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The impact of 50,000 TEU vessels on the container supply chain

By

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Acknowledgements

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Abstract

In this research, it will be assessed what the economic supply chain impact will be when 50,000 TEU vessels would sail around. The scope of the chain is limited to shipping lines, terminal operators, port authorities and consignees. Currently, the largest container vessels (OOCL Hong Kong, 21,413 TEU) already put large pressure on the chain because of the big peak volumes. Despite this, shipping lines are still ordering larger vessels. McKinsey (2015) predicts that vessels will even reach 50,000 TEU levels in 2066, based on economic forecasts and their vision on the shipping industry. Until now, most research has focused on the quantification of scale economies for shipping lines. Whereas, the impact on the rest of the chain is mostly qualitatively assessed. This research attempts to fill this gap by building a framework that enables the quantification of the rest of the chain.

A case study has been performed on the route LL1, which is currently applied by the OOCL Hong Kong. This route runs from China to Northern Europe and a total of 9 ports are called. It will be assessed what adjustments are required for each party within the scope in terms of infrastructure when the OOCL Hong Kong would be replaced by a 50,000 TEU vessel. Based on those adjustments, daily cost increase/savings are calculated per chain party and put together to see the net result. Calculations are based on the following main assumptions. (1) 50,000 TEU vessels will already sail around now, (2) expected demand will already be present in 2018, and (3) it is technically possible to construct a 50,000 TEU vessel. Data is retrieved from official port websites, terminal websites and maritime/logistic journals.

The results are as following. Shipping lines realize savings in capital, operating and bunker costs. The cost savings per TEU are respectively 16%, 55% and 25%. In total, shipping lines save 6.01 million dollars per day by applying 70 vessels of 50,000 TEU instead of 164 vessels of 21,413 TEU. Terminal costs increase due to investments in yards, cranes and quays with respectively 129%, 199% and 30% per day. Port authorities face a daily dredging costs increase of 19.59 million dollars per day due to expansions in ports, the Suez-Canal and the Malacca Strait. Besides, consignees will probably not reap any benefits and only face negative consequences in terms of delays and schedule reliability. A net cost increase of 14.4 million dollar a day will be the result.

To conclude, only shipping lines realize cost savings, if utilization rates are sufficient, and especially dredging costs are very significant in the total cost/benefit overview. Daily chain costs will increase when vessel sizes grow to 50,000 TEU, which is not viable from an economic perspective.

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1. Introduction

Since the invention of the container, container vessels have become bigger and bigger. Where container vessels had a maximum capacity of 10,000 twenty-foot equivalent units (TEU) in 2005, they can already carry an amount of 21,413 TEU in 2018. Shipping lines order those large vessels because they bring economies of scale, which leads to lower unit costs per container. However, shipping lines can only reap the benefits of those vessels if a certain utilization rate is reached. Larger vessels consume more fuel at the same speed, so unit costs will be even higher when vessels are not fully utilized. Besides, other parties within the chain face large investments linked to the increasing vessel sizes. Larger vessels require deeper waterways, cranes with increased outreach and strength, and quays which are longer and stronger (OECD, 2015). Also, they impact the smoothness of container terminal operations, due to the large peak amount that is being transferred to land at once during loading and unloading the vessel.

According to McKinsey (2015), container vessels might increase even further with a capacity up to a 50,000 TEU. They argue that when physical characteristics will remain the same, the logic of scale increase will also remain for shipping lines. However, this future view is not shared by every party within the industry. Jeremy Nixon, CEO of Ocean Network Express, argues that there will not be enough demand for 50,000 TEU vessels that serve the route between Asia and Europe five times a week. Alan Murphy, CEO of Sea Intel Maritime Analysis, was even more critical and mentioned that those vessel sizes are insane and that vessels of 24,000 – 25,000 TEU are “at the edge of what makes sense”. Nissim Yochai, vice president of ZIM Integrated Shipping Services, makes the comparison with the Airbus 380 in the airliner business. He argues that investment costs of those planes are too high to be economically viable and that it holds the same for 50,000 TEU vessels. Malchow (2017) investigated the viability of vessels up to 30,000 TEU on a chain level and concluded that shipping lines do not reap any benefits anymore and other parties within the chain are suffering from the large investments, which leads to a “lose-lose situation”.

The statement of McKinsey is controversial and large players within the industry are skeptical. At the same time, not much research has been performed on 50,000 TEU vessels and it is plausible that the same actors did not foresee the vessel size to reach a 20,000 TEU level. To be economically viable, container vessels should have such a size that it is efficient for the supply chain as a whole. Therefore I would like to contribute to existing literature by investigating the following question: **What is the economic impact of 50,000 TEU vessels on a supply chain level?**

This question will be answered by quantifying the impact as precise as possible to see if the economic benefits of 50,000 TEU vessels still outweigh the costs on a supply chain level.

The paper proceeds as following. First, a literature overview is provided which consists of an introduction part about container shipping, an analysis about the level of competition, and a section about developments in the container shipping market. Second, a methodology section follows which consists of an introduction on the methodology and the quantification steps that will be followed to assess the impact of 50,000 TEU vessels on the parties within the scope that will be assessed (shipping lines, terminal operators, port authorities and consignees). Third, the results of this quantification will follow, which will end with a section that shows an overview of the financial impact on the whole chain. Lastly, the research will end with a conclusion and recommendations for further research.

This research contributes to the knowledge of practitioners and policymakers as it provides insight in the financial impact and magnitude for each party within the chain, which enables them to align their strategic decisions in a better way. Also, it is academically relevant because it provides a framework with detailed calculation methods that can be applied in future studies about the chain impact of bigger container vessels as well. This is one of the first papers that not only talks about the impact on the rest of the chain, but really quantifies it.

2. Literature Review

This section provides an analysis about the developments in the container liner shipping market. It is built up in the following way. First, a general overview of the shipping line market will be provided. After that, the scope of this research will be explained by describing the relevant parties within the chain.

2.1 Container shipping analysis

The container shipping market has been through big developments over the past five decades. This paragraph sketches the broad picture of those developments and elaborates on the most relevant characteristics. This includes a brief introduction about container shipping and its role in transportation, an overview of the level of competition in the market, and an analysis of the market developments.

2.1.1 Introduction in container shipping

Container shipping transport is a way of transporting goods that has been introduced in the 60's of the 20th century. It refers to the transportation of goods in sealed standardized boxes over sea, also known as the "container". Those containers are aboard of vessels that are specially designed to them. In most cases, shipping lines offer liner services which means that they sail fixed roundtrips and call at a predetermined time and frequency at ports on a specific route. Container shipping is a popular way of transporting goods all around the world because it is safe, efficient and relatively cheap. It is safe because goods are packed and sealed in the container at a factory or warehouse, which significantly reduces the risk of theft and damage of goods and thereby reduces the insurance premiums for shippers and shipping lines (The Economist, 2013). Container shipping is efficient, as it eased the loading and unloading process because there is no need to handle the content of a container piece by piece. The introduction of the container directly led to a drop in loading and unloading costs from $5.83 to $0.16 per metric ton. It is relatively cheap because of the before mentioned reasons, but also because a container vessel can carry up to 21,000 containers at once, whereas the longest container train can carry 150 containers and a truck can only carry two or three. So, although the investment and operating costs of a vessel are huge, the carrying capacity makes that those costs can be divided over a large number of containers. As a result, nowadays around 60% of the value of seaborne trade is shipped by container liner vessels (World Shipping Council, 2016). The largest container routes that are nowadays being served are Asia – North America, Asia – North Europe, Asia – Mediterranean, Asia – Middle East and North Europe – north America (World Shipping Council, 2013).

It is crucial to consider that container shipping is characterized by derived demand from world trade developments. This implies that demand for container shipping increases when the world economy expands and declines when the world economy shrinks. An often-used measurement to express this link is the TEU to GDP ratio. This ratio measures how much the transported amount of TEU changes when GDP changes.

Over the past decades, the container growth rate has been higher than the growth in GDP. Figure 1 below shows the developments of this ratio. The left axis shows the year on year (YoY) container handling and the right axis shows the TEU to GDP ratio. In the period 1990-1996, the ratio was consistently higher than 3 and in 1991 and 2001 it even peaked at a level of 6. This was mainly caused by the mass containerization in the period and the increasing shipment of intermediate goods (de Langen, van Meijeren, Tavasszy, Langen, & Meijeren, 2012). After the year 2000, the ratio shows a declining trend but remains at a level higher than 1. Since 2012, the TEU to GDP multiplier is decreasing and this is caused by several drivers: lower growth in emerging markets like China, reshoring of production, dematerialization of demand and uncertainties about geopolitical situations. However, McKinsey (2015) does not believe in a decline of container trade as a whole and argues that as long as the economy is growing, trade is likely to grow as well, despite that the multiplier of growth is lower than 1. They sketch two scenarios for the year 2066 in terms of expected shipped TEUs: 464 million TEU in the low case and 858 TEU in the high case, compared to 182 million TEUs in 2016. Where scenario one and two would imply respectively 1.9 and 3.3% annualized growth.

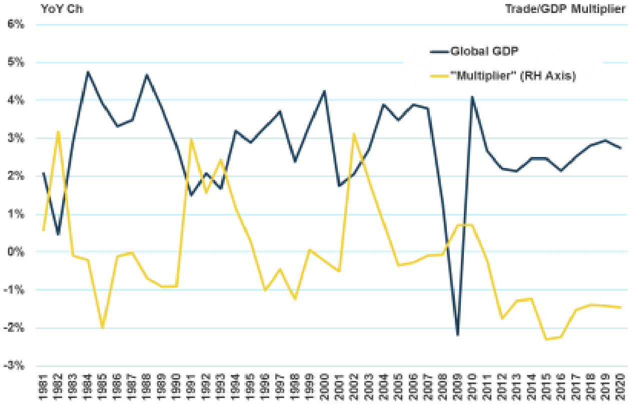


Figure 1: The left side of the graph shows the year on year (YoY) growth in global GDP (blue) and the right side shows the multiplier of container trade / GDP (Source: Frew, 2017)

2.1.2 Level of competition

This section sheds a light on the level of competition in the container shipping market. The analysis will be used to explain the behavior of shipping lines, especially in relation with the ordering of large container vessels. Multiple methods can be applied to analyze the level of competition within a market like; Porter's five forces model, industry lifecycle analysis and a strategic-groups analysis. Porter's model uses five forces to analyze the level of competitiveness in the market. According to Porter, a market which is highly attractive is generally profitable and a low attractiveness refers to low profitability. The following forces will be considered: Internal rivalry, Threat of new entrants, Threat of substitution, Power of suppliers and

Power of buyers. According to Porter, if three or more forces can be considered as high, the attractiveness of the market is low (Porter, 1979). The industry life cycle analysis is based on a biological analogy of birth, growth, maturity and decline/end-of life. One the one hand, this model is good in providing descriptive value, but on the other hand it is criticized for being too simple in terms of predictability and therefore not being reliable enough (Day, 1981). The strategic group analysis is useful in making a management team aware of its competitors but it is not applicable when organizations want to determine how they can achieve and maintain competitive advantage (Thompson & Strickland, 2003). Porter's five forces model will be applied in this research as it is the most widely used model and it provides the most accurate view on the competitiveness position of a company (Brandenburger, 2002). First, the forces will be provided in figure 2 below. Below this figure more elaboration follows about each driving force of competitiveness.

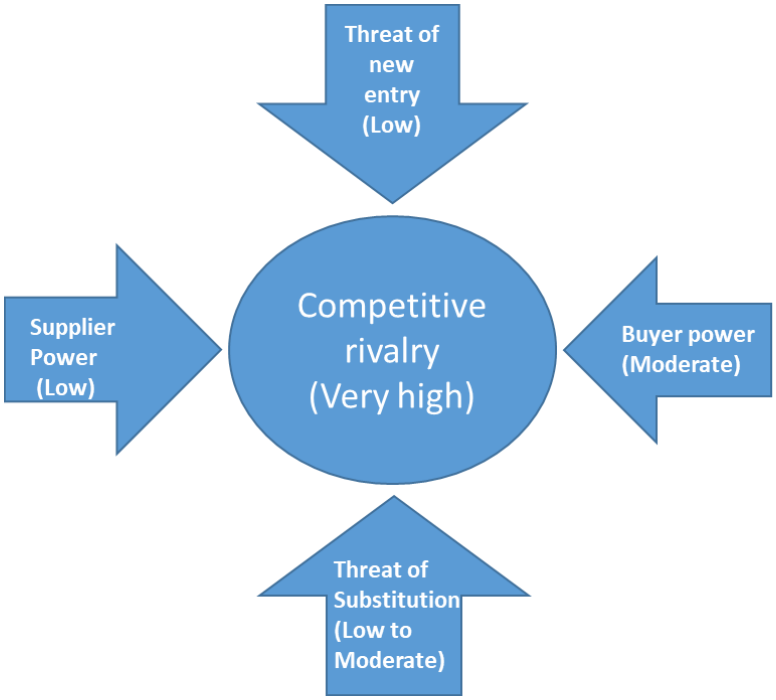


Figure 2: Porter 5-forces model – shipping lines

Threat of new entrants

The first force that will be analyzed is the threat of new entrants. A vessel of 20,000+ TEU can cost more than 150 million dollars, and in order to provide a high enough sailing frequency, a shipping line has to own several of those vessels, so from a financing perspective it is hard to enter the market. Also, there is a trend of overcapacity in the markets, which means that existing shipping lines already have problems to utilize their vessels. This trend is driven by shipping lines that want to achieve economies of scale and thereby invest in larger vessels, even if demand is not sufficient to fill those vessels. Besides, because customers nowadays expect just-in-time transport services, shipping lines are vertically integrating to offer a full chain service to their customers. By doing this in an efficient way, they create higher switching costs for shippers to switch for services offered by new entrants and already existing competitors (Theotokas, 2018). Lastly, current big parties in the industry have several decades of experience and it will not be easy to convince consignees to transfer their transport needs to a new unknown party. To conclude, barriers of entry are high in the liner industry due to high investment costs, overcapacity and high switching costs for consignees which results in low threat of new entrants.

Buyer power

The second force is buyer power. This explains how much negotiation power a buyer has against a shipping line. On the one hand, buyer power is high because shipping lines provide a very homogenous product. Customers are therefore indifferent in the services that liners provide and can therefore switch to another company which offers the service more cheaply. On the other hand, container vessels carry containers for hundreds of consignees at the same time and in most cases those consignees are not organized in a union. So, the customer base is very fragmented which leads to lower buyer power. Only large customers will have a strong position against shipping lines. To conclude, buyer power is moderate because of the homogeneity of services on the one hand and the fragmented customer base on the other hand.

Threat of substitution

The third force is the threat of substitution. The only realistic substitution of container shipping is rail transport. The main differences between liner shipping and rail are the following two aspects: transportation time and price. In most cases, rail transport is a faster transportation mode then liner shipping. At the same time, it is more expensive per TEU-mile. For example, the Asia-Europe route will take 14-19 days by rail and 23-43 days by container vessel. The decisive factor for consignees lies in the perishability of goods. Where perishable goods require fast transport in order to keep its value and usefulness after the transport journey. Perishability is not only applicable to food-related products, but also to products with a high level of technical advancement, like the company Apple that transports their newest Iphone by air instead of by sea (Forbes, 2018). Currently, China is developing the one belt one road initiative. The Chinese government has the ambition to create a rail network that covers a large part of the world. The route between Asia-Europe is already being used and manufacturers like Volvo cars already switched from sea transport to container transport by rail. However, by comparing the capacity of a container vessel and a train (20,000 TEU vs. 84 TEU) it is obvious that rail transport will not easily take over a large part of the container shipments. Also, for many products that are transported by containers, it is not economically viable to pay more for faster transportation by rail. To conclude, rail transport might be a substitute for liner transport, but it needs much more investment in capacity and tariff reduction to become a real alternative for all goods. So, the threat of substitution is low to moderate.

Supplier power

The fourth force is supplier power. Suppliers are the organizations that offer products and services to the shipping lines, which enables them to perform shipping operations. Important suppliers are shipbuilders, container terminals, port authorities, bunker suppliers, and suppliers of lubricants and repair parts. Shipbuilders can put pressure on the profitability of shipping lines by asking high prices for newbuilding vessels. Though, they can only do this when market conditions are favorable because shipping lines can move to other builders. Container terminals do not have a strong position against shipping lines. Shipping lines continuously put pressure on container terminals to improve the efficiency of their services and by investing in new, more efficient and bigger equipment. The forming of alliances between shipping lines makes this position even stronger. More about alliances will follow later. Port authorities have a powerful position on the one hand, because they can prevent a vessel from entering the port or demanding high tariffs for towing and other handlings. At the same time, they have strong incentives to let container vessels entering the port and provide competitive services, because their commission is generally based on those vessels. Lastly, suppliers of bunkers, lubricants and other products are positioned weakly. Shipping lines have many choices among those suppliers and because of their size, they have the strongest position within the negotiations. Concluding, supplier power of most parties is low.

Internal Rivalry

Lastly, internal rivalry will be considered. As shipping lines can hardly differentiate the service they offer, there is a strong internal rivalry in the market between shipping lines. According to Porter (1985), companies can take the following positions: becoming a cost-leader, apply a differentiation strategy, or become a cost leader/ differentiating party within a niche market. As differentiation is hardly possible, most shipping lines apply the cost-leadership strategy to keep ahead of their competitors. To conclude, internal rivalry is very high.

2.1.3 Market developments

This paragraph describes the liner shipping market. The homogeneity of container liner services results in behavior that is especially focused on tariff minimization. Container liners achieve this cost minimization especially by collaborating horizontally in alliances where container vessels are shared under the members of the alliance, which leads to a better utilization of vessels. Also, those alliances lead to a higher total container demand which enables shipping lines to order larger vessels. Where larger vessels lead to economies of scale in multiple cost categories. The paragraph starts with an analysis about strategic alliances. Then, an overview of vessel size development will be provided. After that, the drivers and logics behind economies of scale will be assessed.

2.1.3.1 Strategic alliances

The market of container shipping lines is characterized by fragmentation. Besides vertical integration, shipping lines also cooperate in a horizontal by for forming strategic/global alliances. Within those alliances, shipping lines co-operate with each other by sharing vessels, using joint terminals, sharing sailing schedules and by sharing itineraries and sailing schedules. At the same time, shipping lines keep their independent position by arranging own sales, marketing and pricing strategies. Also, revenue sharing strategies are not in place and shipping lines keep their own management team and company strategies (Panayides & Wiedmer, 2011).

The forming of alliances started in the 1990's, when Sea-land and Maersk started sharing their vessels on the Atlantic and Pacific oceans. Afterwards, more shipping lines started to cooperate by forming alliances and nowadays three large alliances are present which are 2M (Maersk, MSC), Ocean Alliance (CMA CGM, Cosco, OOCL, Evergreen) and The Alliance (NYK Line, Hapag-Lloyd, K-line, MOL, Yang Ming) as shown in figure 3 below. In 2017, those three alliances captured a total market share of 71.8% (Rau & Spinler, 2017).

Figure 3: Overview of three shipping alliances (source: *Barrios, 2017)*

Shipping lines have multiple reasons to participate in alliances. First, they do it to share investment risk of vessels. As a vessel costs several hundred million dollars, it is more attractive to share the risk of such an investment together with other shipping lines. Another reason to form the alliances is to achieve economies of scale. Together, shipping lines have a larger container demand, so they can apply larger vessels to transport large volumes at once. Economies of scale are present, because the costs per TEU decrease when capacity increases (Tran and Haasis, 2015). More will be elaborated on economies of scale in part 2.1.3.3. Third, it results in a higher frequency of shipping services, which is crucial for customers nowadays as they demand Just-in-time deliveries to optimize their supply chain and to minimize their inventory costs. Fourth, alliances result in higher buying power against suppliers. By combining their forces they have a stronger negotiation position and they can force those parties to operate in a way that is beneficial for the themselves (Lim, 1998). Lastly, shipping lines can expand their global reach by sharing space on vessels that operate at different routes around the world. By doing this, more global services can be realized without adding extra vessel capacity (Agarwal & Ergun, 2010).

2.1.3.2 Vessel size development

Since the introduction of container shipping there has been scale increase in vessel size. This paragraph summarizes the growth process over time and explains which barriers were first in place to put a hold on this ongoing development.

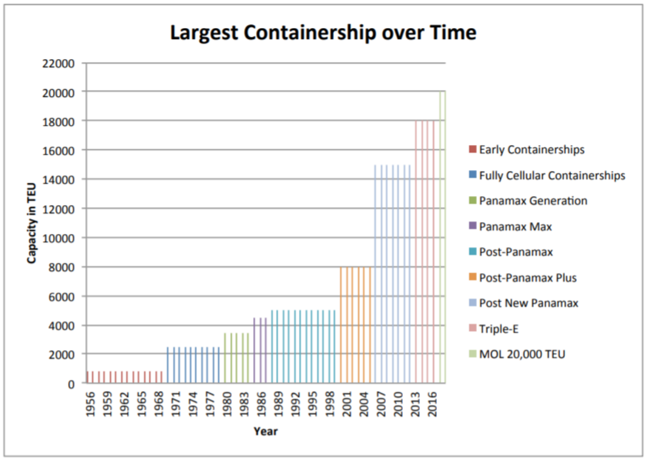


Figure 4: Overview of vessel size development over the period 1956 – 2016 (source: Rodrigue et al., 2018)

As can be obtained from figure 4, the trend of building ever larger container vessels started already very early at the invention of container shipping in the year 1956. In this year, the first container voyage took place with a vessel called *Ideal-X*, a military ship that had been converted to a container vessel. The first generation of container vessels had a capacity that was limited to less than 1,000 TEU. Soon after that in the 1970's, vessel size started to increase, and the first dedicated container vessels were built. Those were named fully-cellular containerships (2,000-2,999 TEU). Fully-cellular ships were very practical because containers could be stacked in different heights and provided space below-deck as well. Another advantage was that container terminal infrastructure had been improved over the years, so installing cranes on the vessels itself was no longer necessary. During the 1980's, vessels kept growing and the size reached the maximum dimensions to pass the Panama-Canal in 1985. Those vessels were named Panamax because they had the maximum dimensions to pass the Panama-Canal (4,000 TEU). Drewry (2001) argued that Panamax vessels were not efficient in terms of hydro dynamics because they needed relatively much ballast water to ensure enough stability which leads to high fuel consumption and a lower container carrying capacity. In 1988, the first Post-Panamax vessels (4500-10,000 TEU) were ordered and built by APL. Those vessels could not pass the Panama-Canal any longer, but they had many advantages. They require less ballast water, consume less bunker fuel, have lower investment costs and stowing those vessels is more practical. Other shipping lines followed the trend and invested in Post-Panamax vessels as well. In 2016, the Panama-Canal increased in dimensions which lead to a new vessel type called New Panamax. Those vessels could sail through the Panama-Canal and were able to carry 12,500 TEU at a maximum. However, in the year 2006 Maersk started operating the Emma Maersk, a vessel that already exceeded the maximum dimensions of the new Panama-Canal (14,5000 TEU). In 2013, Maersk started operating the first Triple-E series (18,000 TEU) and in 2017 OOCL introduced the largest vessel so far with a capacity larger than 21,000 TEU. If the vessels grow even bigger they would not be able to pass the Suez-Canal anymore, so they would fit in the category Malacca-Max vessels because the Malacca Strait is the next bottleneck in the size constraint.

So, by looking at the past decades it is obvious that vessel size increased strongly. Boundaries for the increase in vessel size like the Panama-Canal have been ignored after a while, which implies that the cost increase of a longer sailing distance is compensated by a larger cost decline on the other side due to the increase in scale.

2.1.3.3 Economies of scale

In prior sections, an overview of the container shipping market is provided from different angels. The information in those paragraphs gives a solid overview of past developments and characteristics of the market. This section describes the most important driver of larger container vessels, namely: "Economies of scale".

Economies of scale refers to the decreasing costs per unit when total output increases. In shipping terms this means that costs per container will decrease when vessel size increases. Pearson (1988) argues that costs per container decrease – independent of vessel type – when vessel size increases.

Stopford (1997) divides the costs for shipping lines in the following sections: capital, operating and fuel costs. Kullinane & Khanna (1999) apply the same division of costs and add the factor "distance traveled", to obtain the saving economies per amount of distance traveled. Malchow (2017) quantified economies of scale when vessels grow to 30,000 TEU and they used the same division of costs as well. An important condition to achieve economies of scale is the utilization of a vessel, as unit costs per shipped container will only decrease if the extra costs of the larger vessel can be spread over an even bigger increase in shipped containers. Lim (1998) argues that shipping lines are forced to keep the sailing frequency constant to please their customers, and therefore face problems in filling the vessels full enough in time (Lim, 1998). Jansson & Schneersson (1987) argue that it is important to consider the efficiency of the whole journey, so by not just considering the time at sea but also the time spent in port and terminals. The time spent at those places depends on the handling speed, which mainly not grows as fast as the increase in vessel size. In this way, economies of scale at sea lead to diseconomies in ports. Notteboom & Winkelmans (2001) mention that diseconomies of scale in ports are present because too much pressure is put on ports with respect to terminal equipment, available space and hinterland connectivity. This leads to a drop in productivity and longer turnaround times. In a study of UNCTAD (2017), it is argued that every percent growth in vessel size leads to a longer time in port of 2.9%. Jansson and Shneerson (1987) showed the tradeoff between economies at sea and diseconomies of ports in figure 5. Where Hauling cost refers to the costs at sea and handling costs refers to the costs in the port. As can be seen, the optimum vessel size is at the point where total costs per TEU are the lowest. The relationship is like a U-curve, where the optimum vessel size is at the minimum value of the U-curve.

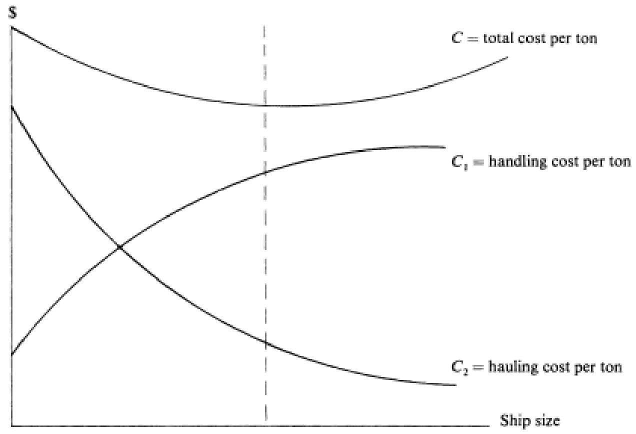


Figure 5: Graphical overview of optimum vessel size

Capital costs

First, capital costs are considered. Capital costs are costs that flow from the purchase of a new vessel. According to (Stopford, 1997), capital costs are present in three forms. First, the purchase price of a vessel should be paid to a shipyard. Second, investors like banks and equity holders put their money at risk by investing in the vessel and they want to receive a return in the form of interest or dividend. The third part is the return payment when the vessel is sold after a period of operations. Figure 6 shows the relation between capital costs per TEU of newbuilding vessels, which is a decreasing function. So, the larger the vessel becomes, the lower the capital cost per TEU will become.

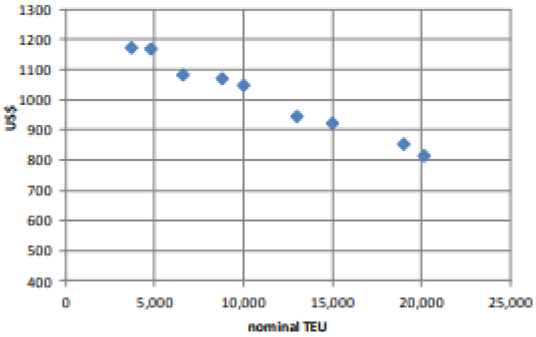


Figure 6: Annual capital costs / TEU (OECD, 2015)

Economies of scale are present with respect to capital costs as an increase in vessel size leads to an increase in price that is lower than the capacity increase of the vessel. An explanation for this can be found in the "cube law". This mathematical relation states that a doubling of a surface leads to a carrying capacity that is cubed. Since the costs of building a vessel are related to the surface of a vessel, a direct costs saving is achieved in the investment costs of a larger vessel (Rodrigue & Browne, 2008). Jansson & Shneerson (1987) argue that the elasticity of size – in terms of TEU – and capital costs is in the range between 0.6 and 0.8, which means that capital costs increase by 0.6 – 0.8 % when capacity increases with 1%. Goss (1977) points out that the cube law is the standard for ship builders and naval architects to calculate carrying capacity when vessel dimensions grow. Veldman (2011) investigated the relation as well, and by using a sample of 1364 vessels he found an elasticity between price and vessel size of 0.726. Though, this relation only holds if the ratio between length, beam and height remains the same, the same steel sorts can be used to build the vessel and when the same engine is used for the propulsion (Goss, 1977). As above conditions generally not hold, the 2/3 law will be less precise in reality than assumed in theory.

Also, it is crucial to consider that vessel prices are not only determined by size but are significantly influenced by the world economy, prices for raw materials and labor, exchange rates, the number of vessels ordered at once, and also negotiation skills of shipbuilders and shipping lines are of significant influence on the price (Malchow, 2017). It is even possible that larger vessels at time *t* are less expensive than smaller vessels at time *t-1*. Thoug, the whole construction market is exposed to the same external forces. So, it is assumed that the relative construction price per TEU remains the same for different vessel sizes as can be seen in figure 7.

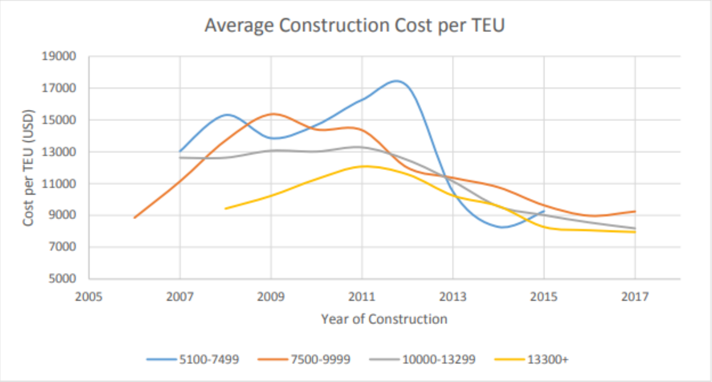


Figure 7: Construction costs / TEU for different vessel sizes (Source: Murray, 2016)

Two methods will be explained to estimate capital costs for different vessels sizes. Naukowe (2016) estimates the relation between vessel size and investment costs by applying a parametric estimation method. For the period 2005-2015 he created an investment costs model for container vessels based on the following operational parameters: DWT, number of containers, service speed, sale price, displacement & weight, gross tonnage, power plant output and fuel consumption. He made the assumption that a linear regression model would be appropriate. The model looks as following:

A second method is proposed by Malchow (2017). He is skeptical about the regression method that is applied because vessel prices are not stable over time, as mentioned before. So, using historical vessel prices does not result in a reliable regression outcome. A solution to overcome this is the selection of a stable variable that is of significant influence in every vessel at every point in time. Malchow (2017) proposed the use of the required amount of steelwork in a vessel, as a vessel is just a floating steelwork. Information about the amount of steelwork is generally hard to obtain, so he proposes to use the vessel displacement as an indicator for vessel weight. This is a reliable approximation as vessels consist almost completely out of steel and the Archimedes Law states that the weight of the water that is displaced by a vessel is equal to the weight of the vessel.

Besides the purchase price of a vessel, it is also relevant to consider the way a vessel is financed. A vessel can be financed by equity, debt and generally a combination of those ways is used to acquire a vessel. With equity finance, investors take a stake in the company and they share both in the risk and rewards of the vessel and its operations. With debt finance, a lender lends the shipping line money to invest in a container vessel. There are multiple debt financing ways like bonds and fixed terms securities and commercial bank loans (Stopford, 1997).

Operating costs

Second, operating costs are considered. These are all costs incurred to operate the vessel on a day-to-day basis. Main components of operating costs are crew, stores and consumables, vessel maintenance, insurance and administration. Those costs are present at any time, independent of the place and the amount of freight the vessel is carrying (Stopford, 2009). As figure 8 shows, economies of scale are present because the function of operating costs / TEU is decreasing. However, the savings are marginally decreasing when vessel size increases.

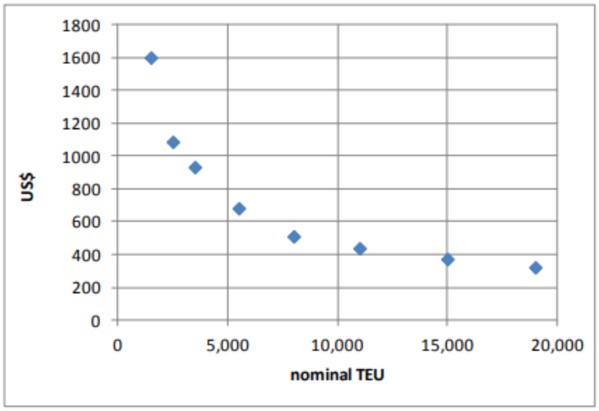


Figure 8: Relation between operating costs per TEU and vessel size (Source: OECD, 2015)

According to Tran & Haasis (2015), operating costs is the most stable cost object when vessel size increases. He argues that this is mainly the case because the number of required crew members does hardly increase when vessel size increases. Crew costs represent around 42% of total operating costs, which is therefore a significant determinant in the cost development (Stopford, 2009). Malchow (2017) states that crewing costs are constant when vessels grow bigger than 1,000 TEU, which implies that no more manning is required when vessel size increases. For example, a Maersk E-class vessel uses the same crew size to operate the vessel as the Maersk Triple-E class with a crew size of 22 employees, whereas the vessel's capacity increased with 3,000 TEU from 15,000 to 18,000 TEU (Maersk, 2014). Malchow (2017) states that the relationship between vessel size and crew costs per TEU is asymptotic, as a doubling from 1,000 to 2,000 TEU has a larger cost saving than an increase of 2,000 to 3,000 TEU. In figure 9 below, the relation between vessel size and crew costs per TEU is shown.

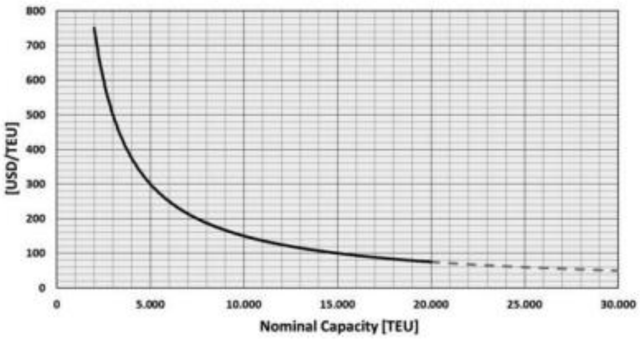


Figure 9: Relation between crew costs per TEU and vessel capacity in TEU (source: Malchow, 2017)

In a research of the OECD (2015), the impact of scale increase on vessel operating costs is assessed for vessels with carrying capacities from 500-12,000 TEU. Operating costs is split in the following categories in this paper: manning (crew), insurance, stores, spares, lubricating oils, repairs and maintenance (R&M), dry docking and management and administration (M&A). A graphical overview of the cost developments is provided in figure 10 below.

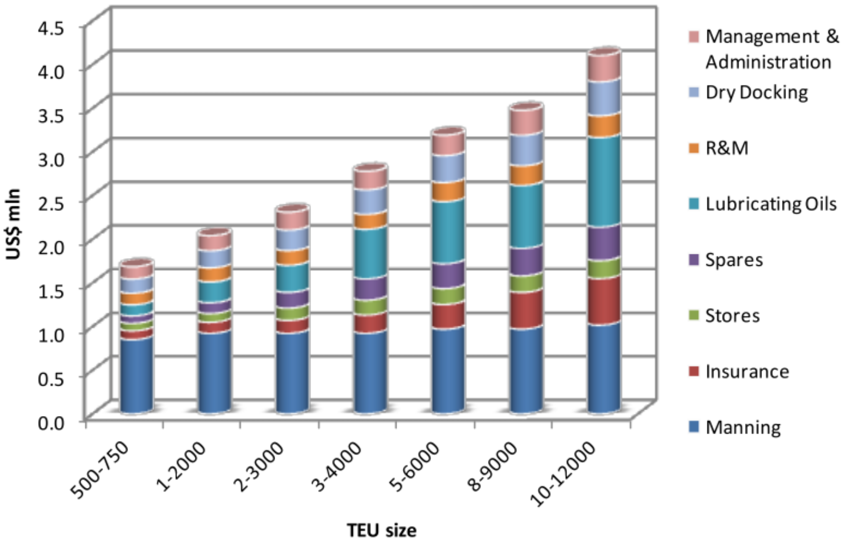


Figure 10: Overview of operating cost categories for a range of vessel sizes between 500 - 12,000 TEU (Source: OECD, 2015)

By analyzing figure 10, it is obvious that crew costs remain almost constant over the range of vessel sizes. The largest increase is visible between the sizes 750 and 1,000 TEU. Then, from 2,000-12,000 TEU the manning costs only increase from around 750 million USD to 900 USD. So, a vessel that increases with 500 % in terms of TEU leads to an increase in crew costs of only 20%. Further, the graph reveals that the total operating costs increase at a lower rate than the increase in capacity. When a vessel increases from

6,000 TEU to 12,000 TEU, this only leads to an approximate cost increase from 3.1 to 4 million USD, which is around 33%.

Now, the separate factors will be analyzed. Larger vessels lead to a larger container administration and more complex stowage planning. This leads to an increase in M&A which is approximately linear. Dry-docking expenses increase at a stronger rate at the smaller vessel sizes and flattens as vessel sizes gets bigger. This could be explained by the handling costs that capture a larger part of the total dry-docking costs whereas larger vessels have to pay more for the space that they use. R&M also increases in a linear way as larger vessels have more surface to maintain, and the equipment on-board is bigger. Lubricating oil is increasing but the increase per TEU is not stable over the range, which could be explained by the shift from single to dual propeller vessels around the border of 10,000 TEU which results in a higher lubricants consumption at every point in time (Sys, Blauwens, Omey, Van De Voorde, & Witlox, 2008). Lubricants are responsible for 25% of total operating costs on a 12,000 TEU vessel. The same holds for spares because spare parts grow bigger and are therefore more expensive for larger vessels. Stores are products like food, medical supplies, cleaning supplies and other things that the crew needs daily. Those costs hardly increase when vessel size increases which is logical because crew costs remain stable as well, and the number of stores is strongly related to the number of crew members on board. The last cost category is insurance costs. As the graph shows, insurance costs increase in an approximate linear way. However, this trend might change to a sharper increase in insurance costs per TEU in the (near) future. The insurability is getting harder for two main reasons. On the one hand, larger vessels bring difficulties when a vessel sinks and has to be removed. At the moment, not much vessels are able to handle those large wrecks, which makes it hard for insurance companies to estimate the possible costs when things go wrong. They estimate that it would take a period of two years before a 19,000 TEU vessel is removed and handled after an incident at open sea. Also, the risk of large shippers increases when vessel size increases. If one shipper puts all his loading in one vessel, he significantly increases the risk (Allianz, 2015).

To conclude, operating costs increase when vessel size increases, but at a lower rate than the increase in size. Most operating cost component increase in a linear way. Crew cost and the linked stores costs remain almost stable over a wide range of vessel sizes.

Bunker fuel

The third cost category is bunker fuel. This is the fuel that is consumed by the propulsion engines The fuel sorts that are mainly used by the diesel engines are IFO 380 and IFO 180, which are mixtures of heavy fuels and light fuels. The numbers 380 and 180 represent the viscosity of the fuel which is higher in IFO 380 compared to IFO 180, due to a higher share of lighter fuel in IFO 180 fuel. IFO 180 is therefore also the most expensive fuel of the two sorts. Bunker fuel is responsible for around 25% of total costs for shipping lines and its price is strongly correlated with the oil price and thereby very volatile. Figure 11 shows this volatility graphically. As can be obtained, the spot price per MT in Q2 of 2008 is more than three times as high as the price in Q3 of 2015.

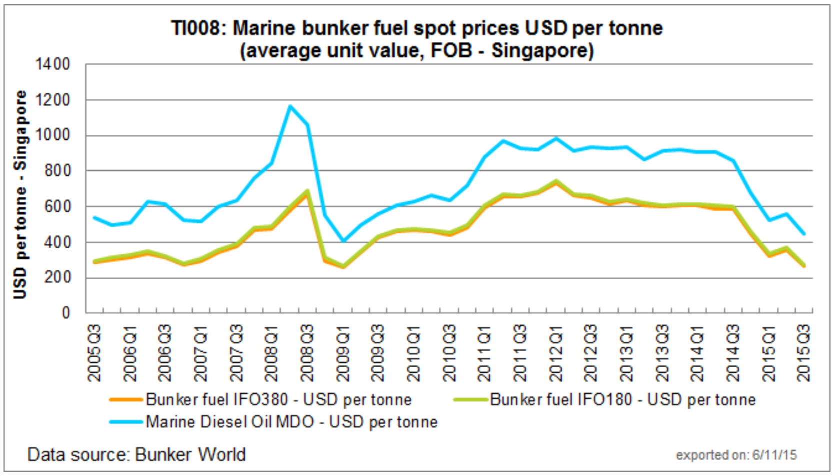


Figure 11: Bunker fuel price development between 2005 – 2015 (Source: Ministry of Transport, 2015)

Reducing bunker fuel costs is one of the main reasons why shipping lines apply larger vessels. The bunker fuel consumption is directly related to the amount of horsepower that is needed to move the vessel. Where the required horsepower to move the vessel is directly related to the resistance of the vessel. So, the higher the resistance, the more horsepower is needed to overcome this resistance and move the vessel through the water. This resistance is composed of three main factors: frictional resistance, residual resistance and air resistance. Where frictional and residual resistance are present under the waterline and air resistance above the waterline. Frictional resistance increases when the wetted area of a vessel increases and when the surface of the vessel becomes less smooth by the occurrence of fouling like algae and barnacles. Frictional resistance represents a significant part of total resistance under all ship types. For low-speed vessels, like container tankers, it will be accountable for 70-90% of total resistance. Whereas, for high speed vessels like container and passenger vessels, it will account for around 40% of total resistance. Residual resistance is split in two factors: wave and eddy resistance. Wave resistance is the loss of energy due to the creation of waves by the propulsion of a vessel. Eddy resistance is flow separation at the end and aft of a vessel, which creates eddies. For low-speed vessels, eddies account for 8-25% of total resistance whereas this is 40-60% for high-speed vessels. Air resistance is generally not very significant, with 2% of total resistance for low-speed vessels. Though, Container vessels have a larger surface above the waterline which results in air resistance to be around 10% of total resistance (MAN Diesel & Turbo, N.D.)

A formula that is often used to calculate the required power for a vessel is the Admiralty formula or Admiralty coefficient. The formula that leads to the coefficient *C* that is shown below.

$$P = \frac{\Delta^{\frac{2}{3}} v^3}{C}$$

Where:

P = propulsion power

Δ = full displacement of vessel

V = speed of vessel

C = admiralty constant

According to this formula, a one percent increase in vessel displacement results in an increase in required power to the power of 2/3 and thereby to an increase in bunker consumption which is lower than the increase in vessel size. Hence, fuel consumption per TEU decreases as vessel size increases. This is shown in figure 12 by displaying the required propulsion power per TEU. As can be seen, this relation is again asymptotic, so a doubling in vessel size leads to a marginal decreasing extra benefit per TEU. Carlton (2012) mentions that the Admiralty relation is a simple and useful formula but simultaneously warns for the bluntness, because it fails to distinguish between hull and engine parameters of efficiency (Carlton, 2012). Also Meyer, Stahlbock, & Voss (2012) are not in favor of using the admiralty formula for calculating the required propulsion power. According to them, the formula was appropriate when vessels were sailing on engines that run on coal. Nowadays, real world conditions have changed and the formula should therefore be threatened with caution. Though, it is a good approximate for this research and the vessel size increase from 21,000 to 50,000 TEU is so large that other methods will not result in more precise estimates (Hopman, 2018).

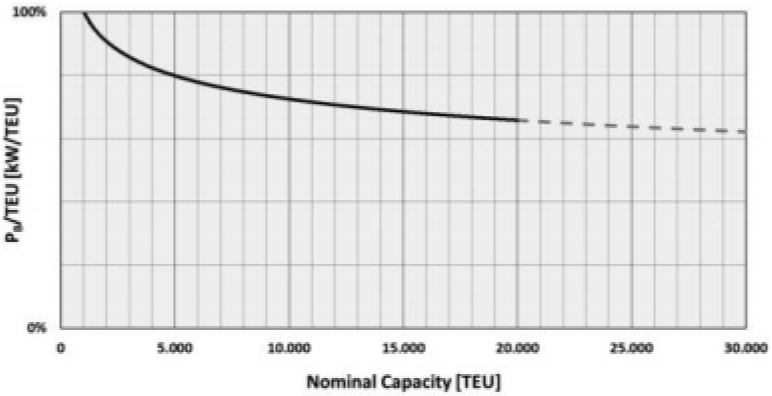
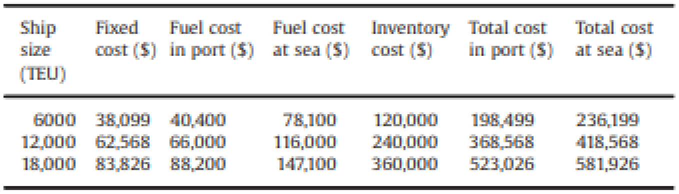


Figure 12: Required propulsion power per TEU (Source: Malchow, 2017)



Ship size (TEU)	Fixed cost ($)	Fuel cost in port ($)	Fuel cost at sea ($)	Inventory cost ($)	Total cost in port ($)	Total cost at sea ($)
6000	38,099	40,400	78,100	120,000	198,499	236,199
12,000	62,568	66,000	116,000	240,000	368,568	418,568
18,000	83,826	88,200	147,100	360,000	523,026	581,926

Table 1: Fuel consumption at sea vs. fuel consumption in a port (Source: Tran & Haasis, 2015)

To conclude, bunker fuel comprises a large piece of total cost and economies of scale are present in the fuel consumption per TEU. The Admiralty formula can support in (rough) propulsion requirement estimations and bunker consumption can be directly linked to this power requirement.

2.1.3.4 Linking main developments in the container shipping market

After the invention of the container it became much cheaper to transport goods all over the world. This has led to a serious boost in world trade as it became viable to produce products at places where it is cheapest to do so, and to transport raw materials and half fabricates to that places by containers. Container transport is marked by the strong multiplier with economic growth. So, demand for container transport increases strongly when the economic situation is good and demand decreases sharply when economic downturns are present. Due to the homogeneity shippers are indifferent in the services between shipping lines and competition is mainly on realizing the lowest prices per container. Shipping lines attempt to be the most efficient in the market and a measure to do this is the forming of alliances in which vessels are shared. This leads to a large worldwide reach of services and a better vessel utilization for the members within the alliance. Another reason for the forming of alliances is the creation of a barrier to entry the market. Also, the parties within the alliance invest in larger vessels because the total demand which can be served at once is larger. Larger vessels lead to economies of scale for shipping lines in capital, operating and bunker fuel costs which leads to a unit costs per container which is decreasing with vessel size. However, vessel utilization is crucial for shipping lines to really reap the benefits of those larger vessels. Due to the strong incentives of shipping lines to order those larger vessels a situation of overcapacity arose in the market and vessels could not be enough utilized anymore. Especially in the economic crisis of 2008 this became problematic. For several years there was a large overcapacity and in 2016 this even resulted in the bankruptcy of the seventh largest player within the market, Hanjin. Despite those developments, shipping lines are still thinking about applying larger vessels to gain more economies of scale. In the research below it will follow what the result will be of this strategic behavior.

2.2 Scope of research

From a shipping line perspective it seems to be a rational decision to increase the size of vessels and this is also proved by prior research about this topic. However, less focus has been put on the impact of those vessels on other parties within the container supply chain. This research therefore attempts to fill this research gap in order to see the economic impact from a chain perspective. While shipping lines benefit from increases in scale, other parties within the chain clearly do not reap the benefits of this ongoing development (Wijnolst, Waals, & Scholtens, 1999). The impact of 50,000 TEU vessels will be assessed for four players within the chain which are: shipping lines, terminal operators, port authorities and consignees. A brief overview of the relevance of each party is mentioned in this paragraph.

First of all, 50,000 TEU vessels will impact the financial position of a shipping line. As mentioned before, it has an impact on the three main cost components: capital costs, operating costs and fuel costs. It is assumed that larger vessels results in cost savings per TEU on all components. Besides, it will impact the sailing routes that the vessels will take and the ports it will call. Also vessel utilization is one variable that should be considered. As vessels grow larger, the risk of not utilizing the vessel with enough containers becomes larger when an economic downturn takes place. Lastly, the larger container vessels increase the supply chain risk which will have an impact on the insurability of those vessels.

Second, terminal operators will be assessed. Much pressure is put on terminal operators to keep up with the growth rate of container vessels. It is much easier for a shipping line to order a new vessel than it is for the terminal operator to adjust the terminals to the required standards for that vessel (JOC, 2014). Terminal operators have no choice other than investing heavily. They have to invest in the size and number of cranes to minimize the turnaround times, quays have to be expanded and also yards need to bigger to handle the larger peak volumes. Also, terminal operating systems need to be optimized in order to remain stable productivity levels and to reduce terminal congestion.

Third, port authorities are impacted by the arising of 50,000 TEU vessels. Many ports are not capable of handling very large container vessels. The draught of the vessel is in most cases the largest bottleneck for not being able to enter the port. Large investments are necessary to achieve and keep the waterways in and towards the port at the required level of depth. Ports have to invest in this in order to serve the shipping lines. Not investing will finally lead to losing large shipping lines as customers. Another issue is the available surface space in ports which is many times too small to accommodate those vessels (Imai et al., 2006). Lastly, the waterways of the Suez-Canal and Malacca Strait will become a bottleneck for the 50,000 TEU vessels which means that dredging activities are needed.

Lastly, the impact on consignees will be assessed. In the end, the focus should be on the client that demands shipping services. Consignees wish to receive the lowest tariff per container. But for most consignees, the reliability of transportation services is even more important. If larger vessels lead at the same time to operational problems in terms of delays and terminal congestion, the benefits of the cost decline per TEU do not outweigh the resulting supply chain problems on the other side (Malchow, 2017).

In figure 13 follows a simplified overview of the different steps in the supply chain of container transportation. As can be seen, shipping lines are in the middle of the chain and have a large impact on the reliability of the whole chain. The consignee refers to the party that wants to ship products to its customers/buyers. The consignees' location can be referred to the factory, or the warehouse that is used for temporary storage. The second step is the logistic operation from seller to the container terminal/port, which mainly happens by truck, barge and rail. The third step is the preparation/storing process at the terminal, just before containers are loaded on a vessel. Fourth, a vessel arrives to load the container and to sail to the container terminal at the other side of the sea. Fifth, the vessel arrives in the terminal and containers are unloaded, stored and prepared for further transport. Sixth, logistic operations take place by barge, rail and truck from the terminal to the shipper/consignee.

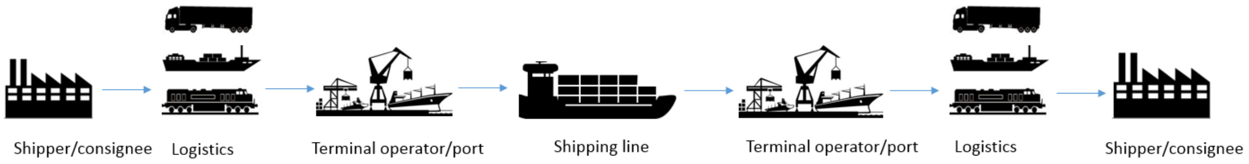


Figure 13: Supply chain overview (own elaborations)

3. Methodology

In this chapter, the methodology that will be applied to assess the economic impact of 50,000 TEU vessels on the container supply chain will be described. It will start with an introduction where the research method and assumptions will be discussed. After that, calculation methods for the impact on each party within the scope will be provided.

3.1 Methodology introduction

This section summarizes the research methodology and the most important assumptions that will be made to perform the study. The developed methodology will be applied to answer the following research question: “What is the economic impact of 50,000 TEU vessels on the container supply chain?” Where the scope of the supply chain is limited to shipping lines, containers terminals, port authorities and consignees.

In the literature review it has become clear how parties within the chain are impacted by growing container vessels. In this methodology I will develop methods that enable us to quantify the impact on each party within the chain. To investigate the impact, one roundtrip has been selected to perform a case study. This roundtrip is called LL1 and it is the roundtrip that the OOCL Hong Kong sails between China and Northern Europe. This route is chosen because the OOCL Hong Kong is the current largest container vessel (21,413 TEU) and it is assumed that the 50,000 TEU vessels will sail over this same route, if they will ever arise. It will be assessed what adjustments are required for each party within the scope in terms of infrastructure. The aim is to also quantify the impact financially, so total investment costs will be estimated and translated to daily capital costs in order to compare the impact for different parties simultaneously. After making those calculations, the costs will be put together to see what the net impact will be on each within the scope.

Due to the inexistence of 50,000 vessels and the large uncertainty about economic forecast, technical developments and the container shipping outlook in general, it is inevitable to work with assumptions. The applied assumptions will follow in tables 1 till 4 below.

General assumptions	Explanation
50,000 TEU vessels will sail around in 2018	McKinsey predicts that the vessels will sail around in the year 2066, which is 48 years from now. However, to assess the impact of those vessels it is assumed that the vessels will be build and operated at the current moment. So, it will be investigated what the impact of 50,000 TEU vessels will be on current parties and infrastructure.
Prices from 2018 will be used as a basis for calculations	Predicting prices for 2066 is arbitrary, and because we assume that 50,000 TEU vessels will sail around now, it is also logical to use current prices.
Expected demand in 2066 will already be present in 2018	McKinsey (2015) generated the demand forecasts for 2066 and it is assumed that those forecasts will become reality in 2018 already.
Relative demand in the world remains the same	By assuming equal relative worldwide container demand, forecasting the required vessel capacity on the considered route (LL1) can be performed by applying the ratio in forecasted demand.

Table 1: General assumptions

Shipping line assumptions	Explanation
Vessels keep current characteristics	Current container vessels are the basis for the extrapolation to 50,000 vessels. The basic components remain the same which are: relative dimensions, propulsion method, vessel speed, relation between vessel price and capacity and the relation between crew size and capacity.
Vessel utilization = 85%	Optimally vessels will be fully loaded when sailing around. However, this is not realistic and like OECD (2015), a utilization rate of 85% will be applied.
Container dimensions remain the same	20 ft. and 40ft. containers will remain the standard in the industry.
Vessels are completely financed with debt	Yearly interest percentage (I) = 6% Yearly depreciation percentage (D) = 5% Residual value after 20 years (rv) = 5%

Table 2: Shipping line assumptions

Container terminal assumptions	**Explanation**
Only one terminal per port needs to be expanded and shipping lines will call at the same ports as they do now	Multiple terminals might be present in each port but only one should be equipped for the 50,000 TEU vessels.
Every terminal is now suited to handle the OOCL Hong Kong, but not more than that	No investigation is done about the real infrastructure and current outlook of the terminals. Assumptions are made about the most probable outlook.
Terminals consist of the same main components in 2066	A terminal consists still out of a gate, yard and berth and its current equipment.
Stacking height in yards remains unchanged	Current stacking height within yards does not increase.
STS cranes remain the same design	-
STS crane handling speed increases equally with the increase in vessel beam	Larger outreach leads to a proportionally increase in speed, so moves per hour per crane remains unchanged.
Crane investment costs increase proportionally with the crane outreach	-
Quay walls will be strong enough to handle the bigger quay cranes	Stress on quay walls is already big and with the larger outreach it will be even bigger. Though, it is assumed that engineers will design quays that are strong enough.
Terminal equipment is completely financed with debt	
• STS Crane capital costs	I = 6% D = 5%
• Quay capital costs	I = 6% D = 2%
• Yard capital costs	Rent / m2 = $58.50,-

Table 3: Assumptions with respect to terminal operators

Port Authority assumptions	
Dredging tariff = $13.92,-	A dredging tariff of $13.92 will be applied in all dredging costs calculations for both canal and port dredging (OECD, 2015).
Dredging costs are financed with debt	I = 6% D = 5%

Table 4: Port authority assumptions

3.2 Calculation methods

3.2.1 Vessel dimensions

Before the impact on the parties in the chain can be assessed, it is crucial to determine how a 50,000 TEU vessel will look like. As the vessel is far bigger than the current vessel sizes, it is uncertain how it will be designed and what dimensions it will have. In this section, a vessel design will be created and this design will later be used to determine the financial and technical impact on shipping lines, terminal operators, port authorities and shippers. Below, the stepwise methodology follows about the estimated dimensions.

The OOCL Hong Kong – the current largest container vessel (21,413 TEU) – will be used as a base for the size increase towards 50,000 TEU. Multiple vessel designs could be created like vessel that only increase in length or vessels that mainly increase in stacking height, but in this research it is assumed that the vessel keeps its relative dimensionsas it is uncertain in which way the vessels will develop. According to Hopman (2018), a vessel that increases relatively the same in all dimensions is technically possible

Vessel dimensions	
Steps	Method
1. Determine increase in capacity	$Increase\ in\ capacity = \frac{TEU.50 - TEU.oocl}{TEU.oocl} .* 100\%$
2. Determine growth factor (x)	$Volume\ = l * w * h$ $Volume\ =\ lf\ *\ wf\ *\ hf$ $Volume\ =\ (1+x) * (1+x) * (1+x)$
3. Determine length, beam, draught & air draught	$Length.50 = Ut.l\ * (1+x) + add.l$ $Beam.50 = Beam.oocl\ * (1+x)$ $Draught.50 = \frac{(Dens.oocl)}{(Dens.50)} * Draught.oocl$ $Airdraught.50 = Airdraught.oocl\ + \Delta St.h - \Delta Draught$

Table 5: Estimation of 50,000 TEU vessel dimensions

As can be obtained from table 5, determining vessel dimensions starts with questioning how much the vessel has to increase in terms of volume. This is done by first calculating the relative capacity increase between the 50,000 TEU vessel and the OOCL Hong Kong, where *TEU.50* and *TEU.OOCL* represent the capacity of respectively the 50,000 TEU vessel and OOCL Hong Kong. In the second step a growth factor will be calculated which expresses the percentage increase in each dimension of the vessel, where *lf, wf and hf* are respectively length, width and height factors. As the vessel keeps its relative dimensions, one single factor will be determined for each dimension. In the last step, the growth factor will be applied to calculate the increase in meters for each dimension. *Ut.l* refers to the utilizable length of a vessel available for container stacking, and *additional length* is the remaining part which consists of the length of the bow and wheelhouse on the vessel. *Beam.oocl* refers to the width dimension of the OOCL Hong Kong, *Dens.oocl* and *Dens.50* represent the container density per m2 of vessel length, and *Draught.oocl* is the water draught of the OOCL Hong Kong. *Ad.oocl* is the air draught of the OOCL Hong Kong and Δ*St.h* is the difference in stacking height between the OOCL Hong Kong and the 50,000 TEU vessel. Further details about vessel dimension variables can be found in appendix B.

3.2.2 Shipping line

First, the incubator of the whole discussion about mega vessels - the container shipping lines - will be assessed. They will be affected in four main areas: capital costs, operating costs, bunker fuel consumption and utilization rates.

Capital costs

Capital costs	
Steps	Method
1. Estimate purchase price of a 50,000 TEU vessel	$P.50 = a0 * S^{a1}$
2. Calculate daily capital costs	$Daily\ capital\ costs = \frac{(i * P) + d * (P.50 - rv)}{365}$

Table 6: Capital costs calculations 50,000 TEU vessel

As mentioned in the literature review, capital costs are the costs that shipping lines have to make in order to own a container vessel. The largest part of the worldwide fleet is financed with debt. So, capital costs related to debt are the debt repayment itself and the periodically interest due. In this research we make the assumption that vessels are completely financed with debt. As table 6 shows, capital costs are calculated by undertaking two steps. The first step is an estimation of the vessel purchase price of a 50,000 TEU vessel. To determine the price, an elasticity method is applied. Where *P.50* is the purchase price in dollars, *a0* is the purchase price of the OOCL Hong Kong, *S* is the ratio in TEU capacity and *a1* is the elasticity factor which represents the relation between vessel capacity and purchase price. In the second step the capital costs will be calculated. Where *i* is the interest percentage, *d* is the depreciation, and *rv* is the residual vessel value at the end of the economic lifetime.

Fuel costs

Fuel costs	
Steps	Method
1. Determine power requirement	$PR = \frac{\Delta^{\frac{2}{3}} * v^3}{C}$
2. Calculate daily bunker consumption costs at sea	$BCS\ in\ \$ = PR * SFOC * 24\ hrs * BP$
3. Calculate daily lubricating oil consumption costs	$LCS = LF * BCS\ in\ \$$
4. Calculate daily fuel costs	$FCd = BCS + LCS$

Table 7: Fuel costs calculations 50,000 TEU vessel

The method that will be used to calculate fuel costs starts with an approximation of the power requirement at service speed. The power requirement *PR* is estimated by using the variables full displacement in Metric Tons $\Delta^{\frac{2}{3}}$, vessel speed v^3 and the admiralty constant *C,* which is a coefficient that represents the efficiency of the hull. The higher the value of *C,* the more efficient the hull is. Second, the daily bunker consumption can be calculated by using *PR,* the specific fuel oil consumption per KW per hour *SFOC*, and the bunker price per kg *BP*. Third, daily lubricating oil costs are calculated by taking a factor for lubricating costs *LF* over daily bunker consumption costs. Finally, total daily fuel costs *Fcd* are calculated by summing daily bunker costs and lubricating oil cost.

Crew costs

Crew costs	
Steps	Method
1. Determine crew size	$CS = a0 * S^{a1}$
2. Estimate avg. yearly salary per crew member	$Avsal.y = totsal/CS$
3. Calculate daily crew costs	$Crew.d = totsal.50/365$

Table 8: Crew costs calculations for 50,000 TEU vessel

Operating costs are all costs that are required to operate a vessel on a day-to-day basis. As mentioned, most cost components from operating costs increase in a linear way with vessel size. Though, there is one component that behaves significantly different which are crew costs. Vessels with a size over 1,000 TEU do not require more personnel, which means that personnel costs remain stable and economies of scale result from making the vessel bigger. Below follows a derivation of crew costs which shows this scale economies for shipping lines. The first step in the crew cost calculation is setting the crew size. This is done by using the base level $a0$ which represents the crew size of the OOCL Hong Kong. *S* is the ratio in TEU capacity between the two vessels and *EL* is an elasticity factor which states the relation between vessel capacity and crew size. Second, the average salary per crew member is determined by dividing the total crew salary *totsal* with the crew size of the OOCL Hong Kong *CS*. Lastly, daily crew costs *Crew.d* are calculated by dividing the total salary of a 50,000 TEU vessel *totsal.50* by 365 days.

Utilization rate

Container demand should be sufficient to fill the container vessels to a profitable utilization rate. This section will shed a light on the method to calculate this required minimum demand.

Two assumptions are crucial:

- Current demand is sufficient to fill vessels to a utilization rate of 85%, which is high enough for shipping lines to make a profit
- Consignees will not agree on a lower sailing frequency

Demand forecast	
Steps	Method
1. Calculate % increase in vessel size	$Capacity\ increase = \left(\frac{TEU.50}{TEU.oocl}\right) * 100\%$
2. Calculate % increase in demand	$Demand\ increase = \left(\frac{Dem.2066}{Dem.2018}\right) * 100\%$
3. Determine difference between step 1 and 2	$\Delta size, demand = \frac{Demand\ increase}{Capacity\ increase}$

Table 9: demand forecast assessment method

Container demand will be sufficient when the increase in demand is equal or higher than the increase in vessel size. If demand is lower, the sailing frequency has to decrease in order to utilize the vessels with enough capacity.

3.2.3 Terminal operator

The terminal operator is the second party that will be analyzed. This party plays a crucial role in transferring cargo from container vessels to the landside, and from this area containers are further transported to the hinterland via other transportation modes like barge, rail and truck. This paragraph will elaborate on the facets of container terminals that are impacted most by the increase in vessel size to 50,000 TEU. The paragraph will start with an elaboration of the basic terminal operations and elements of a container terminal, which is crucial for understanding the analysis. After that, the impact of 50,000 TEU vessels on terminal infrastructure will be assessed. Where the most influenced areas are cranes, quay lengths and yard surface.

Terminal operations summary

Yun & Choi (1999) describe a terminal in terms of subsystems, operations/tasks and required equipment. Where the subsystems are respectively gates, container yards and berths. Operations are divided in four sections: delivery, receiving, unloading and loading. Delivery means transferring imported containers from yard to gate by using transfer cranes as equipment. Receiving means transferring containers for export from gate to yard, using the same transfer cranes. Those activities take place at the landside of the terminal. At the quayside, loading and unloading takes place. Where loading refers to transferring export container from yard to vessel by using quay cranes. Unloading refers to transferring import containers from vessel to quay by using the same quay cranes. Figure 14 below provides a graphical overview of the operations.

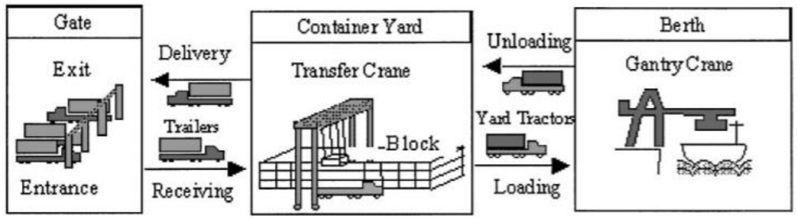


Figure 14: Container terminal operations graphical overview (source: Yun & Choi, 1999)

STS cranes

As vessels grow bigger, the number and size of those cranes needs to grow as well to handle the vessels in an efficient way. Below, the analysis on the STS crane requirements are shown. The aim is to calculate the daily crane capital costs that will be made when 50,000 TEU vessels must be served.

STS cranes	
Steps	Method
1. Determine working area per STS crane in meters	$Working\ area\ = \frac{Vessel.L}{Crane.nr}$
2. Calculate required crane amount	$Crane.nr = \left(\frac{Dens.50}{Dens.oocl}\right) * \left(\frac{L.50}{L.oocl}\right) * Current\ Crane.nr$
3. Estimate purchase price per STS crane	$STS.P = \left(\frac{Or.50}{Or.oocl}\right) * Avg.STS.P$
4. Calculate daily STS capital costs	$Cap.STS = (i + d) * STS.P$

Table 10: Gantry crane calculations for 50,000 TEU vessel

The method to calculate daily STS crane capital costs is as following. First, the current working area per gantry crane is determined by dividing vessel length *Vessel.L* by the number of cranes *Crane.nr*. Second, the required crane amount *Crane.nr* is determined by applying the ratio between the variables *Dens.oocl* and *Dens.50*, which are respectively the container densities per m2 of the OOCL Hong Kong and the 50,000 TEU vessel. Also, a ratio between the two vessel lengths is used in the calculations which are denoted by *L.50* and *L.oocl*. Both ratios are then multiplied by the current crane amount *Current Crane.nr*, which results in the required number of cranes. Third, an estimation is performed on the purchase price of a STS crane by applying a ratio between the required outreach of both cranes *Or.50* and *Or.oocl*. This ratio is multiplied with the average costs of a crane with the current largest outreach *Avg.STS.P* to come to an estimation of the purchase price *STS.P*. Lastly, daily capital costs *Cap.STS* are determined by multiplying *STS.P* with factors for interest *i* and depreciation *d.*

Quays

Quays	
Steps	Method
1. Calculate required quay length per terminal	$Quay\ length = L.50$
2. Calculate quay investment	$Quay.I = Quay/m * L.50$
3. Calculate daily quay capital costs	$Quay.C = (i + d) * Quay.I$

Table 11: Quay calculations for 50,000 TEU vessel

Quays need to be long enough to serve 50,000 TEU vessels. The minimum length of the quay is equal to the length of the container vessel (OECD, 2015). In the optimal situation, information about the quay lengths in 9 terminals over the route LL1 are available. In this situation, it would be possible to check whether the quays are already equipped for the larger vessels. However, information about those lengths is hard to find and if it is provided on terminal websites, it is about total quay length which is not sufficient for this research because only the length per quay is relevant. Using this information as input would therefore be arbitrary. For this reason, it is assumed that quays are currently equipped to serve the OOCL Hong Kong as a maximum vessel size, and that every terminal should expand its quays with 121 meter. Although this assumption might seem arbitrary, it is needed to enable the quantification of the impact. Also, because of the expected increasing growth rates and required vessel capacity, it is logical to assume that this goes hand in hand with expansions in container terminals and thereby also quays.

The method to calculate daily quay capital costs is as following. First, the required length needs to be determined. Where it is assumed that the length of the quay should be equal to the length of the vessel *L.50.* Second, the total quay investment *Quay.I* is determined by multiplying the required length with a tariff for quay investments per meter *Quay.m*. The last step is to calculate daily quay capital costs *Quay.C*, where the quay investment is multiplied with factors for interest *i* and depreciation *d.*

Yards

Yards	
Steps	Method
1. Calculate current yard surface in m2	$Yard\ oocl\ =\ L.oocl * \frac{m2}{vessel\ meter}$
2. Calculate beam factor	$Beam\ factor\ =\ \frac{Beam.50}{Beam.oocl}$
3. Calculate stacking factor	$Stacking\ factor = \frac{Tier.50}{Tier.oocl}$
4. Calculate length factor	$Length\ factor\ =\ \frac{Row.50}{Row.oocl}$
5. Calculate daily capital costs	$Cap.Yard = Yard\ oocl *$ $Beam\ factor * stacking\ factor *$ $length\ factor * \frac{\$T}{Y.m2} / 365$

Table 12: Yard calculations for 50,000 TEU vessel

Due to the higher container density per m2 of vessel and the increase in length, it is necessary to increase the size of the container yards. In the steps below it follows how the daily capital costs of the yard will be determined. First, the size of the current container yards *Yard oocl* need to be estimated. This is done by taking the length of the OOCL Hong Kong *L.oocl* and applying a yard factor in m2 per vessel meter (OECD, 2015). Steps 2, 3 and 4 are respectively calculations about ratios in beam, stacking height and length between 50,000 TEU vessels and the OOCL Hong Kong. Where the ratios are calculated based on container units instead of length in meters. In the last step, daily capital costs are calculated by using *Yard OOCL* and multiplying this with the three factors and a rental tariff per yard meter$\frac{\$T}{Y.m2}$. More information about variables can be found in Appendix B

3.2.4 Port Authority

If a port wants to stay competitive in the market they are forced to create easy entry and exit of the port for the largest vessels. A crucial factor in this is the draught of ports and guiding waterways. This paragraph will assess how much m3 port authorities need to dredge and an estimate of daily dredging costs will be generated. After that, it will be calculated what it would cost to enlarge the Suez-Canal and Strait of Malacca to make those waterways suitable for 50,000 TEU vessels.

Port dredging

Port dredging	
Steps	Method
1. Determine average surface per port	$Based\ on\ estimation\ of\ OECD$ (2015)
2. Calculate extra depth needed	$Extra\ depth = Dr.50 - Current.Dr$
3. Calculate port dredging investment costs	$Dredge.I = Extra\ depth * PortSurf * \frac{\$T.dr}{m3}$
4. Calculate daily dredging capital costs	$Dredge.d = Dredging.I * (i + d)/365$

Table 13: Port dredging costs to serve 50,000 TEU vessels

The methodology of calculating daily dredging capital costs will be described. The first step is to determine the average port size *Avg.Surf* in squared meters. After that, it has to be assessed how much every port on the route LL1 should be deepened, which is done by comparing the draught of a 50,000 TEU vessel *Draught.50* and the draught of the OOCL Hong Kong *Draught.oocl.* Then, port dredging investment costs *Dredge.I* are calculated by multiplying the extra depth, with the port surface *PortSurf* and a dredging tariff per m^3 $\frac{\$T.dr}{m3}$. Finally, daily dredging capital costs *Dredge.d* are determined by multiplying *Dredge.I* with factors for interest *i* and depreciation *d.*

Canal dredging

Sailing route

The container vessels that sail from Asia to Northern Europe currently sail a specific route. The Suez-canal and Malacca Strait enable the shipping lines to reach Europe without having to sail around the Cape in Africa. However, those waterways do not have unlimited depths, widths and height. In this paragraph it will be investigated what the current limitations of those rivers are and how much they need to be deepened to let the 50,000 TEU vessel pass. A rough estimation will be given for the costs of those projects.

First, the current sailing route and its limitations will be analyzed. As can be obtained from figure 15 below, the route starts at Shanghai and the vessel calls at five ports along the Asian coast until it reaches the first constriction, which is the Malacca Strait. After it passed this strait, it heads on towards Europe via the Gulf van Aden and the Red sea. Before it enters the Mediterranean Sea, it has to pass the second constriction which is the Suez-Canal (Egyptian territory). Then it heads on towards Northern Europe where it calls at four ports. After calling at nine ports in total, it sails back to Asia via the same route. It takes the OOCL Hong Kong in total 77 days to complete this journey.

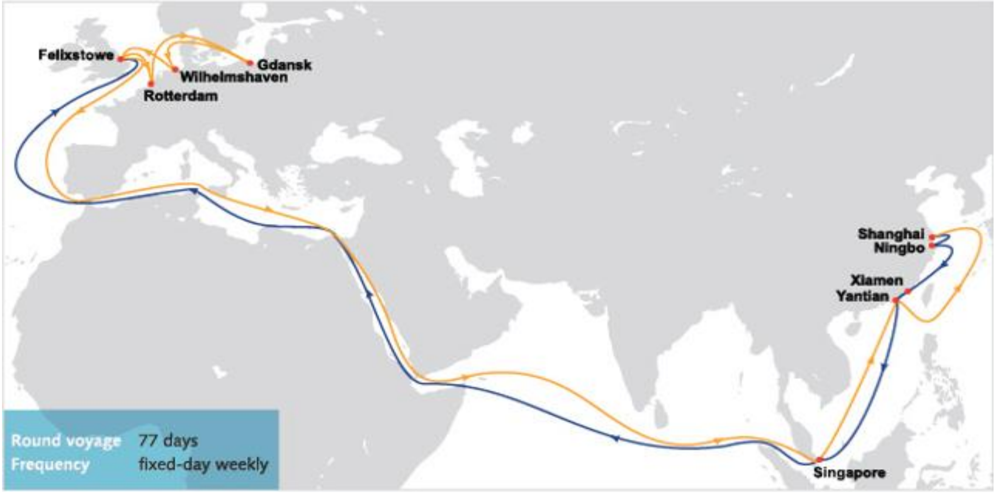


Figure 15: 77-day roundtrip OOCL Hong Kong (Ports: Shanghai, Ningbo, Xiamen, Yantian, Singapore, Rotterdam, Felixstowe, Rotterdam, Wilhelmshaven, and Gdansk)

Canal dredging	
Steps	Method
1. Determine required expansion in m3	*Suez-Canal* Use Wijnolst et al. (1999) as reference to determine the total m3 to be dredged. $Required\ exp.SC. = \frac{Dredging\ m3}{1ft.} * (Dr.50 - Dr.cur)$ *Malacca Strait* $Required\ exp.MS = Required\ exp.SC.* \left(\frac{Malacca.L}{Suez.L}\right)$
2. Calculate daily dredging capital costs	*Suez-Canal* $Dredge.d = (i+d) * \frac{\$T.dr}{m3} * Required\ exp.SC/365days$ *Malacca Strait* $Dredge.d = (i+d)\frac{\$T.dr}{m3} * Required\ exp.MS/365$ days

Table 14: Canal dredging costs methodology

Suez-Canal

The first step is calculating the required expansion *required exp.SC* by using a paper of Wijnolst et al. (1999) where they assess how much m3 has to be deepened when the Suez-Canal gets 1ft. deeper over the whole length. The extra required depth can be calculated by comparing the draught of the 50,000 TEU vessel *Dr.50* with the draught of the OOCL Hong Kong *Dr.oocl*. By combining data over the dredging m3 per/1ft. and the extra required depth, it can be determined how much m3 the *Required exp.SC* will be. The second step is to calculate the daily dredging capital costs *Dredge.C* by multiplying *Required exp.SC* with a dredging tariff per m3 $\frac{\$T.dr}{m3}$ and factors for interest and depreciation costs.

Malacca Strait

It is harder to make an estimation of dredging costs in the Malacca strait because this canal has not undergone large dredging projects. Therefore, a rough estimation will be made about the required dredging activities and costs. The required expansion in m3 will be determined by applying a length factor between the Malacca Strait and Suez-Canal and multiply this with the dredging m3/1ft. for the Suez-Canal. By multiplying this with the required extra depth, it is estimated what the required expansion *Required exp.MS* in m3 of the Malacca strait will be. The same tariff per m3 $\frac{\$T.dr}{m3}$ and cost factors *i* and *d* will be applied to calculate daily dredging capital costs *Dredge.d* for the Malacca Strait.

Cape route

An alternative route would be to sail around the Cape instead of sailing through the before mentioned waterways. This would result in extra sailing miles and thereby extra costs for shipping lines. Also, consignees would be influenced by increased pipeline inventory costs. Further research should focus on the viability of this option, compared to deepening the waterways.

3.2.5 Consignees

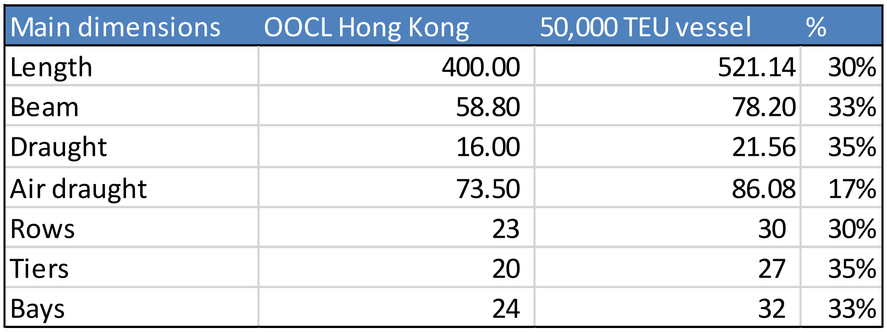
Consignees are crucial to consider when looking from a chain perspective. In the end, consignees are the clients of shipping lines and it is therefore the party that should be served in a proper way by shipping lines. In general, consignees are interested in *frequent* and *reliable* maritime links. In 4.5, the impact for consignees will be assessed theoretically by looking at reliability, price, freight risk, sailing frequency and sustainability.

4. Results

In this paragraph the results of the research methodology will be stated and an analysis on each party within the chain will follow. After that, a result summary follows about the total impact of 50,000 TEU vessels on each party within the scope. In every section a comparison will be made between the costs of shipping containers with the OOCL Hong Kong on the one hand, and the 50,000 TEU vessel on the other hand.

4.1 Vessel dimensions

This section elaborates on the vessel dimensions of the 50,000 TEU vessel which are estimated based on the methodology in 3.2.1.



Main dimensions	OOCL Hong Kong	50,000 TEU vessel	%
Length	400.00	521.14	30%
Beam	58.80	78.20	33%
Draught	16.00	21.56	35%
Air draught	73.50	86.08	17%
Rows	23	30	30%
Tiers	20	27	35%
Bays	24	32	33%

Table 15: vessel dimensions in meters & containers for the OOCL Hong Kong and 50,000 TEU vessel

As can be seen in table 15, the vessel increases almost equally in every direction. The 50,000 TEU vessel will be 121 meters longer, 20 meters wider and 4.5 meters deeper in the water compared to the OOCL Hong Kong. This size increase will have an impact on the whole chain and its infrastructure. This impact will be further analyzed in next sections. The air draught of the 50000 TEU vessel is 86.08 meters, while the maximum air draught of the Suez-Canal is 68 meters due to the limited height of the bridge.

4.2 Shipping line

This section states the results for the three cost segments that change when vessel size changes, namely: capital costs, operating costs and bunker costs. Also, a demand analysis is included where it is assessed whether future container demand will be sufficient to utilize the 50,000 TEU vessels, assuming the same required calling frequency. The results are based on the methodology of 3.2.2.

Daily capital costs	OOCL Hong Kong	50,000 TEU vessel	%
Price	$ 158,333,333	$ 312,037,180	97%
Price per TEU	$ 8,699	$ 7,342	-16%
Interest costs	$ 26,027	$ 51,294	97%
Depreciation costs	$ 20,605	$ 40,608	97%
Total daily capital costs	$ 46,632	$ 91,901	97%
Daily capital costs per TEU	$ 2.56	$ 2.16	-16%

Table 16: Daily capital costs for the OOCL Hong Kong and the 50,000 TEU vessel

In line with the literature, the price of a 50,000 TEU vessel will increase with vessel size. Though, at the same time the price per TEU will decrease due to scale economies in the purchase price of a vessel. This directly leads to a decline in daily capital costs, as the level of interest and depreciation is one to one related to the purchase price of the vessel. Due to the increase from 21,413 TEU to 50,000 TEU capacity, the daily capital costs per TEU drop from $2.56 to $2.16 which is a decline of 16% per TEU.

Daily operating costs	OOCL Hong Kong	50,000 TEU vessel	%
Number of crew members	20	21	5%
Salary / yr / crew member	$ 70,000	$ 70,000	0%
Daily crew costs	$ 3,836	$ 4,027	5%
Daily crew costs per TEU	$ 0.21	$ 0.09	-55%

Table 17: Daily operating costs for the OOCL Hong Kong and the 50,000 TEU vessel

The daily operating costs in this research are focused on the crew costs because other operating cost components are almost 1 to 1 related to vessel size, so they do not impact the shipping line in terms of costs. As the elasticity between crew size and vessel size is low, only one extra crew member is required to operate a 50,000 TEU vessel. It is still questionable whether this person is really needed but it is chosen to stick with the elasticity factor. By expressing the crew costs in per TEU terms, it can be obtained that costs decrease from $0.21 to $0.09 on a daily basis, which is a decline of 55% per TEU.

Daily bunker costs	OOCL Hong Kong	50,000 TEU vessel	%
Bunker consumption in kg	262,077	461,272	76%
Bunker costs	$ 112,693	$ 198,347	76%
Daily bunker costs / TEU	$ 6.19	$ 4.67	-25%

Table 18: Daily bunker costs for the OOCL Hong Kong and the 50,000 TEU vessel including lubricating oil surcharge

Based on the admiralty constant method it is estimated how much bunker fuel a container vessel will consume on a daily basis at operating speed. According to table 18, daily bunker consumption and thereby the costs will overall increase with 76%. Though, due to the increase in capacity, the net saving on fuel costs is 25% per TEU. The OOCL Hong Kong used $6.19 per TEU per day, compared to $4.67 for the 50,000 TEU vessel.

Utilization rates	
% increase in vessel size	134%
% increase in demand (scenario 1)	155%
% increase in demand (scenario 2)	371%

Table 19: Vessel capacity increase vs. demand increase in two scenarios (1.9% & 3.3% annualized growth)

In order to be profitable a shipping line needs to achieve a vessel utilization that is high enough to make a profit. As mentioned in 3.2.2, the assumption is that shipping lines currently utilize their vessels with 85% based on the current demand and sailing frequency. When looking at the viability from a demand perspective it is necessary that the container demand increase is higher than or equal to the increase in vessel size. If this is not the case, changes in the container shipping market are needed. Some possible corrections might be: a lower sailing frequency, bankruptcies of shipping lines which leads to more demand for the surviving shipping lines, or a further concentration in the market by making the alliances even bigger. Table 19 shows the increase in vessel size and the two growth scenarios stated by McKinsey. Both scenarios show larger growth percentages than the increase in vessel size which means that 50,000 TEU vessels can be operated by the current alliances without the need to lower the sailing frequency or concentrating the container shipping market even further. The break-even point of container demand for minimum utilization of 85% will be at the level where the increase in container demand is equal to the increase in vessel size. So, the demand should be at least 424 million TEU/year which is an annualized growth of 1.7% for 50 years in a row.

Total cost comparison shipping line

In the calculations above it is assessed what the cost impact will be when 50,000 TEU vessels will be applied instead of the OOCL Hong Kong (21,413 TEU). This is relevant information, but to assess the impact on a chain perspective it is crucial to know the impact on the total fleet of mega vessels. OECD (2015) estimated that 72 mega vessels would sail around between Asia and North-Europe in 2017, where a mega vessel is equal to 19,000 TEU. It is assumed that the capacity in 2018 will equal the capacity of 2017. For this research a mega vessel is assumed to be equal to 21,413 TEU so for simplicity it will be assumed that the 19,000 TEU vessels can be transformed into 21,413 TEU vessels. By doing this, a hypothetically amount of 64 OOCL Hong Kong vessels are currently sailing between Asia and North-Europe.

McKinsey states two scenarios with respect to worldwide container trade development. The growth rates that will be realized mainly depend on the economic growth of India. In scenario 1, a year on year growth rate of 3.3% is expected and India is expected to "escape velocity". Growth rates would be improved by reformed markets, liberalized trade barriers and other positive developments, which result in an extra 1 billion people that are connected to the worldwide transportation networks. At the same time, developments like 3D printing and nearshoring would only lead to an adaption of supply chains, instead of a decline in total demand. In scenario 2, a year on year growth rate of 1.9% is expected. This more pessimistic scenario assumes that China's rapid growth will not be present in other developing countries in the future. Also, geopolitical tensions would create incentives to intensify nearshoring. Lastly, re-use and dematerialization of society would lead to less physical transportation.

The route LL1, on which the case study is based, runs from China to Northern Europe. Those regions have already experienced large growth rates but are now slowing down. Due to the strong economic situations in those regions, it can be expected that technologies like 3D printing start to have impact at those places the first. Therefore, it is more realistic to assume the "pessimistic" scenario of 1.9% as input for the calculations. OECD (2017) estimated container demand for 2050 for the largest regions in the world. By taking an average of the growth rates from China, Asia and Europe, an average of 1.88% resulted. So, the 1.9% year on year growth seems a valid estimation. The average growth rate of 1.9% leads to an estimated container demand of 464 million TEU in 2066.

Number of vessels on Asia-North Europe	OOCL Hong Kong	50000 TEU vessel
Demand 2018 (182 mil TEU)	64	27
Demand 2066 (464 mil TEU)	164	70

Table 20: number of vessels per vessel type based on the growth rate of 1.9%

As the table shows, the number of required vessels would be less than half of the amount which are needed when the OOCL Hong Kong is applied. In the situation with 464 million TEU worldwide container demand, 164 OOCL Hong Kong vessels would be needed against 70 vessels with 50,000 TEU.

Cost overview shipping line	OOCL Hong Kong	50,000 TEU vessel	Δ	Δ in %
Capital costs	$ 7,608,771	$ 6,421,789	$ (1,186,982)	-16%
Operating costs	$ 625,838	$ 281,422	$ (344,415)	-55%
Bunker costs	$ 18,387,536	$ 13,859,877	$ (4,527,659)	-25%
Total	$ 26,622,145	$ 20,563,088	$ (6,059,057)	-23%

Table 21: daily capital cost comparison in 1.9% growth scenario

Table 21 shows the comparison in costs between using the OOCL Hong Kong and the 50,000 TEU vessel, for all three cost components. Daily capital costs decrease with 1.19 million dollars per day, operating cost decrease with 0.34 million dollars per day and bunker consumption decreases with more than 4.52 million dollars per day. In total, the cost savings are 23% and 6.06 million dollars per day. Although, the costs increase is only 23% on a vessel size increase of 133%, it still leads to a cost saving per TEU for shipping lines which makes it worthwhile to invest in those vessels, if inefficiencies within ports are not becoming bigger than the cost savings.

4.3 Terminal operators

This section shows the results for the main cost components that will be impacted for terminals when vessels grow to 50,000 TEU, which are STS cranes, quays and yards.

Terminal operators are impacted in three ways with respect to STS cranes. First, they need to invest in more STS cranes because of two reasons: the vessel is getting longer and the density of containers per m2 of vessel increases. So, if terminal operators want to keep the same turnaround time for a vessel they need to invest in more cranes per quay meter. Second, they need to invest in larger quay cranes due to higher container stacks and a larger vessel beam which requires a higher outreach of each crane. The number of cranes on the OOCL Hong is 7 on a vessel of 400 meters, which means a working area per crane of 57 meters. Whereas, the 50,000 TEU vessel needs 12 cranes on 521 meters which is a working area per crane of 43 meters. The required crane outreach of the OOCL Hong Kong is 23 rows compared to 30 for the 50,000 TEU vessel. Currently, those crane designs do not exist but until now cranes have always grown with the increase in vessel size so it is assumed that this will happen as well when 50,000 TEU vessels arise. By applying the outreach factor and an average purchase price of the current largest cranes, which is 11.08 million dollars (See Appendix C1), the price of a 50,000 TEU STS crane is estimated on 14.45 million dollars.

Daily STS crane costs	OOCL Hong Kong	50,000 TEU vessel	%
Crane outreach	23	30	30%
Number of cranes per quay	7	12	76%
Daily interest costs	$ 12,751	$ 38,087	199%
Daily depreciation costs	$ 10,626	$ 31,740	199%
Total capital costs	$ 23,377	$ 69,827	199%
Total costs 9 terminals	$ 210,396	$ 628,443	199%

Table 22: STS crane impact by 50,000 TEU vessels

Total STS crane capital costs will be $69,827 per terminal compared to $23,377 for the OOCL Hong Kong. When the vessel sails the LL1 route, it calls in total at nine different terminals. By assuming that every terminal still has to be served, daily STS crane capital cost for all terminals together would increase with $418,047 (199% increase).

Daily quay costs	OOCL Hong Kong	50,000 TEU vessel	%
Length in meters	400	521	30%
Quay costs per meter	$ 45,000	$ 45,000	0%
Quay expansion in meters	0	121	-
Depreciation costs	$ 986	$ 1,285	30%
Interest costs	$ 2,959	$ 3,855	30%
Daily quay costs	$ 3,945	$ 5,140	30%
Total costs 9 terminals	$ 35,506.85	$ 46,260.22	30%

Table 23: Quay costs for the OOCL Hong Kong and 50,000 TEU vessels

Quays need to be lengthened when the vessel grows to 521 meters. The 50,000 TEU vessel grows 121 meters longer and it is assumed that the length of the quay should exactly match the length of the vessel, so the quay needs to be expanded with 121 meters as well. This is an increase of 30%, which means that daily quay capital costs increase with 30% as well from $3,945 to $5,140. By considering again this increase for 9 terminals, the total daily quay capital costs will increase with $10,753.

Daily yard costs	OOCL Hong Kong	50,000 TEU vessel	%
Length	400	521	30%
Depth	580	1,021	76%
Surface	232,000	544,696	135%
Daily yard rental costs	38,137	87,301	129%
Total costs 9 terminals	$ 343,232.88	$ 785,704.82	100%

Table 24: Yard rental costs for the OOCL Hong Kong and 50,000 TEU vessels

Terminals have to adjust their yards to accommodate the larger vessels. Every quay meter is equipped with an amount of 580 yard square meter for the OOCL Hong Kong. However, this required surface will change for 50,000 TEU vessels due to the increase in vessel length and the increased container density per vessel m2. It is assumed that the stacking height cannot increase on the terminals, so that extra surface space is needed on each terminal. The 50,000 TEU vessel requires 544,695m2 yard compared to 232,000 m2 for the OOCL Hong Kong. This leads to a difference of $49,163 of daily yard rental costs per terminal. So, the total daily extra yard rental costs would be $442,471 for all 9 terminals.

Total cost comparison

Based on the before mentioned elaborations a total cost comparison between serving the LL1 route with the OOCL Hong Kong versus the 50,000 TEU vessel can be made. This comparison is shown in table 25 below.

Cost overview 9 terminals	OOCL	50,000 TEU vessel	Δ	Δ in %
Quay	$ 35,506.85	$ 46,260.22	$ 10,753	30%
yard	$ 343,233	$ 785,705	$ 442,472	129%
STS cranes	$ 210,396	$ 628,443	$ 418,047	199%
Total	$ 589,136	$ 1,460,408	$ 871,272	148%

Table 25: Cost comparison for daily costs of 9 terminals in Asia and North-Europe

As can be obtained from the table, quay investments increase with 30% per day and a dollar amount of $10,753. Yards grow with 129% due to the larger peak volume, caused by the bigger calling size. STS cranes increase with 199% and a value of 0.42 million dollars per day. Total daily costs increase with 148 % due to the arising of 50,000 TEU vessels.

4.4 Port authorities

This section shows the results for the main cost components that will be impacted for port authorities when vessels grow to 50,000 TEU, namely: port and canal dredging costs.

None of the nine ports is currently capable of serving the 50,000 TEU vessel due to the big increase in draught compared to the current largest vessel. Based on information in a paper of the OECD (2015) it is estimated how big the average port surface is of each port, which is set at a level of 3.6 million m2. The current depth of every port is known and this information is used to calculate the total m3 to be dredged per port. By looking at the results it is clear that every port should at least invest 180 million dollar to make their port area at the required depth (See Appendix C2). The total daily dredging costs will be 0.6 million dollars for the 9 ports in total. The port of Felixstowe is currently the least equipped to accommodate 50,000 TEU vessels whereas Wilhelmshaven and Singapore are ahead of other ports

Daily Suez canal dredging costs	
Canal Length	192
Canal depth	20.11
Dredging tariff / meter	$ 13.92
Total Expansion in m3	$ 729,983,651
Total investment cost	$ 10,161,372,425
Daily dredging capital costs	$ 3,062,331

Table 26: Dredging costs to get the Suez-Canal equipped for 50,000 TEU vessels

Malacca Strait dredging costs		
Canal Length		926
Canal depth		20
Dredging tariff / meter	$	13.92
Total Expansion in m3	$	3,787,582,936
Total investment cost	$	52,723,154,473
Daily dredging capital costs	$	15,889,170

Table 27: Dredging costs to get the Malacca Strait equipped for 50,000 TEU vessels

Besides port draught, it is also crucial to focus on the rest of the sailing route. Currently, container vessels are passing the Suez-Canal and Malacca Strait to reach Northern Europe. Both waterways are not ready for 50,000 TEU vessels. The Suez canal should be dredged with 1.45 meters over a length of 192km, whereas the Malacca strait has to be deepened with 1.56 meters over 926km. By applying the dredging tariff of $13.92, total dredging costs will be 62.88 billion dollars. This leads to daily capital costs of 18.95 million dollars.

4.5 Consignees

This section will analyze the impact of 50,000 TEU vessels on consignees. The following five factors will be assessed: reliability, price, freight risk, sailing frequency and sustainability.

Reliability

Reliability, in terms of transit time, is one of the key metrics for consignees because a higher service reliability reduces supply chain inventory costs and it enables consignees to realize just-in-time (JIT) deliveries. Transit time can be defined as the time in days it takes to sail from port to port (Notteboom, 2006). Consignees do not want to stock out because this will lead to unsatisfied customers and a loss in foregone revenues. Therefore, they set a Customer Service Level (CSL) that they want to achieve. This means that they set the probability of stocking out on a certain maximum level. The variable that can influence this probability is the safety inventory that is kept. The higher the safety inventory, the lower the chance of stocking out. However, this leads simultaneously to higher inventory costs. So, there is always a trade-off for between the costs of stocking out and the cost of keeping more inventory (Chopra & Meindl, 2013). Reliability affects the amount of safety inventory that should be kept in order to achieve the CSL. The higher the reliability, the lower the need for safety inventory.

The question is how the 50,000 TEU vessels will affect transit reliability. According to Notteboom (2006), transit reliability is influenced by the following main factors: port/terminal congestion, terminal productivity below expectation, delays in access channels, maritime passage reliability and other issues related to the weather, mechanical problems and unexpected waiting times. The factors will be assessed one by one to see in how a 50,000 TEU vessel will impact the transit reliability.

Terminal congestion is bigger when vessels grow bigger. The higher call sizes lead to larger peaks and mega vessels stay on average 20% longer in ports (The Loadstar, 2015). Call sizes will increase with 133%, so the chance is big that terminal congestion gets worse and that it will affect transit reliability negatively. Terminal productivity expectations should not be a problem when 50,000 TEU vessels arise, as long as the real productivity is known and expectations are realistic. Delays in access channels are more probable for 50,000 TEU vessels. In some areas, like Antwerp, the draught is only sufficient at several time windows due to tidal differences. As 50,000 TEU vessels will have a higher draught, which will result in time windows become narrower. As mentioned in 3.2.4, the passages of the Suez-Canal and Malacca Strait have to be deepened to serve the 50,000 TEU vessels. By assuming that this will happen, there is no reason for 50,000 TEU vessels to be more impacted by delays in those waterways. Lastly, problems due to weather and mechanical failures can happen on every vessel. So, sailing with a 50,000 TEU vessel will not increase the probability of having those failures.

To conclude, transit reliability will mainly be impacted negatively due to port/terminal congestion and smaller time windows to pass certain waterways. Though, if enough buffer time is considered in the transit time schedule, the involved parties have some space for delays and within the chain. However, this will lead to higher safety inventory requirements for consignees which is unfavorable.

Price per TEU

Price per TEU is an important criteria for consignees. By looking at the scale economies as described in prior paragraphs, it is tempting to assume that consignees will benefit from this by paying smaller transport tariffs per shipped container. Though, this is not directly the case. It is not that shipping lines are unwilling to share the costs benefits and they are actually doing this. But, is due to the hub- and spoke structure that is used that consignees might not benefit. Scale economies occur during the main haul but it could be that the pre- and onward hauls of the journey are longer or more inefficient, which leads to diseconomies of scale. So, the final price advantage depends on the total price of all parts within the transport network. Besides, the already mentioned longer transit time might increase the transportation costs per TEU. A longer transit time directly leads to larger pipeline inventory costs. The impact of this factor depends on the value and perishability of the goods. Therefore, it depends on the product type whether the price per TEU will finally increase or decrease.

Freight risk

When transporting containers, there is always a risk that something bad will happen during the trip. A container vessel can sink and containers can fall off a vessel which causes serious damage to containers and the goods that are carried. Consignees prefer to minimize this risk and thereby favor transporting their containers on multiple vessels instead of one big vessel. However, due to the developments in vessel size and the presence of only a three alliances, it is hard for consignees to properly manage this risk.

Sailing frequency

High sailing frequencies are favorable for consignees as it enables them to optimize their inventory management. Higher sailing frequencies results in lower lead times, which leads to lower inventory requirement and thereby to lower inventory costs. As mentioned in 4.2, sailing frequencies can only remain at the current levels if the container demand increases enough to utilize the fleet and if this is not the case, corrections need to take place in the market like the forming of bigger alliances or bankruptcies which lead to higher demand per shipping line. So, sailing frequency has an impact on consignees but it not known how container demand will develop and thereby the final impact on consignees is uncertain.

Sustainability

Consignees nowadays are becoming more aware of their carbon footprint, which is the carbon dioxide emission that is created by a certain activity or production process. Their customers expect more environmental awareness in the production process and transport haul, and favor companies which act in an environmentally responsible way. Container shipping is by far the transport mode which pollutes the least greenhouse gasses (GHG) per TEU mile, compared to truck, rail and plane (Liao & Tseng, 2009). On top of that, increasing the scale of container vessels reduces this GHG emission even more due to economies in bunker consumption, assuming enough utilization. Though, the story does not end here. Large container vessels generally apply a hub- and spoke shipping network, so it is important to consider the pre- and onward haulage of the transport network as well. It can be that the main haulage with the large container vessel results in lower GHG emissions per TEU, but that simultaneously the pre- and onward haulage becomes less economic and thereby lead to an increase of GHG emissions. So, using large container vessels sounds tempting for consignees and their customers but it is crucial to assess the larger picture of the chain when talking about sustainability.

4.6 Results summary

This paragraph summarized the results that are obtained in paragraph 4. In this way, an overview of the daily costs impact for each party will provided.

Party	Daily costs Δ	
Shipping line	$	(6,059,057)
Terminal operator	$	861,713
Port authority	$	19,592,349
Net result	$	14,395,006

Table 28: Daily costs change when switching from a 21,413 TEU to a 50,000 TEU vessel

Shipping lines directly achieve economies of scale by applying 50,000 TEU vessels as they gain economies of scale in three areas: capital costs, operating costs and bunker costs. However, they only save costs when utilization rates of the vessel are sufficient to cover the increased vessel costs. The estimated amount of required 50,000 TEU vessels is 70, compared to 164 OOCL Hong Kong vessels. Shipping lines would save 6.06 million dollars per day when applying the bigger vessels. Of which daily capital, operating and bunker costs decline with respectively 1.19, 0.43 and 4.52 million dollars. Daily capital costs per TEU will decline from $2.56 to $2.16 (-16%) for costs, $6.19 to $4.67 (-25%) for bunker costs and $0.21 to $0.09 for operating costs (-55%). Average costs savings are 16% per TEU, which is low by considering the growth of the vessel with 133%.

Container terminals are currently not equipped for 50,000 TEU vessels. In total, 9 terminals are called by the OOCL Hong Kong and every terminal needs additional investments. The investments with the highest impact are quay expansion, increase in the required number and size of STS cranes, and yard capacity expansions due to higher peak volumes. Quays need to be lengthened from 400 to 519 meters, which leads to a daily costs increase of $8.065 (+30%). The required number of cranes per quay increases from 7 to 12, in order to remain the same handling speed. Also, the outreach has to increase from 23 to 30 rows. The total daily STS crane costs will increase from 0.21 to 0.63 million dollars (+200%). Lastly, due to the increased peak volume of the vessel, yard capacity has to increase from 2,320ha to 5,447ha. This leads to a daily cost increase of 0.44 million dollars.

Port authorities are mainly impacted by required dredging activities. Ports along this route are currently able to serve vessels with a draught from 15 up to 18 meters. The draught of the 50,000 TEU vessel will be 21.6 meters which means that all ports have to be dredged. In total, 152 million m3 of port needs to be dredged with total investment costs of 2.13 billion dollars and daily capital costs of 0.64 million dollars. Also, the Suez-Canal and Strait of Malacca do not have sufficient depths to serve the 50,000 TEU vessels.

In total, those canals need to be dredged with respectively 0.73 and 3.79 billion m3, with total investment costs of 63 billion dollars. This results in 18.95 million dollars of daily dredging costs.

Consignees are assessed qualitatively by analyzing the impact on transit time reliability, price per TEU, freight risk, sailing frequency and sustainability. 50,000 TEU vessels might result in lower transit time reliability due to congestion in terminals/port and smaller time windows in certain waterways. Although, the price per TEU might decline for shipping lines, it is doubtful whether consignees reap the benefits of those savings due to hub – and spoke networks that might lead to higher costs for pre- and onward costs. Also, longer transit times might lead to higher pipeline inventory costs which increases the price per TEU. 50,000 TEU vessels increase the freight risk for consignees as it becomes harder to spread the load over multiple independent vessels. The sailing frequency will not become a problem, by assuming the expected increase in worldwide demand from 182 million to 464 million TEU. This increase is higher than the increase in vessel size which means that vessels can keep or even increase the current frequency. Finally, it is not guaranteed that the bigger vessels will be more environmentally friendly. It will hold for the main haul with the mega vessel, but the rest of the chain should be considered as well to judge the environmental friendliness in a way that makes sense.

5. Conclusion and limitations

5.1 Conclusion and discussion

This research has focused on the following question: “What is the economic impact of 50,000 TEU vessels on the container supply chain?” Where the scope of the supply chain is limited to shipping lines, terminal operators, port authorities and consignees. McKinsey (2015) predicted that 50,000 TEU vessels would become reality and operational in 2066 and due to the skepticism about the already big container vessels, it is crucial to know what the economic chain impact will be if those vessel sizes become reality.

The findings will be summarized now. Shipping lines realize economies of scale in three main areas: capital costs, operating costs and bunker fuel costs. The cost savings per TEU are respectively 16%, 55% and 25%. In total, shipping lines save 6.01 million dollars per day by applying 70 vessels of 50,000 TEU instead of 164 vessels of 21,413 TEU. In total, investments in 9 terminals are needed to be get the current biggest ports equipped to serve the 50,000 TEU vessels. Those investments consist of more and bigger STS cranes, longer quays and expansions in yard surface. The cost increase is respectively 199%, 30% and 129%. Total daily terminal costs will increase with 0.87 million dollars. Port authorities are mainly impacted by the required investments in 9 ports and two waterways, which are the Suez-Canal and Malacca Strait. Those investments will result in estimated daily capital costs of respectively 0.64 million, 3.06 million and 15.89 million dollars. The impact on consignees has not been quantified. A qualitative analysis shows that consignees will mainly be impacted in lower transit time reliability and a lower price on the main haul. Though, it depends on the total shipping route and product type whether the price per TEU will decrease over the whole journey.

Based on those findings, it can be concluded that the net result will be a daily costs increase of 14.4 million dollars. So, the economies of scale for shipping lines do not outweigh the extra costs for the remaining parties, which is mainly due to the big dredging activities that are needed. Besides, consignees will probably not reap any benefits and only face negative consequences in terms of delays and schedule reliability. However, this does not imply that the current size developments will stop. Shipping lines have the strongest negotiating position and if one port stops investing in expansions, another port will take over its position by doing so. Therefore, collaborative action between ports and terminals is needed to stop this development. Though, ports like Rotterdam will not easily give up their position and try to remain the frontrunner in mega vessel accommodation. Another option is to stop expanding the main waterways like the Suez-Canal and Malacca Strait, so that those vessels simply cannot reach Europe without making an inefficient detour.

Nevertheless, it is important to put the findings into perspective. There are a few factors that can impact the result strongly. First, economic growth is a strong determinant for the viability of 50,000 TEU vessels. The bigger the growth rate, the more vessels are needed and the higher the total savings will be for the shipping lines. It is impossible to predict economic growth for 50 years from now and it is very uncertain how factors like 3D printing and nearshoring will develop, and what their impact will be on the total container transport demand. Second, the performed estimations around dredging activities are rough estimations and the linked costs are solely recharged to the container shipping industry, while bulk and crude carriers might benefit from the increase in waterway-depths as well. Therefore, probably too much dredging costs are considered in this research which makes the total cost outlook more negative. Lastly, widening the scope of this research by adding hinterland transportation would probably make the cost outlook more negative from a chain perspective. Peak volumes are not only affecting terminals, but hinterland networks are suffering as well. As this is currently already a problem with 21,000 TEU vessels, it will probably be worse when 50,000 TEU vessels arise.

All in all, the research outcome is based on an analysis that is not perfect and full with uncertainties due to the large time horizon over which the estimations are performed. Though, it is one of first papers that quantifies the consequences for a big part of the chain, instead of just assessing qualitatively. Also, it provides a solid framework for future research about the impact of vessel size on the supply chain.

5.2 Limitations & suggestions for further research

The aim of this section is to critically validate the results that have been obtained. Although, the calculations are performed with the largest precision, they have to be interpreted with caution. This is mainly because of the wide scope and the many assumptions that were needed to perform the research. The main limitations will be described below and suggestions for further research will be proposed.

Scope

Notwithstanding the wide research scope, there is one important chain link that is not considered which is hinterland transportation. The larger vessels will lead to larger call sizes and bigger peak volumes in terminals. Though, the impact of this peak does not stop in the terminal and hinterland transportation will be impacted as well. Currently, terminal and road congestion are already a big bottleneck in the efficiency of container handling and by increasing vessel sizes this will only become a bigger problem. Nevertheless, it is decided not to include this chain link in the analysis because the impact is regionally dependent and the rest of the analysis does not go enough into depth to judge the impact at this level. Adding hinterland transportation in the analysis is definitely something that should be done in further research.

Vessel design

The dimensions of the 50,000 TEU vessel are based on a rough estimate where it increases (almost) evenly in each direction. Though, it is not said that future vessels develop in this way. Another option would be to increase the vessel only in the length direction or to stack the containers higher. Applying a different vessel design will not only affect the investment costs of the vessel, but it will also have a strong impact on container terminals which have to adjust their quays, cranes, yards and operations. Also, canal and port draft requirements could be very different from the current estimations and thereby also the investment costs in those projects would change. However, as it is uncertain how those vessels will be designed in the future it is a good starting point to assume that the relative scale dimensions remain the same. A suggestion is to perform the same research, but then with another vessel design.

Propulsion methods of the 50,000 TEU vessel are also questionable. It is assumed that the vessels will use the same heavy fuel – powered combustion engines in 2066. Though, this is not completely realistic. The International Maritime Organization (IMO) stated, for the first time, how they want to tackle climate change and what their goals are in terms of GHG emission reductions. In 2050, GHG emission need to be reduced by at least 50% (IMO, 2018). This can only be achieved by applying alternative propulsion methods like fuel cell technology. A change in the propulsion method will also change the costs structure around fuel savings. However, as those technologies are still under development and too uncertain to insert in the calculations, it is assumed that 50,000 TEU vessels will use current propulsion technologies. If those technologies are more mature, it is recommended to replace the current propulsion methods and to assess the impact again.

Terminal operators

There are a few limitations around terminal requirements. First, it is assumed that every terminal is now equipped to handle the OOCL Hong Kong, but not more than that. This means that calculations might over/under estimate the investments that are required to handle 50,000 TEU vessels. Second, this research has only focused on the cost side for container terminals. So, extra benefits from letting 50,000 TEU vessels entering the terminal are not considered, which might lead to a skewed cost/benefit overview. Third, it is assumed that engineers will be capable of designing the required cranes and quays to handle the vessels. On the one hand it is questionable if this is realistic as the increase in outreach by 7 containers puts a lot of stress on the quays. On the other hand, until now engineers have always been capable of keeping up with scale increase, so it is not odd to assume that they will manage to do so in the future as well. Fourth, it is calculated how much yard capacity each terminal needs, which is more than two times the current capacity. Though, it is uncertain whether each terminal has the space to realize this expansion. Lastly, not all equipment is considered in this research. Every new STS crane also demands more straddle carriers, forklifts and other necessary equipment.

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Appendix A

Interview Hans Hopman

9-7-2018

Function: Professor Ship Design at TU Delft

Goal: Define method for determining vessel dimensions of 50,000 TEU vessel

Interview summary

Q1. Are 50,000 TEU vessel technically possible? If yes, what will change compared to the current largest vessels?

A1. Yes, 50,000 TEU vessel will be possible to design and construct. However, it will be a challenge to do so. It will be challenging for the 3 possible dimensions: length, beam and height.

Length: Especially when vessel increase much in the length direction, the tension on the length construction is huge. Steel hull plates need to become thicker in order to cope with this increase tension.

Beam: if the beam of the vessel becomes relatively wider, the vessel becomes more starch. This might result in problems because the swinging movements of the vessel could become too strong for the containers.

Height: heightening the vessel might become a problem because of the force that a container can handle. More pressure is put on the containers in the lower side of the stack. Containers therefore need to be strengthened or other solutions need to be implemented to reduce the pressure on the lower containers.

However, if the economic forces a strong enough engineers will find a way to overcome those bottlenecks and 50,000 TEU vessels can be realized.

Q2. Are vessel lengths of 800+ meters technically possible?

A2. Yes, by using the right steel thickness and construction it will be possible. However, it is also important to consider the maneuverability of those vessels in ports and terminals. Vessels generally need to be able to swing in a port to sail back from berth to the sea again. A vessel length of 800+ meters might be too big for many ports to make such a swing.

Q3. Let's assume that 50,000 TEU vessels are technically possible, what other bottlenecks need to be overcome in order to make those vessels a success?

A3. Many obstacles need to be overcome to make 50,000 TEU vessels a success on a chain level.

- Demand: the demand for those vessel must to be high enough, which means that the demand for container transport in general needs to grow further in the future. Hans Hopman rather mentions that he expects the demand to stabilize or even shrink in the future due to developments like 3D printing and re-using of materials and products. If this happens, demand might not be sufficient to apply those vessels.
- Terminals: when vessels grow in other directions then length, every gantry crane needs to handle more containers which means that a vessel will stay longer in the terminal, if crane speeds remains the same. Also, current cranes have an outreach of 23 containers but this need to be even further when vessels grow in the beam direction. Another option is to make use of a docking concept, where a vessel is unloaded from two sides.
- Draft: the draughtt of a 50,000 TEU vessel will become too deep for the current infrastructure and waterways. Current large vessels are already called Malaccamax which means that the Malacca Strait is the next obstacle when vessels grow further in size.
- Hinterland: pressure on hinterland is already a problem. Look for example to the congestion on the roads around the Port of Rotterdam. By increasing the vessel size, call sizes will be even bigger and pressure on the hinterland will increase.

Q4. What do you think of the method that I chose to determine the fuel consumption? (Admiralty constant)

A4. Hans Hopman agrees with the method. Although it is a rough method with some noise, it is a good approximate. Also, the size increase is so big that you don't have another choice then making a rough guess.

Q5. How do you see the future of container shipping in 2066?

A5. Other than McKinsey, Hans Hopman does not foresee an increase in demand for container shipping. EDI will play a role in the propulsion installation of container vessels. Every 5 years, vessels need to reduce the CO2 emission with 10%. Different concepts of loading/unloading are expected

Q6. Do you have information available about vessel size, costs, fuel consumption, capacity etc.?

A6. No

Appendix B

Variable	Explanation
$TEU.50$	Capacity 50,000 TEU vessel
$TEU.oocl$	Capacity OOCL Hong Kong
lf, wf, hf	length factor, width factor, height factor
$Ut.l$	Utilizable length for container stacking
$Add.l$	Additional length: Length of the vessel that is not available for container stacking
$Length.50$	Length 50,000 TEU vessel
$Beam.50$	Beam 50,000 TEU vessel
$Draught.50$	Draught 50,000 TEU vessel
$Airdraught.50$	Air draught 50,000 TEU vessel
$Length.oocl$	Length OOCL Hong Kong
$Beam.oocl$	Beam OOCL Hong Kong
$Draught.oocl$	Draught OOCL Hong Kong
$Airdraught.oocl$	Air draught OOCL Hong Kong
$Dens.50$	Containers per m2 on 50,000 TEU vessel
$Dens.oocl$	Containers per m2 on OOCL Hong Kong
$\Delta St.h$	Difference in stacking height between 50,000 TEU vessel and OOCL Hong Kong

B1: List of variables linked to vessel dimensions

Variable	Explanation
$P.50$	Price of 50,000 TEU vessel in \$
$a0$	Base level: price OOCL Hong Kong in \$
S	Ratio of TEU capacity between 50,000 TEU vessel and OOCL Hong Kong
$a1$	Elasticity factor: Capacity in TEUs and purchase price

B2: List of variables linked to capital costs

Variable	Explanation
PR	Power requirement in KW
$\Delta^{\frac{2}{3}}$	Displacement factor in MT
v^3	Speed factor in Knots
C	Admiralty constant
BCS	Bunker consumption costs at sea in $
$SFOC$	Bunker consumption in kg per KW/hr.
BP	Bunker price per KG
LCs	Lubricating costs at sea in $
LF	Lubricating factor
FCd	Daily fuel costs at sea in $

B3: List of variables linked to fuel costs

Variable	Explanation
CS	Crew size
$a0$	Crew size OOCL Hong Kong
S	Ratio of TEU capacity between 50,000 TEU vessel and OOCL Hong Kong
$a1$	Elasticity factor: capacity in TEU & crew size
$Avsal.y$	Average yearly salary in $
$Crew.d$	Daily crew costs in $
$Totsal.50$	Total salary bill

B4: list of variables linked to crew costs

Variable	Explanation
$Vessel.L$	Vessel length
$Crane\ nr.$	Number of cranes per vessel
$Dens.50$	Containers/m2 50,000 TEU vessel
Dens.oocl	Containers /m2 OOCL Hong Kong
$L.50$	Length 50,000 TEU vessel
$L.oocl$	Length OOCL Hong Kong
$Or.50$	Required outreach 50,000 TEU vessel
$Or.oocl$	Required outreach OOCL Hong Kong
$STS.P$	STS crane purchase costs 50,000 TEU vessel
$Cap.STS$	Capital costs STS crane 50,000 TEU vessel

B5: List of variables linked to STS Crane

Variable	Explanation
$L.50$	Length of 50,000 TEU vessel in meters
$Quay.I$	Total quay investment in $
$Quay/m$	Construction tariff / quay meter
$Quay.C$	Daily total quay costs in $

Table B6: List of variables linked to quay costs

Variable	Explanation
$Yard\ OOCL$	Current Yard surface in m2
$Beam\ factor$	Increase in vessel beam
$Stacking\ factor$	Increase in vessel stacking height
$Length\ factor$	Increase in vessel length
$Beam.50$	Beam size 50,000 TEU vessel
$Beam.oocl$	Beam size OOCL Hong Kong
$Tier.50$	Tier size 50,000 TEU vessel
$Tier.oocl$	Tier size OOCL Hong Kong
$Row.50$	Row size 50,000 TEU vessel
$Row.oocl$	Row size OOCL Hong Kong
$Cap.Yard$	Daily yard capital costs in $
$\frac{\$\mathrm{T}}{\mathrm{Y.m2}}$	Tariff in $ per yard m2

B7: List of variables linked to yards

Variable	Explanation
$Extra\ depth$	Required extra depth to serve 50,000 TEU vessel
$Dr.50$	Draught of 50,000 TEU vessel in meters
$Current.Dr$	Current maximum draught per port in meters
$Dredge.I$	Total dredging investment
$Dredge.d$	Daily dredging costs
$\frac{\$T.dr}{m3}$	Tariff per m3 of dredging
$Surf$	Port dredging surface in m2

B8: List of variables linked to port dredging

Variable	Explanation
$Required\ exp.SC$ $Required\ exp.MS$	Required m3 to be dredged for serving 50,000 TEU vessels through the Suez-Canal Required m3 to be dredged for serving 50,000 TEU vessels through the Malacca Strait
$\frac{Dredging\ m3}{1ft.}$	The amount of m3 to be dredged to deepen the Suez-Canal/Malacca Strait with 1ft. over the whole length
$Dr.req$	Required depth to serve a 50,000 TEU vessel
$Dr.cur$	Current maximum vessel draught that can enter the canal
$Malacca.L$	Length of the Malacca Strait in meters.
$Suez.L$	Length of the Suez-Canal in meters
$Dredge.d$	Daily dredging capital costs

B9: List of variables linked to canal dredging

Appendix C

Crane type	Producer	Buyer	Year	Price
Super post-panamax	ZPMC	RSGT	2017	$ 8,750,000
Super post-panamax	-	OECD	2015	$ 10,000,000
Super post-panamax	ZPMC	Port Everglades	2017	$ 13,800,000
Super post-panamax	Konecranes	Port of Houston	2015	$ 14,000,000
Super post-panamax	ZPMC	Port of Cartagena	2017	$ 9,100,000
Super post-panamax	ZPMC	ADPC	2014	$ 9,333,333
Super post-panamax	ZPMC	Philaport	2018	$ 12,000,000
Super post-panamax	PMCM	Port of Miami	2013	$ 9,750,000
Super post-panamax	ZPMC	Port of Catona	2018	$ 13,000,000
Average price	-	-	-	$ 11,081,481

C1: Analysis on STS purchase prices

Ports	Terminal	Berth depth	Meters	Total m3	Total investment	Daily capital costs
Shanghai	Yangshan	17.5	4.11	14,882,027	$ 207,157,810	$ 62,431
Ningbo	NBCT	17	4.61	16,692,027	$ 232,353,010	$ 70,024
Xiamen	XICT	17.5	4.11	14,882,027	$ 207,157,810	$ 62,431
Yantian	YICT	17.6	4.01	14,520,027	$ 202,118,770	$ 60,913
Singapore	Pasir Panjang (T5)	18	3.61	13,072,027	$ 181,962,610	$ 54,838
Felixstowe	Trinity terminal	15	6.61	23,932,027	$ 333,133,810	$ 100,396
Rotterdam	Euromax ECT	16.7	4.91	17,778,027	$ 247,470,130	$ 74,580
Gdansk	DCT Gdansk	15	6.61	23,932,027	$ 333,133,810	$ 100,396
Wilhelmshaven	Eurogate	18	3.61	13,072,027	$ 181,962,610	$ 54,838
Total	-	-	-	-	-	$ 640,848

C2: dredging capital costs for 9 ports on the sailing route