest among three respective networks stated above. The cost of running ULCV is more expensive in general. However, those cost incur to meet higher cargo volume by 34%. As the economies of scale persists in Chapter 7, this relatively upper value is compensated by larger demand to serve.

9.3. Optimal Feeder Network Design

9.3.1. Current Best Feeder Network A (CBFN A)

CBFN A is composed based on OD demand matrix in 2010 and feeder ships given as follows: 1,200 TEU; 3,200 TEU; 4,800 TEU; 7,000 TEU; and 9,600 TEU. These ships sail on average at 16 knot. Regional network is developed for three port clustering alternatives that consist of 10 clusters, 13 clusters, and 15 clusters.

Table 9.9. Cost Structure of CBFN A

	10 Clusters	13 Clusters	15 Clusters
Total cost (in million USD)	209.02	261.85	191.81
Fleet cost (in million USD)	42.86	48.10	36.43
Bunker cost (in million USD)	38.78	39.85	33.02
Port cost (in million USD)	6.08	6.22	6.29
Handling cost (in million USD)	121.30	167.68	116.07
Transshipment cost (in million USD)	-	-	-

Table 9.10. Operational Performance of CBFN A

	10 clusters	13 clusters	15 clusters
Number of routes	20	20	16
Average number of port per route	3	3	4
Number of ships	20	20	16
Best average utilization (in %)	73.43	76.70	74.64

Worst average utilization (in %)	57.43	60.70	58.64
Average utilization (in %)	65.43	68.70	66.64

Cost structure of CBFN A can be retrieved in Table 9.9. A distinctive observation can be made concerning on the relation between total cost and number of hubs. It shows that handling cost remains the largest proportion on cost structure. In addition, bunker cost topples on the second position, while port cost is still the least cost spending.

9.3.2. Current Best Feeder Network B (CBFN B)

CBFN B is composed based on OD demand matrix in 2010 and feeder ships given as follows: 1,200 TEU; 3,200 TEU; 4,800 TEU; 7,000 TEU; and 9,600 TEU. These ships sail on average at 16 knot. Regional network is developed for three port clustering alternatives that consist of 10 clusters, 13 clusters, and 15 clusters.

Table 9.11. Cost Structure of CBFN B

	10 Clusters	13 Clusters	15 Clusters
Total cost (in million USD)	280.11	350.95	257.07
Fleet cost (in million USD)	57.43	64.47	48.82
Bunker cost (in million USD)	51.97	53.41	44.26
Port cost (in million USD)	8.15	8.34	8.43
Handling cost (in million USD)	162.56	224.74	155.56
Transshipment cost (in million USD)	-	-	-

Table 9.12. Operational Performance of CBFN B

	10 clusters	13 clusters	15 clusters
Number of routes	20	20	16
Average number of port per route	3	3	4
Number of ships	20	20	16
Best average utilization (in %)	75.36	78.14	76.69
Worst average utilization (in %)	63.36	66.14	64.69
Average utilization (in %)	69.36	72.14	70.69

Table 9.11 shows cost related indicators in feeder network CBFN B. Result indicates that handling cost remains the largest proportion on cost structure. In addition, bunker cost topples on the second position, while port cost is still the least cost spending.

9.3.3. Current Best Feeder Network C (CBFN C)

CBFN B is composed based on OD demand matrix in 2010 and feeder ships given as follows: 1,200 TEU; 3,200 TEU; 4,800 TEU; 7,000 TEU; and 9,600 TEU. These ships sail on average at 16 knot. Regional network is developed for three port clustering alternatives that consist of 10 clusters, 13 clusters, and 15 clusters.

Table 9.13. Cost Structure of CBFN C

	10 Clusters	13 Clusters	15 Clusters
Total cost (in million USD)	282.35	379.03	254.49
Fleet cost (in million USD)	57.89	69.62	48.34
Bunker cost (in million USD)	52.38	57.68	43.81
Port cost (in million USD)	8.22	9.00	8.34
Handling cost (in million USD)	163.86	242.72	154.00
Transshipment cost (in million USD)	-	-	-

Table 9.14. Operational Performance of CBFN C

	10 clusters	13 clusters	15 clusters
Number of routes	20	20	16
Average number of port per route	3	3	4
Number of ships	20	20	16
Best average utilization (in %)	75.05	77.15	79.32
Worst average utilization (in %)	65.05	67.15	69.32
Average utilization (in %)	70.05	72.15	74.32

Table 9.11 shows cost structure in CBFN B. In line with the previous feeder network, handling cost remains the largest proportion on cost structure. In addition, bunker cost topples on the second position, while port cost is still the least cost spending.

9.4. Optimal Hub and Spoke Network Design

9.4.1. Current Best Network A (CBN A)

CBN A is developed by integrating and synchronizing ship-scheduling and cargo routing between hub ports in CBHN A and feeder ports in CBFN A. The performance of CBN A is measured based on profitability and operation as presented below.

Table 9.15. Profitability of CBN A

	10 Clusters	13 Clusters	15 Clusters
Profit (in million USD)	1,415.43	1,393.65	1,360.99
Revenue (in million USD)	4,384.95	4,519.18	4,429.70
Total cost (in million USD)	2,969.52	3,125.53	3,068.71
Fleet cost (in million USD)	656.52	675.47	675.06
Bunker cost (in million USD)	850.72	872.57	880.03
Port cost (in million USD)	89.94	85.97	101.58
Handling cost (in million USD)	1,372.69	1,492.20	1,409.69
Transshipment cost (in million USD)	-	-	2.84

Table 9.16. Operational Performance of CBN A

	10 Clusters	13 Clusters	15 Clusters
Demand delivered (in %)	89.99	91.78	86.39
Demand rejected (in %)	10.02	8.22	13.61

9.4.2. Current Best Network B (CBN B)

CBN B is developed by integrating and synchronizing ship-scheduling and cargo routing between hub ports in CBHN B and feeder ports in CBFN B. The performance of CBN B is measured based on profitability and operation as presented below.

Table 9.17. Profitability of CBN B

	10 Clusters	13 Clusters	15 Clusters
Profit (in million USD)	1,896.67	1,867.49	1,823.72
Revenue (in million USD)	5,876.29	6,056.60	5,936.47
Total cost (in million USD)	3,979.62	4,189.11	4,112.74
Fleet cost (in million USD)	879.74	905.12	904.58
Bunker cost (in million USD)	1,139.96	1,169.24	1,179.24
Port cost (in million USD)	120.52	115.20	136.12
Handling cost (in million USD)	1,839.40	1,999.54	1,888.99
Transshipment cost (in million USD)	-	-	3.81

Table 9.18. Operational Performance of CBN B

	10 Clusters	13 Clusters	15 Clusters
Demand delivered (in %)	92.68	93.61	88.98
Demand rejected (in %)	7.32	6.39	11.02

9.4.3. Current Best Network C (CBN C)

CBN C is developed by integrating and synchronizing ship-scheduling and cargo routing between hub ports in CBHN C and feeder ports in CBFN C The performance of CBN C is measured based on profitability and operation as presented below.

Table 9.19. Profitability of CBN C

	10 Clusters	13 Clusters	15 Clusters
Profit (in million USD)	1,911.85	2,016.89	1,805.49
Revenue (in million USD)	5,923.30	6,541.13	5,877.10
Total cost (in million USD)	4,011.46	4,524.24	4,071.62
Fleet cost (in million USD)	886.78	977.53	895.54
Bunker cost (in million USD)	1,149.08	1,262.78	1,167.45
Port cost (in million USD)	121.49	124.42	134.76
Handling cost (in million USD)	1,854.11	2,159.51	1,870.10
Transshipment cost (in million USD)	-	-	3.77

Table 9.20. Operational Performance of CBN C

	10 Clusters	13 Clusters	15 Clusters
Demand delivered (in %)	92.68	93.61	88.98
Demand rejected (in %)	7.32	6.39	11.02

Integrating the hub network with feeder network may increase the operational efficiency as reflected in Section 9.4 especially in Table 9.15, Table 9.17, and Table 9.19. As feeder network grows, cost incurs in hub network can be reduced because it is no longer necessary to visit all port on voyage. Least cost combination that always be the case for 10 clusters, however, does not guarantee the highest profitability. Network design with 10 clusters retains profit at peak for CBN A and CBN B where typical ship size in 2010 used. Preference on larger vessel in response to higher demand in CBN C with 13 clusters improves the profitability by 6%. It is triggered by the strategic decision on route simplification so that liner can focus to tap the main market along the trade lane. Moreover, visiting hub ports within that region may increase the network utilization and demand delivered as seen in Table 9.20.

9.5. Optimal Network

This section is extracted from Section 9.4 aiming to indicate straightforwardly the optimality of best networks proposed in this thesis. As presented before, there are three networks that are considered as current best network namely: CBN A, CBN B, and CBN C. These networks differ in term of demand level and ship size. CBN A utilizes demand volume in 2010, while CBN B and CBN C maintain demand volume in 2018. On vessel class, CBN A and CBN B use the one that commonly deployed by standard size in 2010, meanwhile, CBN C considers larger vessels to exhibit the ULCV.

Table 9.21. Profitability of Optimal Network

	CBN A	CBN B	CBN C
Number of clusters	10	10	13
Profit (in million USD)	1,415.43	1,896.67	2,016.89
Revenue (in million USD)	4,384.95	5,876.29	6,541.13
Total cost (in million USD)	2,969.52	3,979.62	4,524.24
Fleet cost (in million USD)	656.52	879.74	977.53
Bunker cost (in million USD)	850.72	1,139.96	1,262.78
Port cost (in million USD)	89.94	120.52	124.42
Handling cost (in million USD)	1,372.69	1,839.40	2,159.51
Transshipment cost (in million USD)	-	-	-

Table 9.22. Operational Performance of Optimal Network

	10 Clusters	10 Clusters	13 Clusters
Demand delivered (in %)	89.99	92.68	93.61
Demand rejected (in %)	10.02	7.32	6.39

Table 9.21 points out the CBN C leads to the highest profit comparing to the rest networks available namely CBN A and CBN C. It could be the reason that the demand growth for container liner at 34% between 2010 and 2018. Consequently, the shift from CBN B to CBN C or by holding demand in 2018 and replacing smaller ships such as Panamax and Post-Panamax with ULCV results in 6% increase in profit. Meanwhile, considering both demand growth and ship size upgrade simultaneously, CBN A and CBN C stand next to each other. It brings Maersk to 42% improvement in profitability afterwards. In term of operational performance, number of clusters are expanded from 10 clusters in CBN A and CBN B to 13 clusters in CBN C to meet the current demand. As shown in Table 9.22, percentage of demand delivered increase up to 93.61% in 2018.

9.6. Estimated Profitability and Optimal Profitability

Chapter 7 appraises the expected profit of ULCV deployment by employing financial estimation of cost analysis. Comparative analysis between the prior approach in Chapter 7 (Table 7.6) and the optimality approach in Chapter 9 (Table 9.7) is considered. It is highly motivated with the accuracy check between the two so that the figures presented in this thesis could represent the factual decision making in the container liner industry.

Table 9.23. Estimated and Optimal Profitability of ULCV

	Estimated Profitability	Optimal Profitability (CBN C)
Ship Size (in TEU)	18,000	16,000 and 18,000
Revenue (in million USD)	6,115.20	6,541.13
Total Cost (in million USD)	4,780.79	4,524.24
Profit (in million USD)	1,334.41	2,016.89

Source: Author estimation based on Notteboom and Carriou (2009) and OECD (2015)
Note:
The simulation is under slow steaming setting at 15 knots.

CBN C is selected as a comparison to the estimated profitability baseline because both are executed under constant slow steaming scenario at 15 knots. Even so, the two in term of vessel size. On the estimated probability, uniform vessel of 18,000 TEU puts upfront. Estimated profitability in Table 9.9 is assumed for all ships deployed annually is the network which is 71 units while calculation in Table 7.6 stands only stands for a ship in a year. Meanwhile, the optimal profitability provided by CBN C is a result of assigning 2 vessel classes namely 16,000 TEU (35 units) and 18 TEU (36 units). In such circumstance, profit difference is about 38% higher for CBN C due to more efficient cargo routing on specified routes in the network while cost saving is about 13%. Furthermore, diversifying the available ship type on the pools may improve profitability and network performance because ship capacity closer to respected cargo volume is chosen.

9.7. Reference Network and Optimal Network

In this section, reference network in Section 9.1 is compared to optimal network that has been presented in Section 9.5. One out of three optimal network is selected based on similar setting shared with reference network. Recalling that calculation presented in reference network is based on demand and ship size used in 2010, the optimal network is found to be CBN A with 10 clusters.

Table 9.24. Comparative Financial Performance

	Reference Network	CBN A with 10 clusters	Difference (in %)
Profit (in million USD)	1,088.79	1,415.43	30
Revenue (in million USD)	4,474.44	4,384.95	-2
Total cost (in million USD)	3,385.01	2,969.52	-12.27

Table 9.24 shows that the shift from reference network to CBN A with 10 clusters allows Maersk to improve its profitability by 30 with cost efficiency of 12%. This finding indicates that properly adjusted network design with combination of maximized cargo flow between ports given minimized distance may encourage more competitive financial performance. The implementation of clustering algorithm, for instance, gives a credit to the combination of shorter path for port visited on hub route. Therefore, selecting main hub ports to call at on route and allocate the rest smaller cargo volumes on an integrated feeder network restricts less cost and generates higher profit especially in the case of ULCV. In general, developing hub and spoke network with thirteen ports in the hub service network is found to be optimal as it allows the highest profitability.

9.8. Conclusion

This chapter presents the empirical result obtained from testing the model performance that has been specified in Chapter 3. The main changes made are two folds. Firstly, it differs from the original Maersk network in term of port rotation. It shows that calling at larger port twice may improve the profitability. Secondly, this thesis suggests ship size and number of ship required as solutions to both RRND and RSCA problem. Although this preference over individual ship registration limits certain degree of approximation to actual case, the purpose of this thesis is served still as discussed beforehand in Section 3.5.

Chapter 10 Discussion

In this chapter, the methodological approach used in this thesis is critically evaluated. It is expected that by doing so the reliability and optimality of the result can be enhanced. The scope of discussion can be specified into two aspects: methodology and data.

On the methodology, this thesis comes up with set of instruments and models. As the proposed network is developed from scratch, assumptions constructed are quite critical. Section 3.5 previously addresses this issue. Initial fleets are categorized by ship class ranging from 10,000 TEU to 22,000 TEU for hub service and from and 1,200 TEU to 9,600 TEU for feeder service in which those are given for an infinite unit. Although it could be the case where empirical gap exists between proposed network and actual condition faced by liner shipping in term of availability of ship, this method is still relevant to solve combined ship-scheduling and cargo-routing with given ship-design.

This thesis carefully observes the clustering phase before constructing two-fold problems which are RRND and RSCA. Clustering provides foundation for the shortest distance and the largest demand, therefore, conducting at least two clustering techniques simultaneously such as PAM and DBSCAN may serve that particular purposes better.

On the data, limited access to AIS database with regards to ship availability implies on several assumptions to hold. Ships are allocated to certain route based on cargo demand since the beginning of planning period and remain on operation within time horizon. However, it still fits to the objective of this thesis in examining the impact of vessel size on optimal profit level. Afterwards, it results in a prescriptive analysis to the extent that preference over ship size should be made to reach optimal profitability.

Moreover, this thesis assumes a limitation of constant demand level across planning timeline to simplify the model. In fact, container liner faces volatility across the period due to higher demand in Christmas and Chinese New Year. This issue is not adequately addressed in this thesis to prevent further complexity of the model. As the model gets more complex, feasible solution could be even more difficult to obtain.

This thesis imposes port restrictions based of the ship class, port draft, and ship draught. Port restrictions in term of draft is considered for the feasibility of ULCV deployment on hub routes. Meanwhile, weekly service window is necessary to maintain regularity of service. Multiple port visits respond high demand in larger ports such that high demand delivered and high profitability could be obtained. Last assumption is taken into account to guarantee the synchronized pickup and delivery between hub and feeder ports.

Chapter 11 Conclusion

Competition among container liner has been tightening inevitably over the last decades. Deployment of larger vessel known as ULCV class marks the contestable market share. It seems to be a logical move for prominent player in the market such as Maersk as it has sufficient capital to deploy and operate larger vessel with higher level of efficiency. Consequently, smaller container liners are prone to bow out after a tense competition with the entrance of ULCV on the main trade lane such as Asia-Europe routes. Furthermore, the previously deployed ships on this service are rerouted to second layer lane such as Asia-South America.

Concerning on that particular issue on container shipping, this thesis stands on an objective: to construct a model representing the situation where cascading phenomena driven by the deployment of ULCV exist in container liner shipping. In order to achieve the aforementioned goal, a network design is proposed as a strategic response to the current situation such that profit is maximized. Therefore, this thesis focuses on the main research question: “To what extent the optimality of network configuration design can be guaranteed under cascading phenomena driven by the deployment of ULCV?”.

An established approach on network design and decision making in container liner shipping promoted by Agarwal and Ergun (2008) is applied where the three levels namely strategic planning level, tactical planning level and operational planning level are discussed separately in Chapter 2. Chapter 3 lays a foundation for sub-question 3 on model for container liner shipping network design by showing the construction of combined model of ship-scheduling and cargo-routing problem. Later, it is translated into 2-phases execution comprising Regional Route Network Design (RRND) and Route Construction and Ship Allocation (RSCA) as previously preferred by Mulder and Dekker (2016). These problems are constructed as a mixed integer programming (MIP) aiming to oversee the optimality of solution as envisaged in sub-question 4 on mathematical programming technique. Clustering algorithms of PAM and DBSCAN for ports are tested to simplify the complexity of models where Chapter 8 presents the upper performance of PAM in this case as shorter average distance is obtained for 10, 13, and 15 clusters.

Regarding to the scope of analysis, this thesis highlights the implication of ULCV deployment on profitability of liner shipping in which Maersk is used as a case study. To capture the cascading phenomena, two consecutive periods are selected based on the development of ULCV namely 2010 and 2018. Maersk original routes in Asia-Europe service network are used as a reference network. There are 1,935 OD pair demand observed between 58 ports for both year, while demand in 2018 is projected by 34% growth from the initial period in 2010. These data are available in Chapter 4.

Sub-research question 1 on the driving factor of the ULCV deployment is approximated by two folds approach comprising theoretical proof in Chapter 5 and empirical analysis in Chapter 7. Both suggests that economies of scale motivate liner decision on ULCV deployment because of lower cost per TEU that leads to higher profitability. Profit grows up to 12% (USD 72.74 million to USD 85.30 million) when the size of ship is upgraded from 14,000 TEU to 16,000 TEU. However, further size upgrade only retains smaller profit growth as the scale power is flattening asymptotically.

In response to the second sub-questions on the shifting in structure of container liner shipping network between 2010 and 2018, network analysis is employed using several properties such as degree centrality and betweenness centrality. This part shows highly centralized and connected ports can be regarded as candidates of additional port to be called on route, among others are Shanghai, Hong Kong, Rotterdam, and Singapore.

Overall, the proposed network CBN A with 10 clusters is the best to compare to reference network because both are performed under slow steaming practice at 15 knots with demand volume in 2010. It allows higher profit by 30 with cost efficiency of 12%. This finding indicates that more competitive financial performance can be induced by properly adjusted network design with combination of maximized cargo flow between ports given minimized distance.

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Appendix A: Data

Table A.1. List of Hub Ports

Port Code	Port Name	Country	Region	2010	2018
AEJEA	Jebel Ali	Dubai	Middle East	X	X
BEANR	Antwerp	Belgium	Europe	X	X
BEZEE	Zeebrugge	Belgium	Europe	X	
CNCWN	Chiwan	China	Asia	X	
CNDCB	Da Chan Bay	China	Asia	X	
CNDLC	Dalian	China	Asia	X	X
CNFOC	Fuzhou	China	Asia	X	
CNHKG	Hong Kong	China	Asia	X	X
CNLYG	Lian Yun Gang	China	Asia	X	
CNNGB	Ningbo	China	Asia	X	X
CNSHA	Shanghai	China	Asia	X	X
CNTAO	Qingdao	China	Asia	X	X
CNTXG	Tianjin	China	Asia	X	X
CNXMN	Xiamen	China	Asia	X	X
CNYTN	Yan Tian	China	Asia	X	X
DEBRV	Bremerhaven	Germany	Europe	X	X
DEHAM	Hamburg	Germany	Europe	X	X
DEWIL	Wilhelmshaven	Germany	Europe		X
DKAAR	Aarhus	Denmark	Europe	X	X
EGDAM	Damietta	Egypt	Middle East	X	
EGPSD	Port Said East	Egypt	Middle East	X	X
EGSUZ	Suez Canal	Egypt	Middle East		X
ESAGP	Malaga	Spain	Europe	X	
ESALG	Algeciras	Spain	Europe	X	X
ESBCN	Barcelona	Spain	Europe	X	
ESVLC	Valencia	Spain	Europe	X	
FRFOS	Fos Sur Mer	France	Europe	X	
FRLEH	Le Havre	France	Europe	X	X
GBFTX	Felixtowe	UK	Europe	X	X
GRPIR	Piraeus	Greece	Europe	X	
HRRJK	Rijeka	Croatia	Europe	X	X
ITGIT	Gioia Tauro	Italy	Europe	X	X
ITGOA	Genoa	Italy	Europe	X	
ITTRS	Trieste	Italy	Europe	X	X
JPNGO	Nagoya	Japan	Asia	X	
JPSMZ	Shimizu	Japan	Asia	X	
JPUKB	Kobe	Japan	Asia	X	
JPYOK	Yokohama	Japan	Asia	X	X
KRKAN	Kwangyang	South Korea	Asia	X	X

KRPUS	Pusan	South Korea	Asia	X	X
KRUSN	Ulsan	South Korea	Asia		X
LKCMB	Colombo	Srilanka	Asia	X	X
MAPTM	Tanger	Morocco	Europe	X	X
MYPKG	Port Klang	Malaysia	Asia	X	
MYTPP	Tanjung Pelepas	Malaysia	Asia	X	X
NLRTM	Rotterdam	Netherlands	Europe	X	X
OMSLL	Salalah	Oman	Middle East	X	X
PLGDN	Gdansk	Poland	Europe	X	X
PTSIE	Port of Sines	Portugal	Europe		X
ROCND	Constanta	Romania	Europe	X	
RUBLT	Baltiysk	Russia	Europe		X
SAJED	Jeddah	Saudi Arabia	Middle East	X	
SAKAC	King Abdullah	Saudi Arabia	Middle East		X
SEGOT	Goteborg	Sweden	Europe	X	X
SGSIN	Singapore	Singapore	Asia	X	X
SIKOP	Slovenia	Koper	Europe	X	X
THLCH	Laem Chabang	Thailand	Asia	X	
TRAMR	Ambarli Port Istanbul	Turkey	Europe	X	
TRIZM	Izmir	Turkey	Europe	X	
TWKHH	Kaohsiung	Taiwan	Asia	X	
TWTPE	Taipei	Taiwan	Asia	X	
UAILK	Chornomorsk	Ukraine	Europe	X	
UAODS	Odessa	Ukraine	Europe	X	
VNVUT	Vung Tau	Vietnam	Asia	X	X
Number of Port of Call				58	39

Source: Mulder (2011) and Maersk (2018)

Table A.2. Distance between Ports

	JPYOK	JPSMZ	JPNGO	JPUKB	KRPUS	KRKAN	CNDLC	CNTXG	CNTAO	CNLYG	CNSHA	CNNGB	CNFOC	TWTPE	CNXMN	TWKHH	CNYTN	CNHKG	CNCWN	CNDCB	VNVUT	THLCH	SGSIN	MYTPP	MYPKG	LKCMB	AEJEA	OMSLL	SAJED
JPYOK	0	96	188	333	626	679	1095	1246	1060	1086	1008	1020	1211	1134	1316	1319	1565	1582	1592	1597	2418	2972	2879	2899	3072	4431	6303	6045	7190
JPSMZ	96	0	119	268	560	614	1030	1181	994	1020	942	954	1146	1064	1250	1254	1500	1516	1526	1531	2355	2907	2818	2838	3011	4370	6242	5984	7129
JPNGO	188	119	0	219	511	565	980	1132	945	971	893	905	1097	1028	1201	1205	1451	1467	1477	1482	2322	2858	2771	2791	2964	4323	6195	5937	7082
JPUKB	333	268	219	0	341	394	810	961	775	801	729	761	999	917	1103	1107	1353	1369	1379	1384	2213	2760	2679	2699	2872	4231	6103	5845	6990
KRPUS	626	560	511	341	0	72	503	654	467	493	445	495	752	688	869	898	1120	1137	1147	1152	1977	2551	2483	2503	2676	4035	5907	5649	6794
KRKAN	679	614	565	394	72	0	437	588	401	427	382	436	699	616	817	840	1062	1084	1094	1099	1905	2493	2428	2448	2621	3980	5852	5594	6739
CNDLC	1095	1030	980	810	503	437	0	188	251	324	477	556	843	851	961	1006	1212	1229	1249	1244	2111	2659	2576	2596	2769	4128	6000	5742	6887
CNTXG	1246	1181	1132	961	654	588	188	0	394	468	621	699	987	996	1105	1150	1356	1372	1382	1387	2242	2773	2720	2740	2913	4272	6144	5886	7031
CNTAO	1060	994	945	775	467	401	251	394	0	89	307	386	675	697	793	838	1044	1061	1071	1076	1959	2526	2408	2428	2601	3960	5832	5574	6719
CNLYG	1086	1020	971	801	493	427	324	468	89	0	258	337	626	641	745	790	996	1012	1022	1027	1876	2407	2360	2380	2553	3912	5784	5526	6671
CNSHA	1008	942	893	729	445	382	477	621	307	258	0	101	390	421	509	554	760	776	786	791	1675	2242	2124	2144	2317	3676	5548	5290	6435
CNNGB	1020	954	905	761	495	436	556	699	386	337	101	0	318	355	436	481	687	704	714	719	1572	2103	2051	2071	2244	3603	5475	5217	6362
CNFOC	1211	1146	1097	999	752	699	843	987	675	626	390	318	0	150	168	235	420	436	456	451	1318	1888	1784	1804	1977	3336	5208	4950	6095
TWTPE	1134	1064	1028	917	688	616	851	996	697	641	421	355	150	0	222	224	446	471	481	486	1312	1877	1812	1832	2005	3364	5236	4970	6124
CNXMN	1316	1250	1201	1103	869	817	961	1105	793	745	509	436	168	222	0	166	270	287	297	302	1150	1714	1638	1658	1831	3190	5062	4804	5949
TWKHH	1319	1254	1205	1107	898	840	1006	1150	838	790	554	481	235	224	166	0	337	354	364	369	1121	1653	1611	1631	1804	3163	5035	4777	5922
CNYTN	1565	1500	1451	1353	1120	1062	1212	1356	1044	996	760	687	420	446	270	337	0	46	56	61	947	1482	1436	1456	1629	2988	4860	4602	5747
CNHKG	1582	1516	1467	1369	1137	1084	1229	1372	1061	1012	776	704	436	471	287	354	46	0	10	15	927	1489	1410	1430	1603	2962	4834	4576	5721
CNCWN	1592	1526	1477	1379	1147	1094	1249	1382	1071	1022	786	714	456	481	297	364	56	10	0	5	937	1499	1420	1440	1613	2983	4844	4586	5731
CNDCB	1597	1531	1482	1384	1152	1099	1244	1387	1076	1027	791	719	451	486	302	369	61	15	5	0	942	1504	1425	1445	1618	2988	4849	4591	5736
VNVUT	2418	2355	2322	2213	1977	1905	2111	2242	1959	1876	1675	1572	1318	1312	1150	1121	947	927	937	942	0	681	646	666	839	2198	4070	3796	4958
THLCH	2972	2907	2858	2760	2551	2493	2659	2773	2526	2407	2242	2103	1888	1877	1714	1653	1482	1489	1499	1504	681	0	831	836	1009	2368	4240	3982	5127
SGSIN	2879	2818	2771	2679	2483	2428	2576	2720	2408	2360	2124	2051	1784	1812	1638	1611	1436	1410	1420	1425	646	831	0	20	193	1552	3424	3166	4311
MYTPP	2899	2838	2791	2699	2503	2448	2596	2740	2428	2380	2144	2071	1804	1832	1658	1631	1456	1430	1440	1445	666	836	20	0	173	1532	3404	3146	4291

MYPKG	3072	3011	2964	2872	2676	2621	2769	2913	2601	2553	2317	2244	1977	2005	1831	1804	1629	1603	1613	1618	839	1009	193	173	0	1370	3243	2985	4130
LKCMB	4431	4370	4323	4231	4035	3980	4128	4272	3960	3912	3676	3603	3336	3364	3190	3163	2988	2962	2983	2988	2198	2368	1552	1532	1370	0	1887	1633	2788
AEJEA	6303	6242	6195	6103	5907	5852	6000	6144	5832	5784	5548	5475	5208	5236	5062	5035	4860	4834	4844	4849	4070	4240	3424	3404	3243	1887	0	894	2152
OMSLL	6045	5984	5937	5845	5649	5594	5742	5886	5574	5526	5290	5217	4950	4970	4804	4777	4602	4576	4586	4591	3796	3982	3166	3146	2985	1633	894	0	1270
SAJED	7190	7129	7082	6990	6794	6739	6887	7031	6719	6671	6435	6362	6095	6123	5949	5922	5747	5721	5731	5736	4957	5127	4311	4291	4130	2788	2152	1270	0
EGPSD	7894	7833	7786	7694	7498	7443	7591	7735	7423	7375	7139	7066	6799	6822	6653	6626	6451	6425	6435	6440	5656	5837	5015	4995	4834	3492	2857	1975	715
EGDAM	7925	7864	7817	7725	7519	7426	7622	7766	7454	7406	7170	7097	6830	6842	6674	6657	6482	6456	6466	6471	5668	5806	5036	5025	4854	3508	2888	2006	746
TRIZM	8718	8650	8617	8518	8329	8278	8422	8566	8254	8206	7970	7898	7630	7644	7484	7450	7275	7256	7266	7271	6478	6654	5832	5825	5639	4303	3687	2805	1539
TRAMR	8669	8608	8561	8469	8273	8219	8366	8510	8198	8150	7914	7841	7574	7591	7428	7401	7226	7200	7210	7215	6425	6599	5790	5770	5609	4267	3632	2750	1490
UAODS	9016	8955	8908	8816	8620	8539	8713	8857	8545	8497	8261	8188	7921	7938	7775	7748	7573	7547	7557	7562	6772	6956	6137	6117	5943	4607	3979	3097	1837
UAILK	9013	8941	8905	8809	8617	8526	8731	8870	8563	8494	8279	8185	7939	7935	7772	7741	7592	7565	7570	7575	6769	6943	6123	6114	5930	4594	3996	3094	1834
ROCND	8872	8811	8764	8672	8476	8422	8569	8713	8401	8353	8117	8044	7777	7794	7631	7604	7429	7403	7413	7418	6628	6802	5993	5973	5812	4470	3835	2953	1693
GRPIR	8481	8420	8373	8281	8085	8033	8178	8322	8010	7962	7726	7653	7386	7412	7240	7213	7038	7012	7022	7027	6246	6413	5602	5582	5421	4079	3444	2562	1302
HRRJK	9139	9078	9031	8939	8743	8691	8836	8980	8668	8620	8384	8311	8044	8070	7898	7871	7696	7670	7680	7685	6904	7071	6260	6240	6079	4737	4102	3220	1960
SIKOP	9178	9117	9070	8978	8782	8727	8875	9019	8707	8659	8423	8350	8083	8109	7937	7910	7735	7709	7719	7724	6943	7124	6299	6279	6117	4776	4141	3259	1999
ITTRS	9186	9120	9078	8986	8790	8735	8883	9027	8715	8667	8431	8358	8091	8114	7945	7918	7738	7717	7727	7732	6948	7116	6302	6282	6109	4773	4149	3267	2007
ITGIT	8822	8761	8714	8622	8426	8371	8519	8663	8351	8303	8067	7994	7727	7753	7581	7554	7379	7353	7363	7368	6587	6768	5943	5923	5762	4420	3785	2903	1643
ITGOA	9305	9244	9197	9105	8909	8854	9002	9146	8834	8786	8550	8477	8210	8237	8064	8037	7862	7836	7847	7852	7071	7252	6426	6406	6245	4903	4268	3386	2126
FRFOS	9405	9344	9297	9205	9009	8954	9102	9246	8934	8886	8650	8577	8310	8332	8164	8137	7962	7936	7946	7951	7166	7340	6526	6506	6345	5003	4368	3486	2226
ESBCN	9476	9415	9368	9276	9080	9029	9173	9317	9005	8957	8721	8648	8381	8407	8235	8208	8033	8007	8034	8039	7241	7409	6597	6577	6416	5074	4439	3557	2297
ESVLC	9556	9495	9448	9356	9160	9109	9253	9397	9085	9037	8801	8728	8461	8487	8315	8288	8113	8087	8097	8102	7321	7489	6677	6657	6496	5154	4519	3637	2377
ESAGP	9758	9690	9650	9558	9362	9275	9455	9599	9324	9239	9040	8930	8663	8684	8517	8490	8315	8326	8336	8341	7518	7683	6872	6859	6679	5343	4758	3839	2579
ESALG	9804	9743	9696	9604	9408	9340	9501	9645	9333	9285	9049	8976	8709	8735	8563	8536	8361	8335	8385	8390	7569	7736	6925	6905	6744	5402	4767	3885	2625
MAPTM	9835	9763	9728	9624	9440	9348	9533	9677	9365	9305	9081	9008	8741	8757	8595	8556	8393	8367	8410	8415	7591	7757	6945	6937	6752	5416	4799	3915	2657
FRLEH	10933	10872	10825	10736	10540	10485	10633	10774	10462	10414	10178	10105	9841	9864	9692	9668	9490	9467	9477	9482	8698	8879	8054	8034	7873	6534	5899	5014	3757
GBFTX	11056	10995	10948	10856	10663	10605	10756	10897	10585	10537	10301	10228	9961	10013	9815	9788	9613	9587	9640	9645	8847	9014	8177	8157	7996	6657	6019	5137	3877
BEZEE	11083	11022	10975	10883	10687	10624	10780	10924	10612	10564	10328	10255	9988	10017	9842	9815	9640	9614	9624	9629	8851	9018	8204	8184	8023	6681	6046	5164	3904

BEANR	11170	11109	11062	10970	10774	10711	10867	10986	10699	10626	10415	10317	10075	10078	9929	9902	9701	9701	9711	9716	8912	9077	8291	8246	8094	6758	6133	5234	3991
NLRTM	11133	11072	11025	10933	10737	10688	10830	10974	10662	10614	10378	10305	10038	10081	9892	9865	9690	9664	9674	9679	8915	9082	8254	8234	8084	6742	6107	5214	3965
DEBRV	11328	11267	11220	11128	10932	10877	11025	11169	10857	10809	10573	10500	10233	10286	10087	10060	9885	9859	9889	9894	9120	9287	8449	8429	8268	6926	6291	5409	4149
DEHAM	11416	11355	11322	11216	11034	10971	11142	11242	10974	10882	10690	10573	10350	10334	10175	10148	9956	9976	9979	9984	9168	9332	8537	8502	8342	7006	6408	5490	4237
SEGOT	11568	11507	11460	11368	11175	11117	11268	11409	11097	11049	10813	10740	10476	10524	10327	10300	10125	10099	10141	10146	9358	9525	8689	8669	8508	7169	6531	5649	4389
DKAAR	11662	11601	11554	11462	11269	11127	11419	11391	11248	11025	10964	10721	10615	10454	10421	10394	10276	10250	10258	10263	9453	9620	8783	8763	8602	7263	6682	5626	4483
PLGDN	11792	11731	11684	11592	11386	11293	11489	11633	11321	11273	11037	10964	10697	10833	10541	10524	10349	10323	10509	10514	9726	9893	8903	8892	8721	7375	6755	5873	4613

	EGPSD	EGDAM	TRIZM	TRAMR	UAODS	UAILK	ROCND	GRPIR	HRRJK	SIKOP	ITTRS	ITGIT	ITGOA	FRFOS	ESBCN	ESVLC	ESAGP	ESALG	MAPTM	FRLEH	GBFTX	BEZEE	BEANR	NLRTM	DEBRV	DEHAM	SEGOT	DKAAR	PLGDN
JPYOK	7894	7925	8718	8669	9015	9013	8872	8481	9139	9178	9186	8822	9305	9405	9476	9556	9758	9804	9835	10933	11056	11083	11170	11133	11328	11416	11568	11662	11792
JPSMZ	7833	7864	8650	8608	8954	8941	8811	8420	9078	9117	9120	8761	9244	9344	9415	9495	9690	9743	9763	10872	10995	11022	11109	11072	11267	11355	11507	11601	11731
JPNGO	7786	7817	8617	8561	8907	8905	8764	8373	9031	9070	9078	8714	9197	9297	9368	9448	9650	9696	9728	10825	10948	10975	11062	11025	11220	11322	11460	11554	11684
JPUKB	7694	7725	8518	8469	8815	8809	8672	8281	8939	8978	8986	8622	9105	9205	9276	9356	9558	9604	9624	10736	10856	10883	10970	10933	11128	11216	11368	11462	11592
KRPUS	7498	7519	8329	8273	8619	8617	8476	8085	8743	8782	8790	8426	8909	9009	9080	9160	9362	9408	9440	10540	10663	10687	10774	10737	10932	11034	11175	11269	11386
KRKAN	7443	7426	8278	8219	8539	8526	8422	8033	8691	8727	8735	8371	8854	8954	9029	9109	9275	9340	9348	10485	10605	10624	10711	10690	10877	10971	11117	11127	11293
CNDLC	7591	7622	8422	8366	8712	8731	8569	8178	8836	8875	8883	8519	9002	9102	9173	9253	9455	9501	9533	10633	10756	10780	10867	10830	11025	11142	11268	11419	11489
CNTXG	7735	7766	8566	8510	8856	8869	8713	8322	8980	9019	9027	8663	9146	9246	9317	9397	9599	9645	9677	10774	10897	10924	10986	10974	11169	11242	11409	11391	11633
CNTAO	7423	7454	8254	8198	8544	8563	8401	8010	8668	8707	8715	8351	8834	8934	9005	9085	9324	9333	9365	10462	10585	10612	10699	10662	10857	10974	11097	11248	11321
CNLYG	7375	7406	8206	8150	8496	8494	8353	7962	8620	8659	8667	8303	8786	8886	8957	9037	9239	9285	9305	10414	10537	10564	10626	10614	10809	10882	11049	11025	11273
CNSHA	7139	7170	7970	7914	8260	8279	8117	7726	8384	8423	8431	8067	8550	8650	8721	8801	9040	9049	9081	10178	10301	10328	10415	10378	10573	10690	10813	10964	11037
CNNGB	7066	7097	7898	7841	8187	8185	8044	7653	8311	8350	8358	7994	8477	8577	8648	8728	8930	8976	9008	10105	10228	10255	10317	10305	10500	10573	10740	10721	10964
CNFOC	6799	6830	7630	7574	7920	7939	7777	7386	8044	8083	8091	7727	8210	8310	8381	8461	8663	8709	8741	9841	9961	9988	10075	10038	10233	10350	10476	10615	10697
TWTPE	6822	6842	7644	7591	7938	7935	7794	7412	8070	8109	8114	7753	8237	8332	8407	8487	8684	8735	8757	9864	10013	10017	10078	10081	10286	10334	10524	10454	10833
CNXMN	6653	6674	7484	7428	7774	7772	7631	7240	7898	7937	7945	7581	8064	8164	8235	8315	8517	8563	8595	9692	9815	9842	9929	9892	10087	10175	10327	10421	10541
TWKHH	6626	6657	7450	7401	7747	7741	7604	7213	7871	7910	7918	7554	8037	8137	8208	8288	8490	8536	8556	9668	9788	9815	9902	9865	10060	10148	10300	10394	10524
CNYTN	6451	6482	7275	7226	7572	7592	7429	7038	7696	7735	7738	7379	7862	7962	8033	8113	8315	8361	8393	9490	9613	9640	9701	9690	9885	9956	10125	10276	10349
CNHKG	6425	6456	7256	7200	7546	7565	7403	7012	7670	7709	7717	7353	7836	7936	8007	8087	8326	8335	8367	9467	9587	9614	9701	9664	9859	9976	10099	10250	10323

CNCWN	6435	6466	7266	7210	7556	7573	7413	7022	7680	7719	7727	7363	7847	7946	8034	8097	8336	8385	8410	9477	9640	9624	9711	9674	9889	9979	10141	10258	10509
CNDCB	6440	6471	7271	7215	7561	7578	7418	7027	7685	7724	7732	7368	7852	7951	8039	8102	8341	8390	8415	9482	9645	9629	9716	9679	9894	9984	10146	10263	10514
VNVUT	5656	5668	6478	6425	6772	6769	6628	6246	6904	6943	6948	6587	7071	7166	7241	7321	7518	7569	7591	8698	8847	8851	8912	8915	9120	9168	9358	9369	9726
THLCH	5837	5806	6654	6599	6964	6951	6818	6413	7071	7124	7116	6759	7243	7340	7409	7489	7683	7736	7757	8882	9014	9018	9077	9082	9287	9332	9525	9507	9893
SGSIN	5015	5036	5832	5790	6136	6123	5993	5602	6260	6299	6302	5943	6426	6526	6597	6677	6872	6925	6945	8054	8177	8204	8291	8254	8449	8537	8689	8783	8903
MYTPP	4995	5025	5825	5770	6116	6114	5973	5582	6240	6279	6282	5923	6406	6506	6577	6657	6859	6905	6937	8034	8157	8184	8246	8234	8429	8502	8669	8763	8892
MYPKG	4834	4854	5639	5609	5943	5930	5812	5421	6079	6117	6109	5762	6245	6345	6416	6496	6679	6744	6752	7873	7996	8023	8094	8084	8268	8342	8508	8602	8721
LKCMB	3492	3508	4303	4267	4607	4594	4470	4079	4737	4776	4773	4420	4903	5003	5074	5154	5343	5402	5416	6534	6657	6681	6758	6742	6926	7006	7169	7263	7375
AEJEA	2857	2888	3687	3632	3979	3996	3835	3444	4102	4141	4149	3785	4268	4368	4439	4519	4758	4767	4799	5899	6019	6046	6133	6107	6291	6408	6531	6682	6755
OMSLL	1975	2006	2805	2750	3097	3094	2953	2562	3220	3259	3267	2903	3386	3486	3557	3637	3839	3885	3915	5014	5137	5164	5234	5214	5409	5490	5649	5626	5873
SAJED	715	746	1539	1490	1837	1834	1693	1302	1960	1999	2007	1643	2126	2226	2297	2377	2579	2625	2657	3757	3877	3904	3991	3965	4149	4237	4389	4483	4613
EGPSD	0	31	824	779	1126	1115	982	590	1248	1287	1294	931	1413	1513	1585	1665	1864	1913	1941	3042	3165	3195	3279	3256	3437	3525	3677	3771	3898
EGDAM	31	0	848	793	1150	1137	996	607	1265	1307	1310	962	1434	1536	1603	1683	1877	1930	1951	3073	3196	3212	3271	3276	3468	3526	3707	3701	3867
TRIZM	824	848	0	55	397	384	251	390	1150	1186	1190	837	1321	1420	1504	1588	1762	1643	1675	2798	3121	3062	3147	3126	3378	3261	3432	3535	3800
TRAMR	779	793	55	0	347	344	203	349	1097	1137	1145	790	1273	1373	1460	1542	1731	1698	1730	2853	2976	2992	3079	3053	3248	3336	3487	3582	3829
UAODS	1126	1150	397	347	0	13	170	694	1444	1484	1492	1137	1620	1720	1807	1889	2078	2040	2156	3195	3391	3334	3421	3395	3663	3751	3903	3997	4244
UAILK	1115	1137	384	344	13	0	160	681	1441	1477	1481	1128	1612	1707	1798	1879	2075	2027	2059	3280	3305	3418	3397	3482	3687	3645	3816	3911	4184
ROCND	982	996	251	203	170	160	0	552	1300	1340	1348	993	1476	1576	1663	1745	1934	1894	2012	3049	3247	3188	3359	3249	3519	3607	3759	3853	4100
GRPIR	590	607	390	349	694	681	552	0	790	829	837	483	966	1066	1153	1235	1432	1484	1505	2614	2737	2773	2847	2834	3009	3095	3249	3343	3590
HRRJK	1248	1265	1150	1097	1444	1441	1300	790	0	103	110	581	1064	1164	1251	1338	1554	1603	1628	2732	2855	2892	2973	2953	3127	3215	3367	3461	3708
SIKOP	1287	1307	1186	1137	1484	1477	1340	829	103	0	8	620	1103	1202	1290	1377	1593	1642	1667	2772	2894	2931	3009	2992	3166	3254	3406	3500	3747
ITTRS	1294	1310	1190	1145	1492	1481	1348	837	110	8	0	625	1109	1208	1296	1383	1598	1647	1672	2777	2925	2936	3014	3000	3205	3260	3436	3531	3804
ITGIT	931	962	837	790	1137	1128	993	483	581	620	625	0	484	583	671	758	973	1022	1047	2152	2275	2311	2389	2372	2547	2635	2787	2881	3128
ITGOA	1413	1434	1321	1273	1620	1612	1476	966	1064	1103	1109	484	0	208	350	508	798	847	871	1997	2100	2136	2213	2197	2372	2460	2630	2706	2953
FRFOS	1513	1536	1420	1373	1720	1707	1576	1066	1164	1202	1208	583	208	0	172	331	641	680	712	1830	1932	1969	2029	2030	2204	2285	2462	2538	2804
ESBCN	1585	1603	1504	1460	1807	1798	1663	1153	1251	1290	1296	671	350	172	0	161	499	513	545	1663	1786	1802	1881	1863	2058	2129	2297	2392	2639
ESVLC	1665	1683	1588	1542	1889	1879	1745	1235	1338	1377	1383	758	508	331	161	0	338	382	411	1512	1635	1672	1752	1712	1907	1995	2147	2241	2488

ESAGP	1864	1877	1762	1731	2078	2075	1934	1432	1554	1593	1598	973	798	641	499	338	0	65	87	1219	1343	1358	1429	1422	1627	1677	1854	1949	2222
ESALG	1913	1930	1643	1698	2064	2054	1894	1484	1603	1642	1647	1022	847	680	513	382	65	0	32	1155	1278	1294	1370	1355	1550	1618	1789	1884	2131
MAPTM	1941	1951	1675	1730	2077	2059	1933	1505	1628	1667	1672	1047	871	712	545	411	87	32	0	1137	1273	1276	1347	1340	1545	1595	1786	1869	2154
FRLEH	3042	3073	2798	2853	3195	3280	3049	2614	2732	2772	2777	2152	1997	1830	1663	1512	1219	1155	1137	0	163	171	252	232	431	500	674	769	1015
GBFTX	3165	3196	3121	2976	3323	3332	3179	2737	2855	2894	2925	2275	2100	1932	1786	1635	1343	1278	1273	163	0	83	141	123	303	360	530	606	872
BEZEE	3195	3212	3062	2992	3334	3336	3188	2773	2892	2931	2936	2311	2136	1969	1802	1672	1358	1294	1276	171	83	0	87	64	269	347	519	627	861
BEANR	3279	3271	3147	3079	3421	3397	3280	2847	2973	3009	3014	2389	2213	2029	1881	1752	1429	1370	1347	252	141	87	0	149	356	405	597	680	965
NLRTM	3256	3276	3126	3053	3395	3400	3249	2834	2953	2992	3000	2372	2197	2030	1863	1712	1422	1355	1340	232	123	64	149	0	215	305	467	584	809
DEBRV	3437	3468	3331	3248	3595	3605	3451	3009	3127	3166	3205	2547	2372	2204	2058	1907	1627	1550	1545	431	303	269	356	215	0	117	344	456	686
DEHAM	3525	3526	3261	3336	3683	3645	3539	3095	3215	3254	3260	2635	2460	2285	2129	1995	1677	1618	1595	500	360	347	405	305	117	0	402	485	770
SEGOT	3677	3707	3432	3487	3834	3843	3690	3249	3367	3406	3436	2787	2630	2462	2297	2147	1854	1789	1786	674	530	519	597	467	344	402	0	151	368
DKAAR	3771	3701	3527	3582	3929	3938	3785	3343	3461	3500	3531	2881	2706	2538	2392	2241	1949	1884	1869	769	606	627	680	584	456	485	151	0	379
PLGDN	3898	3867	3800	3829	4176	4211	4032	3590	3708	3747	3804	3128	2953	2804	2639	2488	2222	2131	2154	1015	872	861	965	809	686	770	368	379	0

Source: Lachner and Boskamp (2011)

Table A.3. Demand between Ports

	JPYOK	JPSMZ	JPNGO	JPUKB	KRPUS	KRKAN	CNDLC	CNTXG	CNTAO	CNLYG	CNSHA	CNNGB	CNFOC	TWTPE	CNXMN	TWKHH	CNYTN	CNHKG	CNCWN	CNDCB	VNVUT	THLCH	SGSIN	MYTPP	MYPKG	LKCMB	AEJEA	OMSLL	SAJED
JPYOK	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9826	3083	2731
JPSMZ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1756	551	488
JPNGO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7419	2328	2062
JPUKB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7891	2476	2193
KRPUS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	41983	13171	11667
KRKAN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6358	1995	1767
CNDLC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15986	5015	4442
CNTXG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30552	9585	8490
CNTAO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	36031	11304	10013
CNLYG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10608	3328	2948
CNSHA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	87801	27546	24399
CNNGB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	36884	11572	10250
CNFOC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4132	1296	1148
TWTPE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3512	1102	976
CNXMN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16436	5157	4568
TWKHH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30136	9455	8374
CNYTN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	42727	13405	11874
CNHKG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	73688	23118	20477
CNCWN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16023	5027	4453
CNDCB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5341	1676	1484
VNVUT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6496	2038	1805
THLCH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16230	5092	4510
SGSIN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	90837	28499	25243
MYTPP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21071	6611	5855

MYPKG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25670	8054	7134
LKCMB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12166	3817	3381
AEJEA	3215	575	2428	2582	13737	2080	5231	9997	11790	3471	28730	12069	1352	1149	5378	9861	13981	24112	5243	1748	2126	5311	29723	6895	8400	3981	0	0	0
OMSLL	1009	180	762	810	4310	653	1641	3136	3699	1089	9014	3786	424	361	1687	3094	4386	7565	1645	548	667	1666	9325	2163	2635	1249	0	0	0
SAJED	893	160	675	718	3818	578	1454	2778	3276	965	7984	3354	376	319	1495	2740	3885	6700	1457	486	591	1476	8260	1916	2334	1106	0	0	0
EGPSD	1003	179	757	805	4285	649	1632	3118	3678	1083	8962	3765	422	358	1678	3076	4361	7521	1635	545	663	1657	9272	2151	2620	1242	0	0	0
EGDAM	321	57	242	257	1370	207	522	997	1176	346	2865	1203	135	115	536	983	1394	2404	523	174	212	530	2964	687	838	397	0	0	0
TRIZM	53	9	40	42	226	34	86	164	194	57	472	198	22	19	88	162	230	396	86	29	35	87	489	113	138	65	210	66	58
TRAMR	621	111	469	499	2653	402	1010	1931	2277	670	5549	2331	261	222	1039	1904	2700	4657	1013	338	411	1026	5741	1332	1622	769	210	66	58
UAODS	42	7	31	33	178	27	68	130	153	45	373	156	18	15	70	128	181	313	68	23	28	69	385	89	109	52	166	52	46
UAILK	32	6	24	26	137	21	52	100	118	35	287	121	14	11	54	99	140	241	52	17	21	53	297	69	84	40	128	40	36
ROCND	201	36	152	161	859	130	327	625	737	217	1796	754	85	72	336	616	874	1507	328	109	133	332	1858	431	525	249	799	251	222
GRPIR	475	85	358	381	2028	307	772	1476	1741	512	4241	1782	200	170	794	1456	2064	3560	774	258	314	784	4388	1018	1240	588	1887	592	524
HRRJK	49	9	37	39	210	32	80	153	180	53	438	184	21	18	82	150	213	368	80	27	32	81	453	105	128	61	195	61	54
SIKOP	116	21	88	93	496	75	189	361	426	125	1037	436	49	41	194	356	505	870	189	63	77	192	1073	249	303	144	461	145	128
ITTRS	94	17	71	75	400	61	152	291	344	101	837	352	39	33	157	287	407	703	153	51	62	155	866	201	245	116	372	117	103
ITGIT	947	169	715	761	4046	613	1541	2945	3473	1022	8462	3555	398	338	1584	2904	4118	7102	1544	515	626	1564	8755	2031	2474	1173	37	1181	1046
ITGOA	519	93	392	417	2216	336	844	1613	1902	560	4635	1947	218	185	868	1591	2256	3890	846	282	343	857	4795	1112	1355	642	2062	647	573
FRFOS	299	53	225	240	1275	193	486	928	1095	322	2667	1121	126	107	499	916	1298	2239	487	162	197	493	2760	640	780	370	1187	372	330
ESBCN	609	109	460	489	2601	394	991	1893	2233	657	5441	2285	256	218	1018	1867	2648	4566	993	331	403	1006	5629	1306	1591	754	2421	759	673
ESVLC	1236	221	933	992	5280	800	2011	3843	4532	1334	11043	4639	520	442	2067	3790	5374	9268	2015	672	817	2041	11425	2650	3229	1530	49	1541	1365
ESAGP	98	18	74	79	419	63	160	305	360	106	876	368	41	35	164	301	426	735	160	53	65	162	906	210	256	121	390	122	108
ESALG	1029	184	777	826	4397	666	1674	3200	3774	1111	9196	3863	433	368	1721	3156	4475	7718	1678	559	680	1700	9514	2207	2689	1274	409	1284	1137
MAPTM	338	60	255	272	1445	219	550	1052	1240	365	3022	1270	142	121	566	1037	1471	2536	552	184	224	559	3127	725	884	419	1345	422	374
FRLEH	744	133	562	598	3179	481	1211	2314	2728	803	6649	2793	313	266	1245	2282	3236	5580	1213	404	492	1229	6879	1596	1944	921	2958	928	822
GBFTX	1048	187	792	842	4480	678	1706	3260	3845	1132	9369	3936	441	375	1754	3216	4559	7863	1710	570	693	1732	9693	2248	2739	1298	41	1308	1158
BEZEE	787	141	595	632	3364	510	1281	2448	2887	850	7036	2956	331	281	1317	2415	3424	5905	1284	428	521	1301	7280	1689	2057	975	3131	982	870

BEANR	2472	442	1867	1985	10563	1600	4022	7687	9066	2669	22091	9280	1040	884	4135	7582	10750	18540	4031	1344	1634	4084	22855	5302	6459	3061	9829	3084	2731
NLRTM	3295	589	2488	2646	14080	2132	5361	10247	12084	3558	29446	12370	1386	1178	5512	10107	14330	24713	5374	1791	2179	5443	30465	7067	8609	4080	13102	4110	3641
DEBRV	1534	274	1158	1232	6555	993	2496	4770	5625	1656	13708	5759	645	548	2566	4705	6671	11505	2502	834	1014	2534	14182	3290	4008	1899	6099	1914	1695
DEHAM	2371	424	1790	1904	10130	1534	3857	7372	8694	2560	21186	8900	997	847	3966	7271	10310	17780	3866	1289	1567	3916	21918	5084	6194	2936	9426	2957	2619
SEGOT	277	49	209	222	1182	179	450	860	1014	299	2471	1038	116	99	463	848	1202	2074	451	150	183	457	2556	593	722	342	1099	345	306
DKAAR	231	41	174	186	987	149	376	718	847	249	2064	867	97	83	386	708	1005	1732	377	126	153	382	2136	495	604	286	918	288	255
PLGDN	81	15	61	65	348	53	132	253	298	88	727	305	34	29	136	250	354	610	133	44	54	134	752	175	213	101	324	102	90

	EGPSD	EGDAM	TRIZM	TRAMR	UAODS	UAILK	ROCND	GRPIR	HRRJK	SIKOP	ITTRS	ITGIT	ITGOA	FRFOS	ESBCN	ESVLC	ESAGP	ESALG	MAPTM	FRLEH	GBFTX	BEZEE	BEANR	NLRTM	DEBRV	DEHAM	SEGOT	DKAAR	PLGDN
JPYOK	3065	980	138	1622	109	84	525	1240	128	303	245	2473	1355	780	1590	3228	256	2688	883	1943	2738	2057	6457	8606	4007	6192	722	603	213
JPSMZ	548	175	25	290	19	15	94	222	23	54	44	442	242	139	284	577	46	480	158	347	489	368	1154	1538	716	1107	129	108	38
JPNGO	2314	740	104	1225	82	63	396	936	97	229	185	1868	1023	589	1201	2437	193	2029	667	1467	2068	1553	4875	6499	3025	4676	545	456	160
JPUKB	2462	787	111	1302	87	67	422	996	103	243	196	1986	1088	626	1277	2592	206	2158	709	1561	2199	1652	5185	6912	3218	4973	580	484	171
KRPUS	13096	4186	590	6929	465	359	2243	5297	547	1295	1045	10567	5788	3331	6794	13790	1094	11484	3774	8303	11700	8787	27587	36772	17118	26456	3086	2578	908
KRKAN	1983	634	89	1049	70	54	340	802	83	196	158	1600	877	504	1029	2088	166	1739	572	1257	1772	1331	4178	5569	2592	4006	467	390	138
CNDLC	4986	1594	225	2638	177	137	854	2017	208	493	398	4024	2204	1268	2587	5251	417	4373	1437	3161	4455	3346	10504	14001	6518	10074	1175	981	346
CNTXG	9530	3047	429	5043	339	261	1632	3854	398	943	761	7690	4212	2424	4944	10035	796	8357	2747	6042	8514	6394	20076	26760	12458	19253	2246	1876	661
CNTAO	11239	3593	506	5947	399	308	1925	4546	470	1112	897	9069	4967	2859	5831	11835	939	9855	3239	7126	10041	7541	23676	31558	14692	22705	2648	2212	779
CNLYG	3309	1058	149	1751	118	91	567	1338	138	327	264	2670	1463	842	1717	3485	276	2902	954	2098	2956	2220	6971	9292	4326	6685	780	651	229
CNSHA	27388	8755	1234	14491	973	751	4691	11077	1144	2709	2186	22100	12105	6966	14209	28840	2288	24016	7893	17364	24468	18376	57694	76903	35801	55329	6453	5391	1899
CNNGB	11505	3678	518	6087	409	315	1970	4653	481	1138	918	9284	5085	2926	5969	12115	961	10089	3316	7294	10279	7719	24236	32305	15039	23243	2711	2265	798
CNFOC	1289	412	58	682	46	35	221	521	54	127	103	1040	570	328	669	1357	108	1130	371	817	1151	865	2715	3619	1685	2604	304	254	89
TWTPE	1095	350	49	580	39	30	188	443	46	108	87	884	484	279	568	1154	92	961	316	695	979	735	2308	3076	1432	2213	258	216	76
CNXMN	5127	1639	231	2713	182	141	878	2074	214	507	409	4137	2266	1304	2660	5399	428	4496	1478	3251	4580	3440	10800	14396	6702	10358	1208	1009	356
TWKHH	9400	3005	423	4974	334	258	1610	3802	393	930	750	7585	4155	2391	4877	9899	785	8243	2709	5960	8398	6307	19802	26395	12288	18990	2215	1850	652
CNYTN	13328	4260	600	7052	473	365	2283	5390	557	1318	1064	10755	5891	3390	6914	14034	1113	11687	3841	8450	11907	8942	28076	37423	17422	26925	3140	2623	924
CNHKG	22986	7348	1035	12162	816	630	3937	9296	961	2273	1835	18548	10159	5846	11925	24204	1920	20156	6624	14573	20535	15422	48420	64541	30046	46435	5416	4524	1594

CNCWN	4998	1598	225	2644	178	137	856	2021	209	494	399	4033	2209	1271	2593	5263	418	4383	1440	3169	4465	3353	10528	14034	6533	10097	1178	984	347
CNDCB	1666	533	75	881	59	46	285	674	70	165	133	1344	736	424	864	1754	139	1461	480	1056	1488	1118	3509	4678	2178	3366	393	328	116
VNVUT	2026	648	91	1072	72	56	347	820	85	200	162	1635	896	515	1051	2134	169	1777	584	1285	1810	1360	4268	5690	2649	4093	477	399	141
THLCH	5063	1618	228	2679	180	139	867	2048	212	501	404	4085	2238	1288	2627	5331	423	4439	1459	3210	4523	3397	10665	14216	6618	10228	1193	997	351
SGSIN	28335	9058	1276	14992	1007	777	4853	11460	1184	2802	2262	22864	12523	7207	14700	29837	2367	24847	8166	17965	25314	19012	59689	79562	37039	57242	6676	5577	1965
MYTPP	6573	2101	296	3478	233	180	1126	2658	275	650	525	5304	2905	1672	3410	6921	549	5763	1894	4167	5872	4410	13846	18455	8592	13278	1549	1294	456
MYPKG	8007	2560	361	4237	284	220	1371	3239	335	792	639	6461	3539	2037	4154	8432	669	7022	2308	5077	7154	5373	16868	22484	10467	16177	1887	1576	555
LKCMB	3795	1213	171	2008	135	104	650	1535	159	375	303	3062	1677	965	1969	3996	317	3328	1094	2406	3390	2546	7994	10656	4961	7667	894	747	263
AEJEA	0	0	180	2110	142	109	683	1613	167	394	318	3217	1762	1014	2069	4199	333	3496	1149	2528	3562	2675	8400	11196	5212	8055	940	785	277
OMSLL	0	0	56	662	44	34	214	506	52	124	100	1009	553	318	649	1317	105	1097	361	793	1118	839	2635	3513	1635	2527	295	246	87
SAJED	0	0	50	586	39	30	190	448	46	110	88	894	490	282	575	1167	93	972	319	703	990	743	2334	3111	1448	2239	261	218	77
EGPSD	0	0	56	658	44	34	213	503	52	123	99	1004	550	316	645	1310	104	1091	358	789	1111	835	2620	3492	1626	2513	293	245	86
EGDAM	0	0	18	210	14	11	68	161	17	39	32	321	176	101	206	419	33	349	115	252	355	267	838	1116	520	803	94	78	28
TRIZM	66	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TRAMR	770	246	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
UAODS	52	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
UAILK	40	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ROCND	249	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GRPIR	589	188	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HRRJK	61	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SIKOP	144	46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ITTRS	116	37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ITGIT	1174	375	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ITGOA	643	206	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FRFOS	370	118	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ESBCN	755	241	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ESVLC	1533	490	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

ESA GP	122	39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ESA LG	1276	408	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MAP TM	419	134	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FRL EH	923	295	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GBF TX	1300	416	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BEZ EE	977	312	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BEA NR	3066	980	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NLR TM	4087	1306	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DEB RV	1903	608	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DEH AM	2940	940	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SEG OT	343	110	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DKA AR	286	92	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PLG DN	101	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Source: Lachner and Boskamp (2011)

Appendix B: Maersk Route, Ship, and Routes

Table B.1.
Maersk Routes in 2010 and 2018 (Asia-Europe-Asia)

AE1		AE2		AE3		AE5		AE6	
2010	**2018**	**2010**	**2018**	**2010**	**2018**	**2010**	**2018**	**2010**	**2018**
JPYOK	CNSHA	KRPUS	CNTXG	CNDLC			CNTXG	JPYOK	JPYOK
CNHKG	CNNGB	CNTXG	CNTAO	CNTXG			CNTAO	JPNGO	CNNGB
CNYTN	CNHKG	CNDLC	KRPUS	KRPUS			KRPUS	CNSHA	CNSHA
MYTPP	CNYTN	CNTAO	CNNGB	CNSHA			CNNGB	CNNGB	CNYTN
GBFTX	MYTPP	KRKAN	CNYTN	CNNGB			CNSHA	CNXMN	MYTPP
NLRTM	LKCMB	CNSHA	MYTPP	TWTPE			CNYTN	CNHKG	PTSIE
DEHAM	GBFTX	DEBRV	ESALG	CNCWN			MYTPP	CNYTN	BEANR
DEBRV	NLRTM	DEHAM	GBFTX	CNYTN			MAPTM	MYTPP	GBFTX
MAPTM	DEBRV	NLRTM	BEANR	MYTPP			DEBRV	SAJED	FRLEH
SAJED	NLRTM	GBFTX	NLRTM	MYPKG			DEHAM	ESBCN	EGPSD
AEJEA	MAPTM	BEANR	ESALG	EGPSD			SEGOT	ESVLC	SGSIN
CNDCB	OMSLL	MYTPP	SGSIN	EGDAM			DKAHS	ESALG	CNSHA
CNNGB	LKCMB	KRPUS	CNHKG	TRIZM			DEWIL	MAPTM	CNHKG
CNSHA	SGSIN		CNYTN	TRAMR			DEBRV	MYTPP	CNYTN
TWKHH	CNNGB		CNTXG	ROCND			BEANR	VNVUT	CNXMN
JPYOK	CNSHA			UAILK			NLRTM	CNYTN	JPYOK
				UAODS			EGSUZ	CNHKG	
				EGDAM			SGSIN	JPYOK	
				EGPSD			CNSHA		

MYTPP			CNTXG
MYPKG			
CNDLC			

AE7

2010	2018
CNSHA	CNNGB
CNNGB	CNSHA
CNXMN	MYTPP
CNHKG	NLRTM
CNYTN	DEHAM
ESALG	DEBRV
MAPTM	DEWIL
NLRTM	GBFTX
GBFTX	BEANR
DEBRV	FRLEH
ESAGP	MAPTM
CNYTN	OMSLL
CNHKG	AEJEA
CNSHA	CNNGB

AE9

2010	2018
THLCH	
MYTPP	
MYPKG	
LKCMB	
BEZEE	
GBFTX	
DEBRV	
NLRTM	
FRLEH	
MAPTM	
OMSLL	
LKCMB	
MYPKG	
SGSIN	
THLCH	

AE10

2010	2018
	CNDLC
	KRPUS
	KRKAN
	CNNGB
	CNSHA
	CNXMN
	CNYTN
	MYTPP
	NLRTM
	DEBRV
	PLGDN
	DEBRV
	GBFTX
	MYTPP
	CNSHA
	CNDLC

AE11

2010	2018
CNTAO	
CNSHA	
CNFOC	
CNHKG	
CNCWN	
CNYTN	
MYTPP	
MYPKG	
OMSLL	
EGPSD	
ITGIT	
ITGOA	
FRFOS	
ITGOA	
EGDAM	
ESPSD	
OMSLL	
MYPKG	
SGSIN	
CNLYG	

AE12

2010	2018
CNSHA	
KRPUS	
CNHKG	
CNCWN	
MYTPP	
MYPKG	
EGPSD	
GRPIR	
SIKOP	
HRRJK	
ITTRS	
EGDAM	
ESPSD	
SAJED	
MYPKG	
SGSIN	
CNSHA	

CNTAO

Source: Mulder (2011) and Maersk (2018)

Table B.2.
Maersk Ships and Capacities in 2010 (Asia-Europe-Asia)

AE1

Ship	**Capacity (TEU)**
Sofie Maersk	8160
Albert Maersk	8272
Carsten Maersk	8160
Maersk Singapore	8478
Clementine Maersk	8648
Maersk Seoul	8450
Maersk Taurus	8400
Sine Maersk	8160
Axel Maersk	8272
Cornelia Maersk	8650
Average	**8365**

AE2

Ship	**Capacity (TEU)**
Maersk Seville	8478
Maersk Saigon	8450
Adrian Maersk	8272
Maersk Salina	8600
Maersk Savannah	8600
Anna Maersk	8272
Arthur Maersk	8272
Maersk Stepnica	8600
Maersk Semarang	8400
Maersk Stralsund	8500
Average	**8444**

AE3

Ship	**Capacity (TEU)**
Maersk Kinloss	6500
CMA CGM Debussy	6627
Maersk Kuantan	6500
Maersk Kowloon	6500
CMA CGM Corneille	6500
Maersk Kelso	6500
CMA CGM Musset	6540
Maersk Kwangyang	6500
CMA CGM Bizet	6627
Maersk Kensington	6500
CMA CGM Baudelaire	6251
Average	**6504**

AE6

Ship	**Capacity (TEU)**
Mathilde Maersk	9038
Maersk Antares	9200
Gunvor Maersk	9074
Mette Maersk	9038
Marit Maersk	9038
Gerd Maersk	9074
Maersk Altair	9200

AE7

Ship	**Capacity (TEU)**
Eugen Maersk	14770
Elly Maersk	14770
Evelyn Maersk	14770
Edith Maersk	14770
Estelle Maersk	14770
Maersk Algol	9200
Ebba Maersk	14770

AE9

Ship	**Capacity (TEU)**
Maersk Sembawang	6478
Maersk Sebarok	6478
Maersk Serangoon	6478
SL New York	6420
Maersk Seletar	6478
Maersk Kendal	6500
Maersk Sentosa	6478

Gudrun Maersk	9074
Marchen Maersk	9038
Maren Maersk	9038
Georg Maersk	9074
Grete Maersk	9074
Maersk Alfirk	9200
Margrethe Maersk	9038
Average	**9086**

Eleonora Maersk	14770
Emma Maersk	14770
Gjertrud Maersk	9074
Average	**13643**

Maersk Semakau	6478
Maersk Senang	6478
Average	**6474**

AE10

Ship	Capacity (TEU)
A.P. Moller	8160
Skagen Maersk	8160
Sally Maersk	8160
Arnold Maersk	8272
Svendborg Maersk	8160
Svend Maersk	8160
Columbine Maersk	8648
Maersk Tukang	8400
Clifford Maersk	8160
Maersk Salalah	8600
Maersk Stockholm	8600
Average	**8316**

AE11

Ship	Capacity (TEU)
Charlotte Maersk	8194
Maersk Surabaya	8400
Maersk Santana	8478
CMA CGM Faust	8204
Soroe Maersk	8160
Susan Maersk	8160
Caroline Maersk	8160
Cornelius Maersk	8160
Chastine Maersk	8160
Average	**8231**

AE12

Ship	Capacity (TEU)
Maersk Kyrenia	6978
Safmarine Komati	6500
CMA CGM Belioz	6627
Safmarine Kariba	6500
CMA CGM Balzac	6251
Maersk Karachi	6930
CMA CGM Ravel	6712
CMA CGM Flaubert	6638
CMA CGM Voltaire	6456
Average	**6621**

Source: Mulder (2011)

Table B.3.
Maersk Ships and Capacities in 2018 (Asia-Europe-Asia)

AE1

Ship	Capacity (TEU)
MAYVIEW MAERSK	18270
METTE MAERSK	18270
MARCHEN MAERSK	18270
MAJESTIC MAERSK	18270
MARSTAL MAERSK	18270
MAGLEBY MAERSK	18270
MUNKEBO MAERSK	18270
MARIBO MAERSK	18270
MAERSK M. MOLLER	18270
MERETE MAERSK	18270
MORTEN MAERSK	18340
MSC OLIVER	19224
MSC ERICA	19437
MONACO MAERSK	20568
MILAN MAERSK	20568
MANILA MAERSK	20568
MADRID MAERSK	20568
MUNICH MAERSK	20568
Average	**19029**

AE2

Ship	Capacity (TEU)
MSC BETTINA	14000
ELLY MAERSK	15500
EDITH MAERSK	15500
ELEONORA MAERSK	15500
MSC VENICE	15908
MSC LONDON	16652
MSC INGY	17590
METTE MAERSK	18270
MARCHEN MAERSK	18270
MARIBO MAERSK	18270
MSC ERICA	19437
MILAN MAERSK	20568
MANILA MAERSK	20568
Average	**15510**

AE5

Ship	Capacity (TEU)
MARY MAERSK	18270
METTE MAERSK	18270
MSC OLIVER	19224
MILAN MAERSK	20568
MSC ERICA	19437
MUNICH MAERSK	20568
MONACO MAERSK	20568
Average	**19083**

AE6

Ship	Capacity (TEU)
MAERSK SINGAPORE	8452
MAERSK SEVILLE	8466
SEROJA LIMA	8540
GUSTAV MAERSK	9038
GUNVOR MAERSK	9930
GUDRUN MAERSK	9930
GUNDE MAERSK	9700
GUTHORM MAERSK	11008
MAERSK ANTARES	11294
MAERSK EDMONTON	13092
MAERSK ESSEX	13092
MAERSK EINDHOVEN	13092
MSC SAVONA	14000
MAERSK HANOI	15226
MAERSK HANGZHOU	15226
ELEONORA MAERSK	15500
EVELYN MAERSK	15500
ELLY MAERSK	15500
MURCIA MAERSK	20568
MARSEILLE MAERSK	20568
MANCHESTER MAERSK	20568
Average	**13430**

AE7

Ship	Capacity (TEU)
MARSTAL MAERSK	18270
MAGLEBY MAERSK	18270
MORTEN MAERSK	18340
MSC ZOE	19224
MSC MIRJA	19437
MSC ELOANE	19462
MSC RIFAYA	19472
MOSCOW MAERSK	20568
Average	**18293**

AE10

Ship	Capacity (TEU)
MARSTAL MAERSK	18270
MAGLEBY MAERSK	18270
MAERSK M. MOLLER	18270
MSC ELOANE	19462
Average	**18270**

Source: Mulder (2011)

Table B.4.
Maersk Route Capacities in 2010 and 2018 (Asia-Europe-Asia)

2010		**2018**	
Route	**Average (TEU)**	**Route**	**Average (TEU)**
AE1	8365	AE1	19029
AE2	8444	AE2	17583
AE3	6504		
		AE5	19083
AE6	9086	AE6	13430
AE7	13643	AE7	19130
AE9	6474		
AE10	8316	AE10	18568
AE12	6621		
AE11	8231		
Average	**8690**	**Average**	**17804**

Source: Mulder (2011) and Maersk (2018)

Table B.5.
Maersk Vessel Speed in 2010 (Asia-Europe-Asia)

AE1		**AE2**		**AE3**	
Ship	**Design Speed (knot)**	**Ship**	**Design Speed (knot)**	**Ship**	**Design Speed (knot)**
Sofie Maersk	25	Maersk Seville	25.3	Maersk Kinloss	24.3
Albert Maersk	24.1	Maersk Saigon	24.6	CMA CGM Debussy	24.5
Carsten Maersk	23.2	Adrian Maersk	24.8	Maersk Kuantan	25.1
Maersk Singapore	24.8	Maersk Salina	24.2	Maersk Kowloon	23.9
Clementine Maersk	25.6	Maersk Savannah	24.9	CMA CGM Corneille	23.3
Maersk Seoul	23.3	Anna Maersk	24.7	Maersk Kelso	26.3
Maersk Taurus	25.1	Arthur Maersk	25.9	CMA CGM Musset	23.8
Sine Maersk	23.6	Maersk Stepnica	24.9	Maersk Kwangyang	25.4
Axel Maersk	25.8	Maersk Semarang	23.9	CMA CGM Bizet	23.3
Cornelia Maersk	24.7	Maersk Stralsund	23.7	Maersk Kensington	24.7
Average	**25**	**Average**	**25**	CMA CGM Baudelaire	22.7
				Average	**24**

AE6	
Ship	**Design Speed (knot)**
Mathilde Maersk	23.6
Maersk Antares	24.2
Gunvor Maersk	24.2
Mette Maersk	24.2
Marit Maersk	24.6
Gerd Maersk	24.8
Maersk Altair	24.1
Gudrun Maersk	26.2
Marchen Maersk	24.6
Maren Maersk	24.6
Georg Maersk	24.8
Grete Maersk	26.5
Maersk Alfirk	24.2
Margrethe Maersk	24.2
Average	**25**

AE7	
Ship	**Design Speed (knot)**
Eugen Maersk	25.2
Elly Maersk	25.2
Evelyn Maersk	25.5
Edith Maersk	24.4
Estelle Maersk	25.3
Maersk Algol	26.1
Ebba Maersk	25
Eleonora Maersk	24.9
Emma Maersk	26
Gjertrud Maersk	24.9
Average	**25**

AE9	
Ship	**Design Speed (knot)**
Maersk Sembawang	23
Maersk Sebarok	20.8
Maersk Serangoon	22.7
SL New York	24.4
Maersk Seletar	23.7
Maersk Kendal	24
Maersk Sentosa	22.6
Maersk Semakau	22.6
Maersk Senang	23.2
Average	**23**

Source: Mulder (2011)

AE10

Ship	Design Speed (knot)
A.P. Moller	23
Skagen Maersk	25.7
Sally Maersk	23.8
Arnold Maersk	24.8
Svendborg Maersk	23.4
Svend Maersk	25
Columbine Maersk	11.6
Maersk Tukang	24.3
Clifford Maersk	25.2
Maersk Salalah	23.7
Maersk Stockholm	24.8
Average	**23**

AE11

Ship	Design Speed (knot)
Charlotte Maersk	24.1
Maersk Surabaya	26
Maersk Santana	25
CMA CGM Faust	25.3
Soroe Maersk	24.5
Susan Maersk	25.7
Caroline Maersk	24.1
Cornelius Maersk	24.6
Chastine Maersk	25.1
Average	**25**

AE12

Ship	Design Speed (knot)
Maersk Kyrenia	23.1
Safmarine Komati	24
CMA CGM Belioz	22.4
Safmarine Kariba	24
CMA CGM Balzac	26.3
Maersk Karachi	23.6
CMA CGM Ravel	26
CMA CGM Flaubert	25.6
CMA CGM Voltaire	27
Average	**25**

Table B.6.
Maersk Vessel Speed in 2018 (Asia-Europe-Asia)

AE1				AE2			
Ship	**Design Speed (knot)**	**Average Speed (knot)**	**Speed Optimization (%)**	**Ship**	**Design Speed (knot)**	**Average Speed (knot)**	**Speed Optimization (%)**
MAYVIEW MAERSK	23.8	15.3	64	MSC BETTINA	22.2	13.2	59
METTE MAERSK	24.2	15.4	64	ELLY MAERSK	25.5	14.3	56
MARCHEN MAERSK	24.6	15.2	62	EDITH MAERSK	24.4	14.6	60
MAJESTIC MAERSK	24.4	15.4	63	ELEONORA MAERSK	24.9	14.2	57
MARSTAL MAERSK	23.9	15.3	64	MSC VENICE	24.9	15.5	62
MAGLEBY MAERSK	20.7	16.6	80	MSC LONDON	24.1	15.1	63
MUNKEBO MAERSK	23.9	15.5	65	MSC INGY	25.4	15.1	59
MARIBO MAERSK	23.2	15	65	METTE MAERSK	24.2	15.4	64
MAERSK M. MOLLER	25.6	15.5	61	MARCHEN MAERSK	24.6	15.2	62
MERETE MAERSK	23.7	14.5	61	MARIBO MAERSK	23.2	15	65
MORTEN MAERSK	24.1	15.3	63	MSC ERICA	25	15.1	60
MSC OLIVER	25.6	15.4	60	MILAN MAERSK	24.7	13.9	56

MSC ERICA	25	15.1	60
MONACO MAERSK	24.8	13.7	55
MILAN MAERSK	24.7	13.9	56
MANILA MAERSK	24.5	12.7	52
MADRID MAERSK	25.3	14.7	58
MUNICH MAERSK	25.5	15.1	59
Average	**24**	**15**	**62**

MANILA MAERSK	24.5	12.7	52
Average	**24**	**15**	**60**

AE5

Ship	Design Speed (knot)	Average Speed (knot)	Speed Optimization (%)
MARY MAERSK	25	15.5	62
METTE MAERSK	24.2	15.4	64
MSC OLIVER	25.6	15.4	60
MILAN MAERSK	24.7	13.9	56
MSC ERICA	25	15.1	60
MUNICH MAERSK	25.5	15.1	59

AE6

Ship	Design Speed (knot)	Average Speed (knot)	Speed Optimization (%)
MAERSK SINGAPORE	24.8	13.4	54
MAERSK SEVILLE	25.3	13.3	53
SEROJA LIMA	23.2	12.7	55
GUSTAV MAERSK	26.1	13.1	50
GUNVOR MAERSK	24.2	13.2	55
GUDRUN MAERSK	26.2	13.2	50

MONACO MAERSK	24.8	13.7	55
Average	**25**	**15**	**60**

GUNDE MAERSK	25.1	13.1	52
GUTHORM MAERSK	25.2	13.6	54
MAERSK ANTARES	23.8	13.1	55
MAERSK EDMONTON	25.8	14.4	56
MAERSK ESSEX	24.6	14.0	57
MAERSK EINDHOVEN	25.3	13.4	53
MSC SAVONA	24.5	13.3	54
MAERSK HANOI	21.6	12.7	59
MAERSK HANGZHOU	22.0	12.7	58
ELEONORA MAERSK	24.9	14.2	57
EVELYN MAERSK	25.5	14.2	56
ELLY MAERSK	25.5	14.3	56
MURCIA MAERSK	23.6	14.1	60
MARSEILLE MAERSK	24.3	14.7	60
MANCHESTER MAERSK	24.9	14.7	59
Average	**25**	**14**	**55**

AE7			
Ship	Design Speed (knot)	Average Speed (knot)	Speed Optimization (%)
MARSTAL MAERSK	23.9	15.3	64
MAGLEBY MAERSK	20.7	16.6	80
MORTEN MAERSK	24.1	15.3	63
MSC ZOE	25	14.9	60
MSC MIRJA	24.5	15.3	62
MSC ELOANE	21.2	12.5	59
MSC RIFAYA	24.5	15.1	62
MOSCOW MAERSK	24.8	15	60
Average	**24**	**15**	**64**

AE10			
Ship	Design Speed (knot)	Average Speed (knot)	Speed Optimization (%)
MARSTAL MAERSK	23.9	15.3	64
MAGLEBY MAERSK	20.7	16.6	80
MAERSK M. MOLLER	25.6	15.5	61
MSC ELOANE	21.2	12.5	59
Average	**23**	**15**	**66**

Source: Maersk (2018)

Table B.7.
Maersk Average Vessel Speed in 2010 and 2018 (Asia-Europe-Asia)

Route	**Average Speed**	
	2010	**2018**
AE1	24.5	15.0
AE2	24.7	14.6
AE3	24.3	NA
AE5	NA	14.9
AE6	24.6	13.6
AE7	25.3	15.0
AE9	23.0	NA
AE10	23.2	15.0
AE11	24.9	NA
AE12	24.7	NA
Average	24	15

Source: Author estimation based on Mulder (2011) and Maersk (2018)

Appendix C: Maersk Network Properties

Table C.1.
Maersk Network Properties in 2010

Port	In-degree Centrality	Out-degree Centrality	Betweenness Centrality
MYTPP	9	9	0.41
EGPSD	4	4	0.36
EGDAM	4	4	0.31
MYPKG	8	8	0.24
CNSHA	7	7	0.22
MAPTM	4	4	0.20
DEBRV	4	4	0.18
OMSLL	3	3	0.15
CNHKG	7	7	0.14
KRPUS	3	3	0.13
SAJED	3	3	0.11
CNYTN	7	7	0.10
GBFTX	4	4	0.09
CNCWN	3	3	0.08
CNNGB	4	4	0.08
TRIZM	1	1	0.07
TRAMR	1	1	0.07
ROCND	1	1	0.07
UAILK	1	1	0.07
UAODS	1	1	0.07
ESPSD	2	2	0.07
ITGOA	2	2	0.06
GRPIR	1	1	0.06
SIKOP	1	1	0.06
HRRJK	1	1	0.06
ITTRS	1	1	0.06
SGSIN	3	3	0.05
CNTAO	2	2	0.05
ESALG	2	2	0.04
CNDLC	2	2	0.04
JPYOK	2	2	0.04
NLRTM	4	4	0.04
ITGIT	1	1	0.04

AEJEA	1	1	0.03
CNDCB	1	1	0.03
BEANR	1	1	0.02
ESBCN	1	1	0.02
ESVLC	1	1	0.02
TWTPE	1	1	0.02
LKCMB	2	2	0.02
VNVUT	1	1	0.01
CNTXG	2	2	0.01
FRLEH	1	1	0.01
ESAGP	1	1	0.01
THLCH	1	1	0.01
TWKHH	1	1	0.01
BEZEE	1	1	0.01
JPNGO	1	1	0.01
CNFOC	1	1	0.00
CNXMN	2	2	0.00
DEHAM	2	2	0.00
CNLYG	1	1	0.00
KRKAN	1	1	0.00
FRFOS	1	1	0.00

Table C.2.
Maersk Network Properties in 2018

Port	In-degree Centrality	Out-degree Centrality	Betweenness Centrality
CNSHA	8	8	0.46
MYTPP	6	6	0.36
GBFTX	5	5	0.23
NLRTM	6	6	0.20
CNNGB	6	6	0.19
DEBRV	6	6	0.16
SGSIN	4	4	0.15
KRPUS	3	3	0.14
CNYTN	7	7	0.13
MAPTM	3	3	0.11
CNDLC	1	1	0.08
LKCMB	2	2	0.07
DEHAM	2	2	0.06
DEWIL	2	2	0.06
ESALG	2	2	0.06
OMSLL	2	2	0.05
BEANR	4	4	0.05
FRLEH	2	2	0.05
CNTAO	2	2	0.04
CNTXG	2	2	0.04
CNXMN	2	2	0.03
DKAHS	1	1	0.03
KRKAN	1	1	0.03
SEGOT	1	1	0.03
PTSIE	1	1	0.03
EGPSD	1	1	0.02
AEJEA	1	1	0.02
EGSUZ	1	1	0.01
JPYOK	1	1	0.01
CNHKG	3	3	0.00
PLGDN	1	1	0.00

Table C.3.
Maersk Weighted Demand Network Properties, 2010

Port	Closeness Centrality	Port	Closeness Centrality
AEJEA	0.93	TWTPE	0.70
EGDAM	0.93	VNVUT	0.70
EGPSD	0.93	BEANR	0.69
OMSLL	0.93	BEZEE	0.69
SAJED	0.93	DEBRV	0.69
CNCWN	0.70	DEHAM	0.69
CNDCB	0.70	DKAAR	0.69
CNDLC	0.70	ESAGP	0.69
CNFOC	0.70	ESALG	0.69
CNHKG	0.70	ESBCN	0.69
CNLYG	0.70	ESVLC	0.69
CNNGB	0.70	FRFOS	0.69
CNSHA	0.70	FRLEH	0.69
CNTAO	0.70	GBFTX	0.69
CNTXG	0.70	GRPIR	0.69
CNXMN	0.70	HRRJK	0.69
CNYTN	0.70	ITGIT	0.69
JPNGO	0.70	ITGOA	0.69
JPSMZ	0.70	ITTRS	0.69
JPUKB	0.70	MAPTM	0.69
JPYOK	0.70	NLRTM	0.69
KRKAN	0.70	PLGDN	0.69
KRPUS	0.70	ROCND	0.69
LKCMB	0.70	SEGOT	0.69
MYPKG	0.70	SIKOP	0.69
MYTPP	0.70	TRAMR	0.69
SGSIN	0.70	TRIZM	0.69
THLCH	0.70	UAILK	0.69
TWKHH	0.70	UAODS	0.69