Erasmus University Rotterdam

Erasmus School of Economics

Master Thesis Urban, Port and Transport Economics

On the impact of container megaships on Rotterdam's hinterland transport chain

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Date final version: 30-4-2020

Abstract

Since their introduction, container vessels have always been increasing in size and capacity. The last ten years, however, have seen growth rates far higher than anything before. Logically, this increase in ship size has consequences for other actors in the transport chain: port authorities, deep-sea terminals and hinterland transport companies, among others. If the current growth rate continues, it is likely that vessels with a capacity of 30.000 TEU will sail in the year 2025. This research measures the time impact ships of this size will have on the hinterland transport leg of the Port of Rotterdam. It is expected that the average call size of megaships will increase by 98,41%. Despite this higher volume, the impact on hinterland transport was found to be limited, as the infrastructure surrounding the Port of Rotterdam is sufficient to be able to deal with these increased peak volumes and the volume is spread out over different modes of transport. Most of the time cost associated with bigger vessels is a result of the longer period of time a ship spends at the container terminal.

Introduction

Container vessels have been growing steadily ever since their first introduction back in the late 1960's. Recent years have seen a dramatic splurge however: whereas it took nearly 40 years for ships to reach a carrying capacity of 10,000 twenty-foot equivalent units (TEU), it only took just over a decade to grow further to more than 20,000 TEU. Economies of scale are claimed to be the main driver for this growth. As the transport of containers is a service with little to no options of differentiation, competition between container liners is price-based. The result of this is that in order to make a profit, the costs of the carrier must be as low as possible. Consequently, vessels are growing in size to be able to carry more containers in a single haul, therefore spreading the transport costs over more containers.

When considering the rapid development over the previous ten years, it seems highly likely that this trend will continue in a quite similar manner. At the moment of writing, the world record for largest container ship has been breached: the MSC Gülsün has a carrying capacity of 23,000 TEU, surpassing its predecessor OOCL Hong Kong with a more than 1,500 TEU difference. It can be guessed that if this pace of growth will last, the current record will not stand for very long. A scenario in which a 30,000 TEU ship will be delivered in 2025 is ambitious, yet plausible, as sketched by McKinsey (2018). This would mean that the carrying capacity will grow with an additional 30% in the coming 5 years.

However, this vast increase in ship size does cause serious issues for other parties involved within the supply chain. For instance, deep-sea container terminals now must cope with ships over twice the size as compared to 10 years ago, resulting in hefty investments to be able to facilitate these vessels. These investments include, among others, more and bigger cranes, an increased depth of the water and a larger terminal yard to store the additional containers. When considering the scope of research, these investments will have to be enhanced even further. Additionally, the ever-growing number of containers being delivered to a terminal must also be dealt with. This means that higher volumes have to be transported from the seaside terminal to the hinterland as swiftly as possible. One can imagine the consequence hereof: more trucks, barges and trains will have to be deployed to deal with the goods that were off-loaded.

Logically, it will take more time for a larger volume to be handled. What remains unclear, however, is whether the time needed for transport will increase in a linear or in an exponential fashion. Consequentially, the research question of this paper is whether container mega-vessels will put a disproportional strain on the transport chain into the hinterland as a result of their higher peak volumes.

In order to formulate an answer to this research question, this thesis will try to quantify the time costs associated with these larger peak volumes, with a research scope limited to the Port of Rotterdam. It will only focus on one part of the supply chain, namely between transport leg to the hinterland. The actors involved in this scope of research are the hinterland transport modes trucks, barges, and trains. The paper is structured in the following way: first, a broad theoretical framework is provided, including a brief overview of the container industry and current and future developments within the sector. Chapter two encapsulates the utilised methodology to measure the impact of the megaships. Next, the results are provided, followed by their interpretation. The research is wrapped up with the conclusion and discussion concerning future research options.

THEORY

Historical overview

Containerization is a transportation technique introduced in the 1950s, solving some major problems at the time. First, the use of containers made it possible to (off)load several tonnes of cargo at once, making it a much faster and less labour-intensive process than it was before, when dockworkers carried the cargo by hand. Additionally, because the job became less labour-intensive, ports and terminals were less prone to union strikes, which, at the time, were quite common. Secondly, the large metal boxes protected the cargo from weather and stealing dockworkers, making it less vulnerable from damage and theft, lowering insurance premia and thus, lowering overall costs (The Economist, 2013). Thirdly and most importantly, the introduction of the container enabled a swift switch between different modes of transport, since the container could easily be moved from a ship directly onto a truck, cutting weeks off delivery times (Stopford, 2009). Despite the fact that sizeable investments had to be made in order to facilitate this new way of trading, these costs could be spread out over many units, making the per unit cost bearable. As a result of this faster, cheaper, and safer way of trading, volumes started to grow, and it was not long before ships started growing as well.

It is important to note that the rise in popularity of containers had an extra, far-reaching consequence. Since more and more goods were now getting transported in uniform boxes, the possibility of container liners to differentiate themselves rapidly became obsolete. In fact, only one deciding factor of differentiation remained: costs. And in order to keep these costs as low as possible, ships have become increasingly big over the years to profit from economies of scale.

Economies of scale

Figure 1 shows the development of the carrying capacity of the world's largest vessels, measured in twenty-foot equivalent units (TEU), the standard measure for a container. There are three main cost drivers indicated in the shipping industry: capital costs, operating costs and voyage costs (Stopford, 2009; Veenstra, 2018; among others). Capital costs are the costs associated with the purchase of a vessel, operating costs include salaries for the crew, insurance, administration and maintenance and voyage costs are the costs made when actually sailing the ship, boiling down mostly to fuel costs, but also including dues for canals and port-related tariffs.

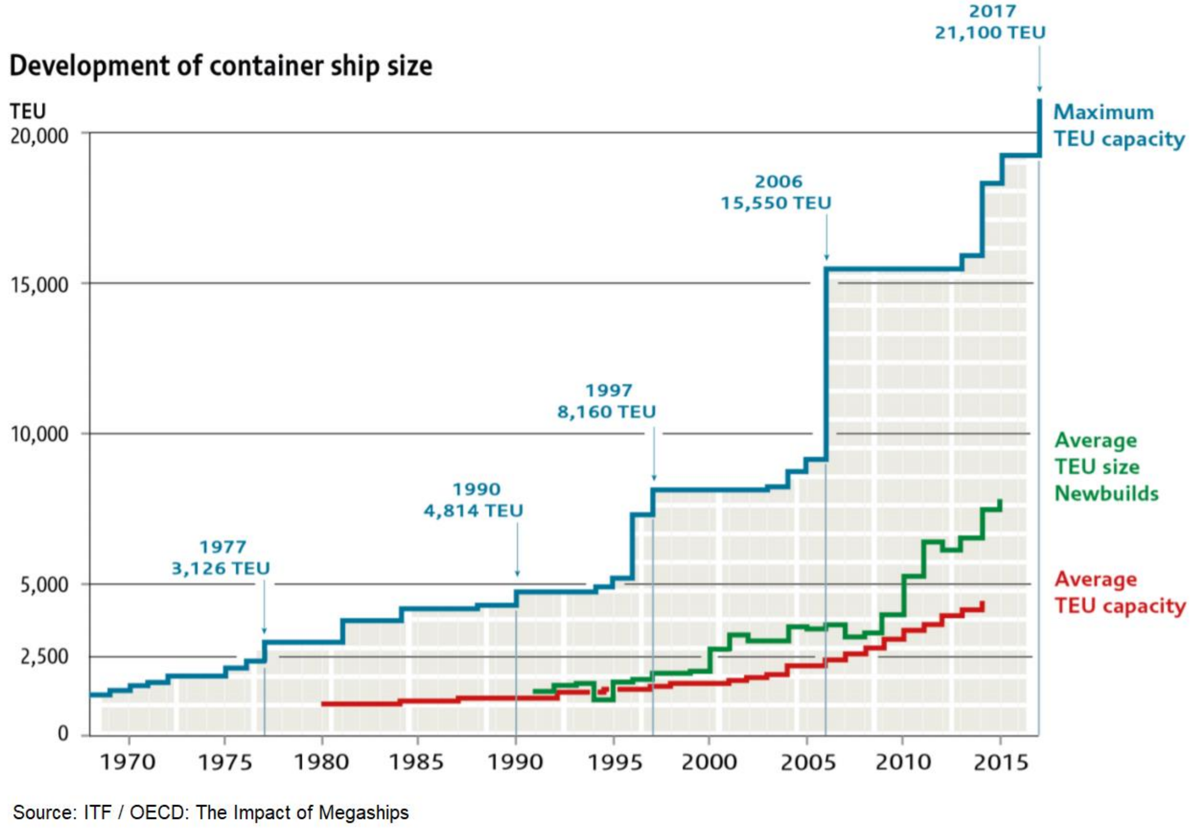

Figure 1 - Development of container ship size (Source: OECD, 2015)

Despite the fact that ships – naturally – become more expensive once they get bigger, the purchasing cost per TEU gets smaller. However, this is a decreasing function. Differently put, the cost advantage gets smaller if more TEUs are added, as can be seen in *figure 2*. Similarly, money can be saved on the crewing costs when ships increase in size. As it requires an equal amount of crew members to sail a 1,000 TEU ship as to sail a 20,000 TEU vessel, the same specific crewing costs can be smeared out over a twentyfold of containers (Malchow, 2017). This function is also asymptotic: a capacity-increase from 1,000 to 2,000 TEU lowers the costs per unit by 50%, the same increase from 19,000 to 20,000 TEU only brings a 5% advantage to the table. The same goes for fuel costs, as the specific propulsion power per TEU gets smaller when a vessel increases in size. Again however, this is a decreasing function, making the marginal benefit lower as the ships get bigger (Malchow, 2017). In fact, over half the costs saved on fuels were not a result of economies of scale, but rather due to more efficient engines (OECD, 2015).

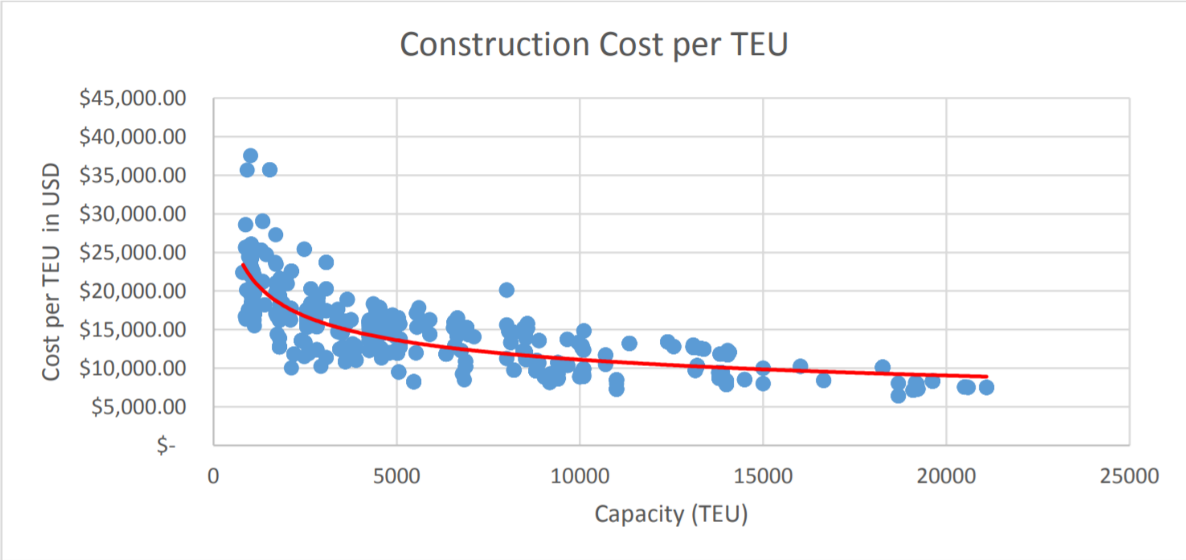

Figure 2 - Construction cost vessels per TEU (Source: USMMA, 2016)

Although the fact that the marginal benefits gained by using bigger vessels are decreasing is well-known and especially well-grounded in academic literature, container liners are still placing orders for record-breaking ships. In June 2019, the latest record holder, the MSC Gülsün, with a capacity of 23,000 TEU, had its maiden voyage. According to Nieuwsblad Transport (2019) another 32 ships of similar size are on their way. As said, the main reason for this continuous investment is to be found within the homogeneousness of the product, as the only way shipping lines can differentiate themselves from each other is pricewise (Wijnolst et al., 1999). As a result, they try to offer their cargo space as cheaply as possible, facilitated by the lower costs per TEU.

However, this search for the lowest costs per TEU has had its consequences. Because of the fact that mega-ships are ordered in increasingly rapid progression, the world's total fleet capacity has massively expanded in the past two decades. *Figure 3* displays the developments in worldwide capacity from 1996 to 2015. It is clear that up until 2007, the trading capacity and the actual trading volumes were highly correlated. During the financial crisis of 2008, trade volumes harshly decreased while capacity kept on growing, resulting in a massive gap between supply and demand, or, to quote the International Transport Forum / OECD, "ship size is completely disconnected from developments in the actual economy" (2015). Applying basic economic laws, it seems clear that freight rates have dropped since 2007, as supply is significantly larger than demand. Because of this, the profitability of container liners has decreased, in turn causing them to look for cheaper ways of offering their product, which is often an even bigger ship in order to bring down costs per TEU, leading to a vicious circle of overcapacity, lower freight rates and even more overcapacity.

Differently put, deep-sea container liners have to continuously invest massive sums of money to be able to offer their product at the cheapest rate possible in order to still attract new business, ultimately lowering the freight rates even more on the long term.

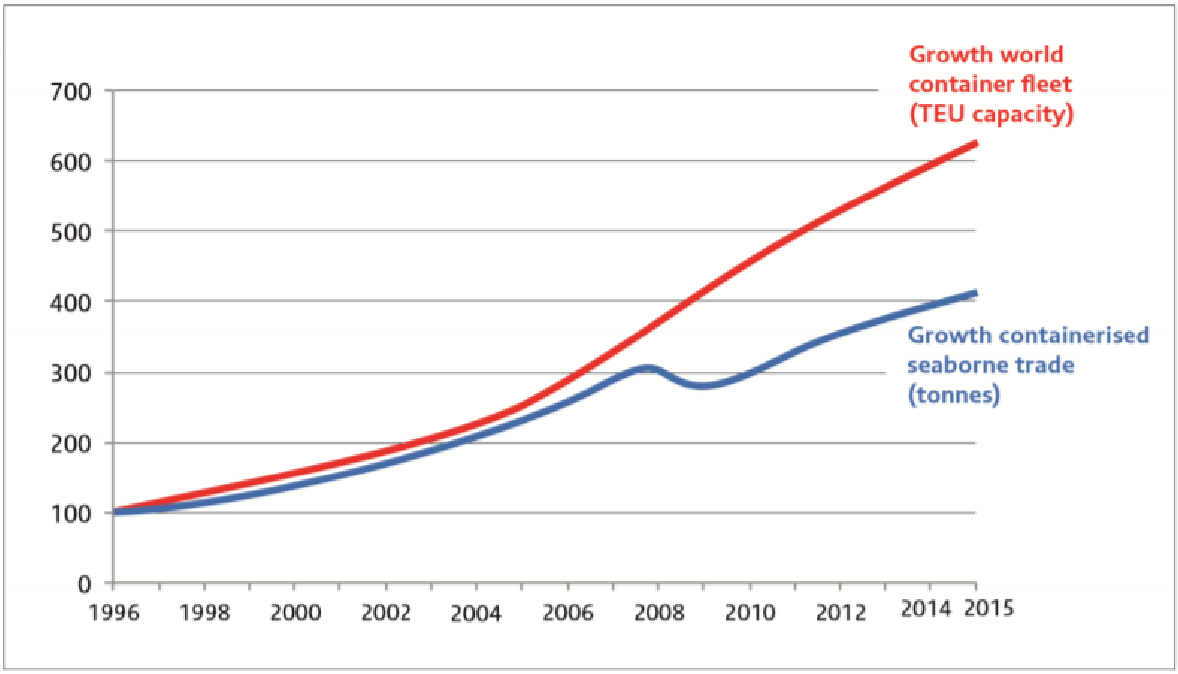

Figure 3 - Disconnection fleet capacity and trade volumes (Source: OECD, 2015)

Consequences megaships

Doing increasingly bigger investments for increasingly lower returns is one consequence of the growth in maximum vessel capacity, to be borne by the container liners. However, they are not the only actors who have to pay for the breakneck speed at which ships are growing. When merely discussing the dimensions of such a vessel, there are two crucial parties who will have to make significant investments as a result of its increased size. First, there are port authorities who want to remain competitive. In order to achieve this, they will have to take care of deep enough waters for the megaships to be able to arrive, regardless of tides (Merk, 2018). Dredging to achieve enough depth and later maintaining this can be a costly activity, costing around €12 per m^3 (ITF/OECD, 2015). While this might not seem as a lot at first glance, this number could rapidly add up when considering the length of quay walls, and, more importantly, rivers and access channels. In the case of the port of Antwerp for example, the distance from sea to port over the river Schelde is well over 60 kilometres long. This distance, combined with the fact that currently the maximum water depth independent of tide is 'merely' 13.10 metres (Port of Antwerp 2012; 2018) and that MSC Gülsün's maximum draught is 16.50 metres (MarineTraffic, 2020), makes it safe to state that could be highly expensive to stay accessible for megaships.

Secondly, deep-sea container terminals wanting to serve the new vessels are also impacted. In order to be able to attract the megaships, a multitude of investments will have to be done. The first of these investments is the purchase of ship-to-shore (STS) cranes. As a 30,000 TEU ship will naturally be larger than the current record-holder of 23,000 TEU, the cranes must have the means to reach out further than the ones which are in place now (Prokopowicz & Berg-Andreasse, 2016; Baik, 2017; among others). Additionally, as the new generation of ships will most likely also be longer than the MSC Gülsün, more cranes are required to serve it. A result of more and larger cranes is that they put a heavier strain on the quay walls. Consequentially, these will have to be strengthened to cope with their increased load (Merk, 2018; Park & Suh, 2019). Finally, the yards of the terminals also need to be expanded to temporarily store the increased number of freshly offloaded containers (Van Saase, 2018).

It is essential to note that even though these investments can rapidly add up to tens of millions or even hundreds of millions of euros, port authorities and terminals are practically obliged to make them. The reason for this is as simple as it is unfair: the shipping lines have the dominant position within the supply chain. If a port authority or terminal is not willing to invest enormous sums of money to serve the megaships, the shipping lines can easily choose to skip the respective port, making it lose all of its business with said shipping line. Since the three main shipping alliances (2M Alliance, Ocean Alliance and THE Alliance) together control over 80% of the total global trading volume (Van Donge & De Roo, 2019), the impact of losing business with one shipping line (which in practice would boil down to one shipping alliance) can be imagined. Merk (2018) noted that the risk of so-called port shifts is vast, as shifts of over 1 million TEU are no exception within the Hamburg – Le Havre range. This illustrates the need for ports with contestable hinterlands to adhere to the shipping lines' requirements.

The result of the growth of container vessels for port authorities and terminals is thus again the same as it was for the container liners themselves – having to do sizeable investments in order to remain in business.

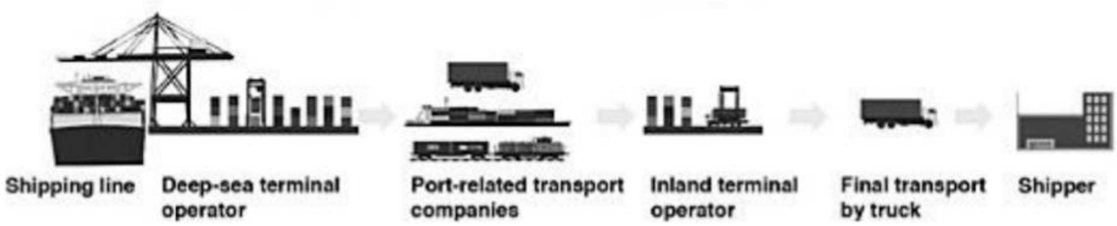

Figure 4 - Main actors in the container supply chain (Source: Nijdam & Van der Horst, 2018)

Whereas the previous paragraphs dealt with the upfront investments of the ability of handling megaships, there is also an operational side to the process. *Figure 4* provides a schematic overview of the actors involved within the container supply chain (Nijdam & Van der Horst, 2018). Larger ships mean larger peak volumes to be dealt with, as slot utilization in (mega)ships is an essential factor in the ability to fully reap the benefits of the economies of scale (Grimstad & Neumann-Larsen, 2013; Lu & Yeh, 2019). When discussing volume issues, the parties are impacted slightly different. Deep-sea container terminals have to handle increasingly growing volumes, resulting in ships that are moored for longer periods of time, occupying more cranes to unload them (Slack et al., 2018). It is possible likely that these volumes grow disproportionately, for multiple reasons. First of all, only a few ports are able to facilitate ships with a capacity of 30,000 TEU. Imai et al. (2011) and Lu & Yeh (2019) confirm that mega containerships indeed have fewer calls as a result of their size. Secondly, Notteboom (2006) identified terminal operations as the number one source of delays in a ship's sailing schedule. In order to reap the most of the cost benefits associated with their size, deep-sea container ships spend as much time at sea as possible by sailing more in a hub-and-spoke network. Consequentially, the number of ports of call of the megaship will be lower, therefore increasing the call size (Davidson, 2015; Pinder, 2016). This expectation is in line with Park & Suh (2019), who estimate that if a vessel's capacity increases from 15,000 to 22,500 TEU, the number of lifts per call (LPC) more than doubles.

Furthermore, various studies have been conducted to investigate the effect of a larger ship on terminal productivity, with an overall lower crane productivity as a common result. This is a consequence of the larger distances the cranes have to cover from ship to shore, decreasing the handling speed and therefore lengthening a vessel's stay at berth (ITF/OECD, 2015). Unfortunately, this problem cannot be fully tackled by simply adding more cranes, as these show decreasing marginal returns to scale – once a certain number of cranes has been reached, they start to get in each other's way (Ducruet et al., 2014). Another factor contributing to a longer turnaround time is the ad hoc stowage in the exporting region. As a ship is bigger, it needs to collect containers from multiple sources, resulting in a sub-optimal stowage (Haralambides, 2019). This ad hoc stowage has consequences in the port where the ship offloads. Mongelluzzo (2015) noted that there is an "extraordinary randomness of container discharges" as a result of the increasing ship size. The importance of proper stowage was quantified by Comtois & Slack (2019), who showed that significant differences in turnaround time exist between container liners regardless of terminal conditions, thus leaving room for improvement in stowage planning. This importance was confirmed by JOC (2014), who showed that the world's best performing ports worked with pre-received stowage plans in order to plan the STS cranes' usage as efficiently as possible. The results of these issues add up disproportionately: according to the UNCTAD (2017) the time at the container terminal increases with 2.9% for every 1% increase in ship size.

It turns out then that there is general consensus in the literature that, in addition to spending large sums of money to remain in business, deep-sea container terminals also experience negative operational effects as a result of the growth in ship capacity.

Hinterland transport companies can also feel the consequences. The larger a container ship is, the more prone it becomes for delays, either at sea or at terminals, with the volumes impacted getting bigger. This proneness for delays is the result of several factors. Firstly, because of the consolidation of freight in the exporting region, the reliability of the ship's sailing schedule depends on its feeder loops (Notteboom, 2006), which are higher in number than with smaller ships, leading to more potential sources for a late departure followed by a late arrival. Secondly, the previously mentioned ad hoc stowage results in more moves per call, therefore increasing the time a ship spends at berth. Notteboom (2006) identified terminal operations and -congestion as a major source for unreliability in a ship's schedule. Thirdly, shipping lines are usually not willing to increase their sailing speed to mitigate the effects of earlier delays. In fact, they rather employ the practice of slow steaming in order to save on bunker costs (Finnsgård et al., 2018).

As a result of this higher proneness for arriving late, transport planning becomes more difficult because the exact time and date of pick-up becomes increasingly uncertain, leading to inefficient use of the transport companies' assets. According to Murphy (2018), only 65% of deep-sea container ships arrived on time in 2018. The fact that these delays affect large volumes, are illustrated by JOC (2014), who state that over half of the arrivals of ships with a capacity of 10,000 TEU or more are delayed by more than 12 hours.

Barging companies are facing an extra problem. Often, they are getting served at the same quay walls as the container mega-vessels (Streng & van Saase, 2019). This has two consequences: first, the employment of the same cranes for container liners and barges leads to a much lower productivity, as these cranes are actually too large to serve barges. Secondly, if a barge is being served and a container mega-ship arrives, the barge will have to leave its spot in order for the container liner to be served. This has two reasons, being the fact that a delay of the container liner has a bigger impact on the rest of the supply chain and that container terminals often have a negotiated contract with the shipping company, as opposed to the barge company. This is an extra incentive for terminals to give the mega-ships priority over barges (Van der Horst & De Langen, 2008). The quay-sharing problem barging companies face can be tackled by introducing barge-only quays, something which the Port of Rotterdam has already done in their expansion of the Maasvlakte area. For example, the Rotterdam

World Gateway (RWG) terminal has a barging quay of over 500 metres long, resulting in undisturbed serving of the inland vessels (RWG, 2018).

Additionally, a consequence of growing volume leads to more containers which have to be picked up from the terminal shortly after unloading. Especially when combined with less precise planning, this can lead to congestion and longer waiting times at the terminal. This has been researched and quantified by Jansson and Schneerson as far back as 1982, who applied queuing theory on the container terminal, thereby quantifying the costs incurred.

Again, there seems to be ample literary support for the negative consequences for the hinterland transport companies. These are mostly the result of planning issues, leading to longer waiting times and therefore inefficient use of assets for barge and truck operators.

The final impacted actors are the consignees. As mentioned earlier on, seagoing ships require a certain utilisation rate to exploit their economies of scale. If bigger ships are used yet are not fully utilized, the cost per TEU will rise rather than fall (Willmington, 2002; Grimstad & Neumann-Larsen, 2013). As this is something shipping liners want to avoid at all costs, it is likely that they will 'scrape' cargo off other ships in order to load the 30,000 TEU ship as full as possible, to still be able to offer the lowest possible cost. As a result, it can take longer to find enough cargo for a vessel before it can sail, meaning that the frequency at which container liners call at ports becomes lower unless there is a massive surge in cargo demand (van der Jagt, 2003; Davidson, 2015). The lower frequency of calling is an ongoing process. Merk (2018) noted that the sailing frequency on the Asia – Europe trade lane has been decreasing for some time already, steadily dropping from 38 weekly services in 2013 to 33 in the year 2016. This lower frequency makes it more difficult for the final customers to adhere to a just-in-time strategy. As a result, companies will have to keep larger inventories, making their inventory costs more expensive (Haralambides, 2019). In fact, the lower frequency and increased unreliability of the shipping lines has led to some companies redesigning their products in order to reduce their lead time (Finnsgård et al., 2018).

As mentioned in the introduction in this paper, the scope of this research limits itself to the hinterland leg of the transport chain, i.e. the moment a container is picked up from the terminal to the delivery to the shipper. The reason for this is that most previous research concerning mega-vessels focused themselves either on technical feasibility of the ships (such as Wijnolst et al., 1999), on the potential economies of scale of operating such a vessel (Imai et al., 2006) and on the disadvantages and costs for deep-sea terminals and their respective operations (Van Hassel et al., 2016; Musso & Sciomachen, 2019). Papers exploring the cost-side of the hinterland transport leg were rather limited but included

Grosso (2011) and Blauwens et al. (2012). However, these papers were not applied to increasing peak volumes.

Upfront, the expectation is that larger ships will not necessarily put a strain on the hinterland transport leg which is disproportional to their carrying capacity. Whereas the consequences of bigger vessels have been proved to be mostly negative for other parties than the container liners, both upfront and operationally, these seem to limit themselves mostly to terminal operations and waiting times. Concerning the actual hinterland transport itself, the growth in volume can be spread out over four different modes of transport, therefore mitigating the chances of severe delays for one specific mode. Secondly and perhaps most importantly is the fact that it is likely that as a result of the growth in ships, their calling frequency will go down (van der Jagt, 2003; Imai et al., 2011; Davidson, 2015; Merk, 2018). This gives the container terminals and hinterland transport modes the time to push the containers towards the hinterland, before a new vessel arrives, as shown by Musso & Sciomachen (2019).

Case study Port of Rotterdam

In order to formulate an answer to the research question of this paper, a case study is performed based on the Port of Rotterdam. There are several reasons why Rotterdam is the focal port here. First of all, the problem at hand is highly significant for Rotterdam, since it is the biggest container port in the Hamburg – Le Havre range (Port of Rotterdam, 2019b). This means it is an often-used port of call for liner shipping. Additionally, especially since the expansion of the Maasvlakte II area, it is a port capable of receiving the biggest vessels without much trouble. Due to its location directly near the sea and the standards to which the expansion was executed, it can handle drafts of 20 metres independent of tides (Port of Rotterdam, 2019a). As a result of these facilities, it is almost certain that 30,000 TEU ships will call on the Port of Rotterdam.

Secondly, being so easily accessible also makes the Dutch city a popular choice as a first or last port of call on a roundtrip made by the shipping lines. The position of the first or last port of call is an advantageous one, as the volumes transferred from ship to shore and in reverse are often bigger than when being a ‘regular’ port of call (Port of Rotterdam, 2015a). This means if effects of larger volumes are present, they should be extra visible in Rotterdam. Moreover, being the first port of call gives a port the advantage of having the most accurate planning. This is the case as the vessel has had little opportunity to get delayed at other ports, but only at sea (Notteboom, 2006; Bell et al., 2013). Lastly, it is a port and hinterland area that is well known to the writer, which can ease the actual analysis – as the transport routes and bottlenecks are familiar from practical experience, the analysis can be executed in a more accurate way.

Rotterdam's hinterland and modalities

The consignees which could impacted by megaships arriving in the Port of Rotterdam are mostly located in the north-western part of Europe's mainland, or in other words, the hinterland of the Port of Rotterdam. *Figure 5* displays the weekly liner services of either barge, train or short sea shipping the NUTS1 regions have with each seaport within the Hamburg – Le Havre range, providing a fairly accurate depiction of each seaport's served hinterland. Although the graphic representation is from the year 2014, the general image still holds up. In the Port of Rotterdam's (2019c) annual report of 2018, it shows that although there are some shifts in each port's market share, these are not enormous, as can be seen in *figure 6*. Drawing from *figure 5,* it can be deducted with a reasonably high level of certainty that Rotterdam's hinterland served through the inland methods of barge, truck and railway transport, consists of The Netherlands, Belgium apart from Antwerp and Zeebrugge, and the Western part of Germany, as these locations cannot be reached through short-sea shipping.

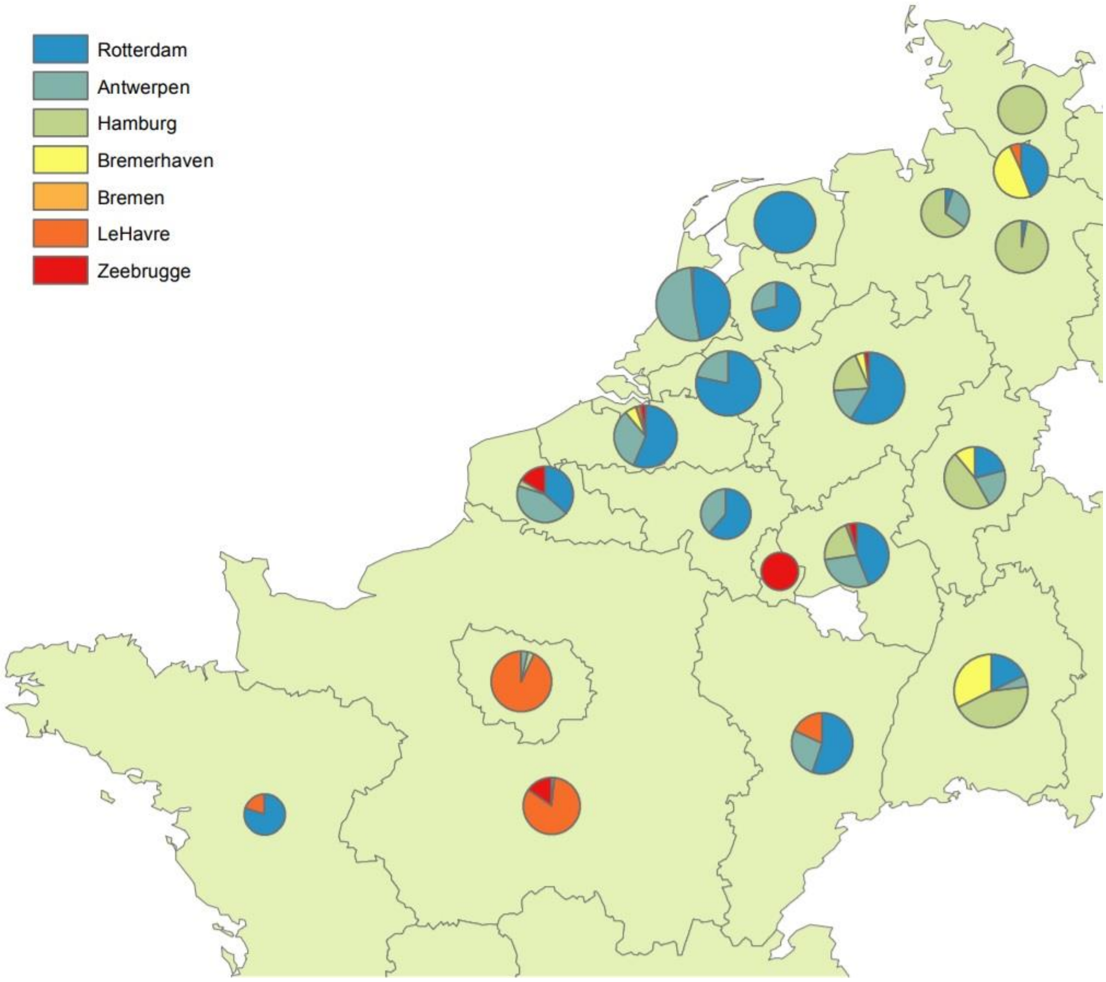

Figure 5 - Hinterland of the ports in the H-LH range (Source: KIM, 2014)

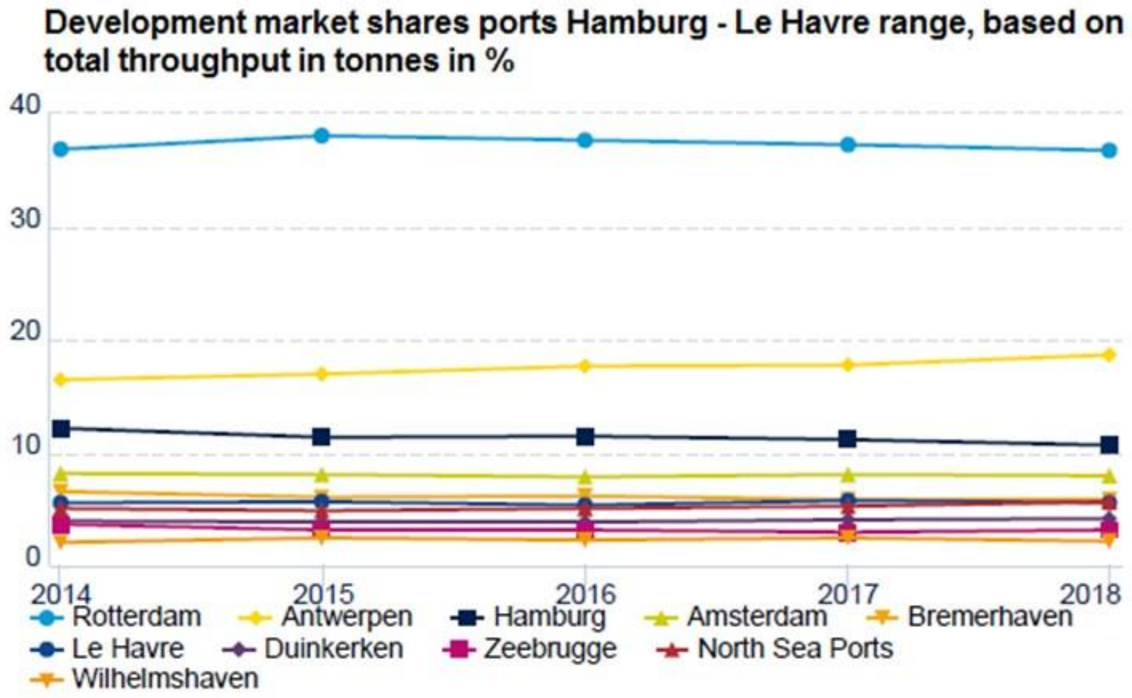

Figure 6 - Development market shares ports H-LH range. Source: Port of Rotterdam (2019c)

Naturally, one very import mode of transport is missing from these data, being road transport. Despite extensive efforts to decrease its importance, trucking has remained a crucial factor in processing the vast stream of containers entering Rotterdam. *Figure 7* gives a clear overview of the development of the modal split of goods transported inland from the port of Rotterdam for the period 2005-2017. Between the years 2009 and 2010, road transport's share decreased sharply by around 6.5 percent point, which was mostly compensated by a harsh increase in the portion of barges. However, since then, the segment of goods that was moved over the road has increased 1.5 percent point again, balanced by a decline in the use of inland waterways. Rail has always remained a steady factor, being constantly around a share of 6% of the total tonne-kilometres. This modal split provides an intuition of the modes of transport which are impacted most by increasingly large peak volumes, namely road- and inland waterway transport.

However, it is highly likely that this modal split will be different in the year 2025, as this is an important point of attention for the port authority. In fact, the Port of Rotterdam deems it so crucial to move away from road transport that they have used it as a condition in the terminals' bids for leasing land during the construction of Maasvlakte II. Contractually, terminals have to work towards a maximum of 35% of road transport in the year 2035 (Port of Rotterdam, 2013), resulting in a lower percentage for truck transport than is currently the case.

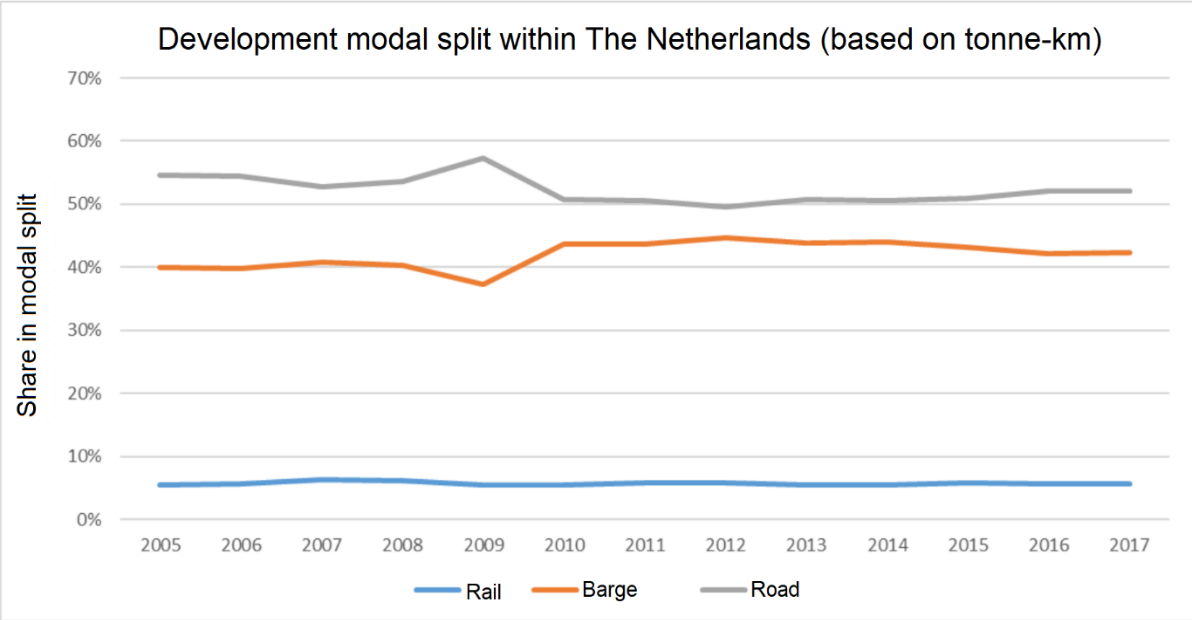

Figure 7 - Development modal split within the Netherlands (Source: KiM, 2019)

Each of the possible transport modes has their pros and cons. Transport through trucks is highly flexible and can guarantee an exact place of delivery, yet it is the most expensive option per TEU (Corman & Negenborn, 2018). Additionally, it has to make use of motorways, which are already quite crowded because of other road users. Finally, the number of containers one truck can carry is highly limited. Barges, on the other hand, can carry more containers in one haul and are relatively cheap, but their reach is limited because it is dependent on the availability of waterways. Other disadvantages are that it is a slow means of transport and that it is unreliable in time. The use of railways is also quite restricted, as the Dutch railways are very crowded and the 'goods-only' tracks only focus on the main routes towards Germany. Moreover, it cannot always reach the final destination of the container. What speaks for it, however, is the fact that it is a reasonably fast method of transporting goods and that it can carry more than a few containers on one train (Corman & Negenborn, 2018). *Figures 8* and *9* contain an overview of the two Dutch main freight corridors, known as corridor East, which follows the river Rhine and crosses into Germany at the border town of Lobith, and corridor Southeast, which is located more southward through the province of Brabant, crossing the border to Germany near the Dutch city of Venlo. The figures split the corridor into separate modalities, displaying the millions of tons transported through each mode, where road transport is indicated by the purple line, barges with a blue line and railway transport with a black and white chequered line. Naturally, not the whole volumes in *figures 8* and *9* consist of containers, but also of dry- and wet bulk, among others. It does, however, give a perfect visual representation of the most used exit roads departing from Rotterdam, along with confirmation that the first part of the route, being the A15 highway near Rotterdam and the Meuse river, is used for both corridors, making it a highly busy area. This makes the highway an ideal benchmarking location.

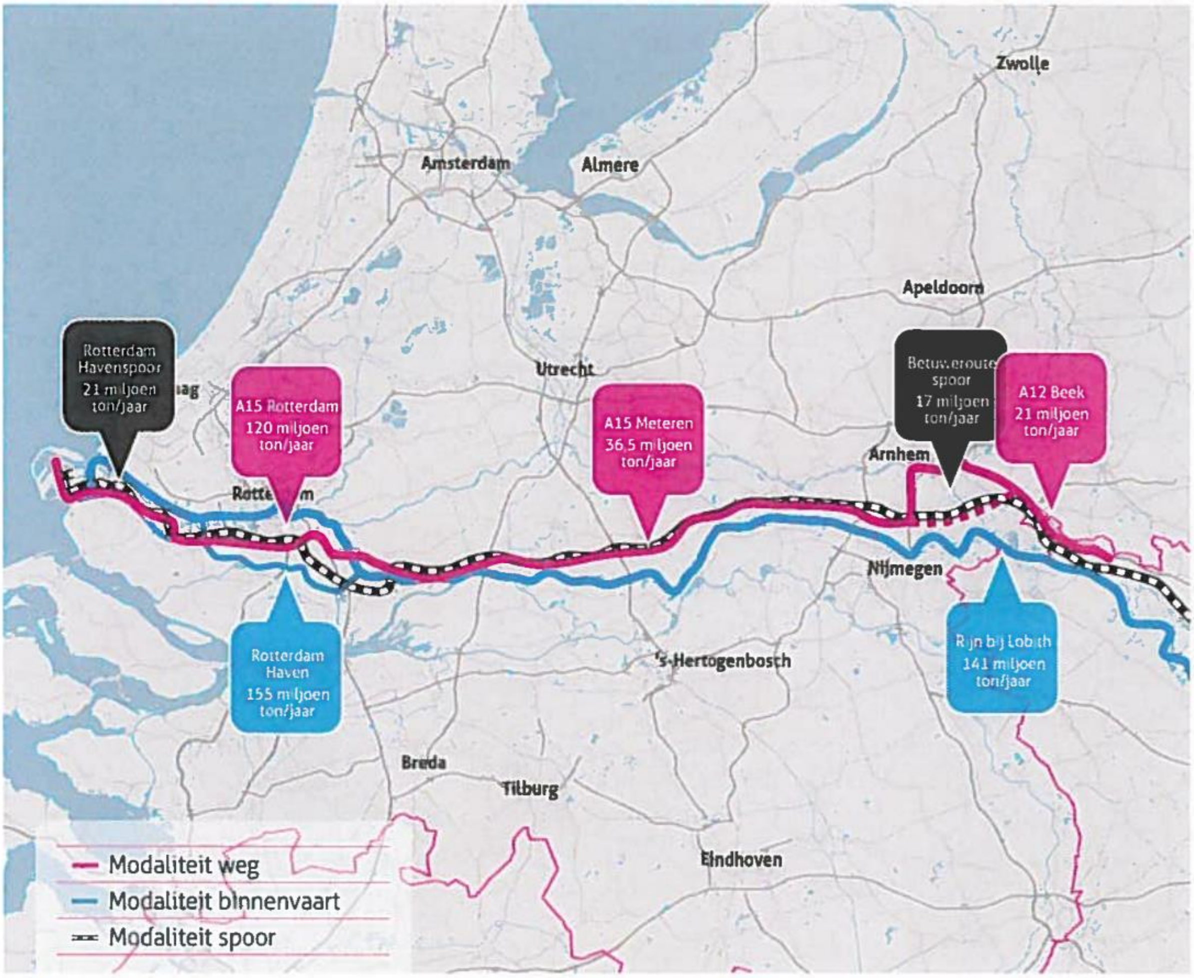

Figure 8 - Cargo corridor 'East' (Source: Ministry of Infrastructure and Environment, 2017)

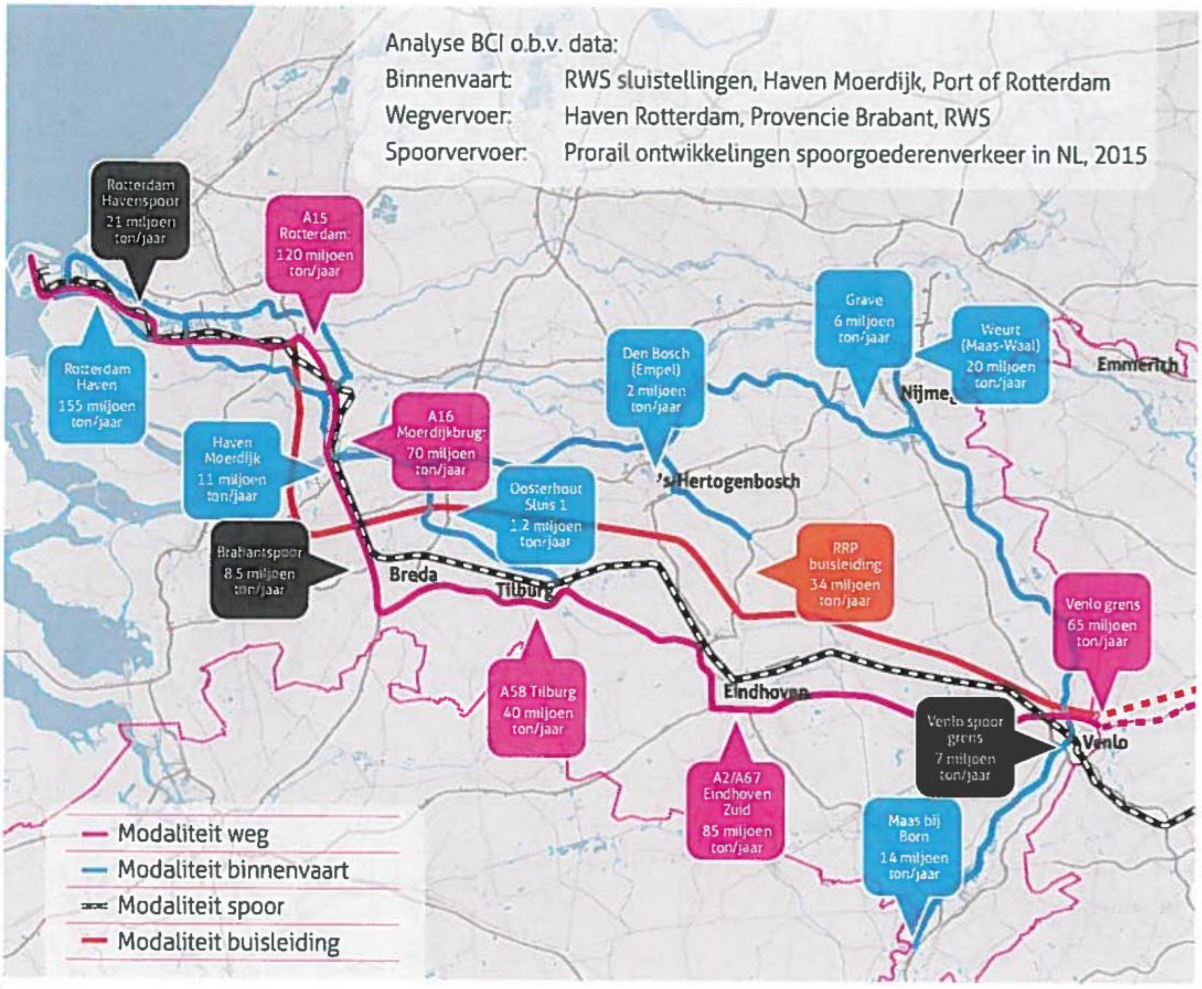

Figure 9 - Cargo corridor 'Southeast' (Source: Ministry of Infrastructure and Environment, 2017)

Road capacity

By now, it is clear that the A15 highway is an exit road for the Port of Rotterdam which is highly utilized. The question remaining now is whether the current situation can hold, or whether it is very prone to delays if the amount of traffic using the road will increase further. Urban economist Jan Brueckner (2011) developed a framework for highway congestion. The left graph of *figure 10* shows the average speed of a road. With the level of traffic T beneath a certain threshold, being $\overline{T}$ here, the average speed equals the maximum speed limit there. Once the level of traffic surpasses the threshold, the average speed decreases exponentially. The right part of *figure 10* provides a visual representation of what happens to the costs of using that very road then: once the traffic level moves past the road's capacity, the cost of usage increases exponentially.

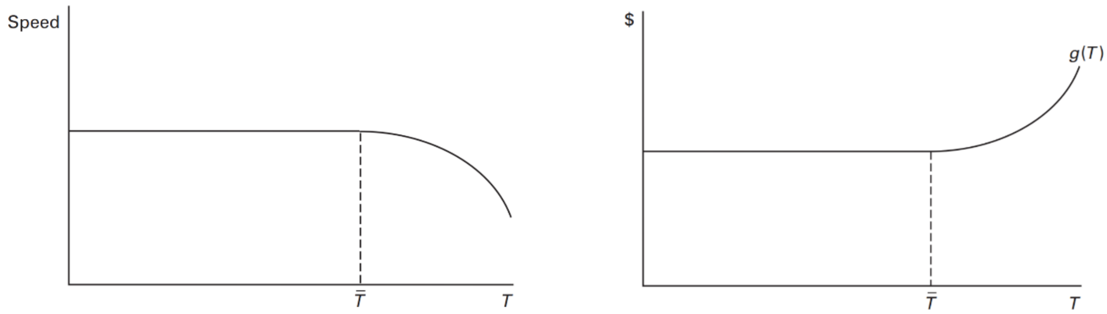

Figure 10 - Average speed and costs of road usage (Source: Brueckner, 2011)

With the amount of cargo that is already being moved over the A15, one can imagine that the additional traffic generated when handling the mega-vessel peak volumes will put an extra strain on the road. The question then is whether the road is built for this higher capacity, or whether the additional trucks will take the traffic level past the threshold.

A same situation can be sketched for the inland waterways, yet with a slight difference. On rivers, 'regular' congestion is not the first problem. Instead, this is the waiting times in front of locks. When a certain route is congested to such an extent that the number of barges waiting in front of locks cannot fit in the first available lock bay, the time a ship is idle will rapidly add up, with 45 minutes per lock bay easily (Rijkswaterstaat, 2010). *Figure 11* details the locations of the locks close to Rotterdam-oriented routes identified as (potential) bottlenecks in 2020 by the same Rijkswaterstaat (2010). However, four of the five issues occur in the route between Rotterdam and Antwerp, making it irrelevant for this research. The fifth, near the city of Nijmegen, is called 'Sluis Weurt', located in a canal between the rivers Waal and Meuse. According to the Dutch ministry of Infrastructure (2017), 20 million tons of goods pass the locks annually, while its I/C (intensity/capacity) factor has been identified as 0.6, making it a capacity bottleneck (Rijkswaterstaat, 2010). This means that waiting times are increasing exponentially with more ships arriving there, which is plausible given the fact that the number of barges will increase as well to deal with the new peak volumes.

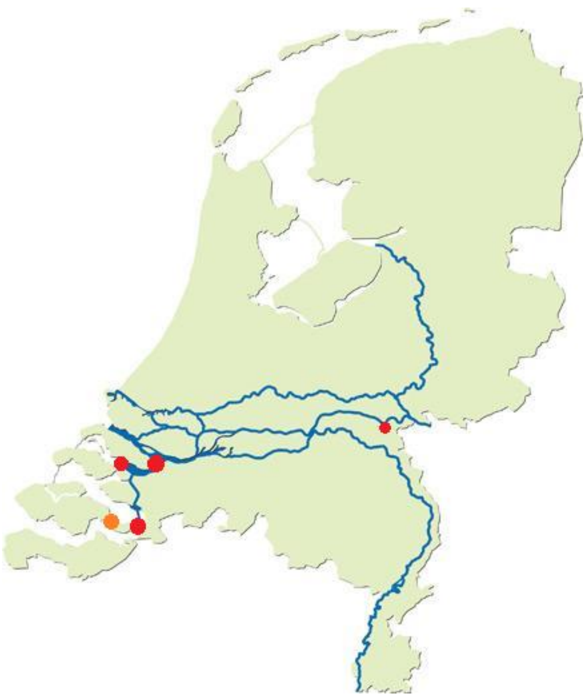

Figure 11 - Locks in the Netherlands

DATA AND METHODOLOGY

Introduction

In this chapter, the intended manner of research, the accompanying gathering of data and potential additional assumptions will be elaborated upon. In other words, everything that is needed to answer the research question of this paper, being “Will container mega-vessels put a disproportional strain on the transport chain into the hinterland as a result of their higher peak volumes?” will be explained. To serve as a prime example, the Port of Rotterdam will be used to investigate the effect of 30.000 TEU ships, as compared to the current maximum capacity of around 23.000 TEU.

In order to be able to formulate a thorough conclusion of this research, data about several specific topics needed to be gathered. When adhering to the order of the logistical process, the first thing to be determined, is the increase in the number of containers per call, as this would be the basis for all further calculations. This number is not only related to ship size, but also to shipping demand. The last factor contributing to the number of containers per call, is the effect of being the first or last port of call in a roundtrip.

The next crucial item is the time the container terminal is occupied with handling the vessel, which would be a result of both crane productivity and call size. Depending on this handling time is the assumption concerning the outbound flow of containers. Additionally, the shift in modal split has to be calculated. Current capacities of other modes of transport must also be known. For barge shipping, this includes waiting time at locks, road transport can be covered by road capacity and usage and train transport is likely to be restricted by the train tracks’ usage and the handling time.

In order to cope with the limitations of unavailable data and future predictions, several assumptions will have to be made. In table 1, an overview of assumptions can be found.

There is enough cargo to make 30.000 TEU ships sail fully loaded, but the calling frequency is lower.
The shift towards a maximum of 35% truck transport in the year 2035 is linear, with its share divided among barge and rail transport according to their current ratio.
One truck can transport one container (not considering the TEU-factor)
One barge can transport 120 containers (based on Ginckels, 2014; accounted for TEU-factor)
One train can transport 48 containers (based on Rail Cargo, 2010; accounted for TEU-factor)
Outbound flow of containers happens at the same rate as the inbound flow.

All trucks traverse the A15 highway south of Rotterdam, before splitting in the corridors East / Southeast.

Table 1 - List of assumptions

Data collection

As the data needed for this research is so diverse, the sources vary greatly. Numbers on crane productivity can be retrieved from news articles and/or the Port of Rotterdam. Figures regarding Rotterdam's modal split development are taken from the Port of Rotterdam authority and Kennisinstituut voor Mobiliteit (the Dutch institute for mobility). Goemans et al. (2011) offered clarity about the intended capacity of highways in their contribution to the Nationaal Verkeerskunde Congres (National Traffic Congress). CBS (2020) provided the number of registered vehicles in the Netherlands. Data on road usage was found using INWEVA, an initiative under supervision of the Dutch ministry of Transport. This same ministry is also responsible for the figures about lock times. Lastly, information regarding railway planning is taken from the Port of Rotterdam authority (2020).

Methods of analysis

In order to estimate the exact impact of container mega-vessels as accurately as possible, the first thing to determine is the number of extra TEUs it will deliver on its call in the Port of Rotterdam. As this data is nearly always confidential, no ready-to-use numbers are available. As a result, the call size will have to be estimated. This is a difficult estimation, as multiple sources contradict each other. Based on the data of a large European terminal operator, McKinsey (2018) found that a ship's capacity and its call size were only moderately correlated. On the other hand, IHS Markit (2019) claims that in recent years, call size growth is larger than the growth in vessel capacity, based on more than 450 container ports worldwide. This is in line with the earlier mentioned Park & Suh (2019), who estimate that if a vessel's capacity increases from 15,000 to 22,500 TEU, the number of lifts per call more than doubles. This presents several issues. First, it is not disclosed by McKinsey on which European terminal operator they have based their findings. As a result, it is not clear whether it is entirely applicable to the Port of Rotterdam, as this has a 'premium' position, often being the first (and last) port of call in the HLH-range. Secondly, as IHS Markit base themselves on so many container ports, their data can also not be fully applied to Rotterdam, since a call size increase in the #450 port in the world does not mean a similar increase in the #10 port.

At first, the most intuitive option was to go for the golden mean, meaning that an $x\%$ increase in a ship's capacity would cause the same $x\%$ increase in call size. However, this would neglect the fact that larger ships call on ports less frequently (van der Jagt, 2003; Imai et al., 2011; Davidson, 2015;

Merk, 2018) and that the call sizes therefore would increase exponentially. As a result, it is estimated that a 1% increase in ship size leads to a 1,7% increase in call size.

In their report *The Impact of Mega-Ships* (2015), the International Transport Forum (ITF) and the Organisation for Economic Cooperation and Development (OECD) conducted a thought experiment in which they based themselves on a call size of 3.263 TEU for ships of 19.000 TEU capacity in Northern European ports. This is a number which was confirmed as in line with reality for the Port of Rotterdam by a researcher connected to the Erasmus University in personal communication. In their footsteps, I will use these numbers as the basis for my own calculations.

This call size is expected to grow exponentially as compared to ship size. After determining the new call size (in TEUs), the number of containers needed will be calculated. This depends entirely on the so-called TEU-factor, which is the average number of TEUs per container. As there are both 20ft and 40ft containers in use, this number will lie somewhere 1 and 2, therefore making the number of moves needed lower than the increase in TEUs. With this new number of moves at the deep-sea terminal is combined the terminal's berth productivity, it should be possible to define the additional time needed at berth. However, berth productivity in the new situation is difficult to estimate, as three factors have a significant influence. On the one hand, crane productivity will most likely go down due to the larger distances it has to cover as the vessel is bigger, while on the other hand, more cranes can probably be deployed as a result of ship's increased length, leaving room for additional gantries. As any outcome here will be based on multiple guesses (ship dimensions, number of cranes, new number of moves per hour), it is at risk of losing touch with reality. Most importantly however, is that it is not known what the number of inefficient moves as a result of ad hoc stowage are. JOC (2014), Mongelluzzo (2015), Comtois & Slack (2019) and Haralambides (2019) all emphasised the effect improper stowage has on a ship's turnaround time. As the number of moves is an undefined amount higher than call size, it is safer to base berth time on actual numbers – in this case, that means that for each 1% increase in ship size, terminal time will increase with 2.9% (UNCTAD, 2017). The ground number for berth time which I will adhere to is found in the previously mentioned report by ITF and OECD (2015), being 23.6 hours on average for the call size of 3.263 TEU. This figure is more or less equal to a more recent research by Park and Suh (2019), who found that the average berth time for ships with a size between 10.000 and 20.000 TEU is 21.5 hours.

The next item is Rotterdam's modal split. As mentioned earlier, the port authority has contractually established a maximum of 35% of truck transport in the year 2035 (Port of Rotterdam, 2013). Whereas nothing has been made public regarding repercussions if this target were not to be achieved, still the current share of road transport can be assumed to decrease in the coming years, as at least an attempt to achieve the goal should be made. As already stated in *table 1,* the assumption is that this shift will occur in a linear fashion. Moreover, the decrease in truck transport will be proportionally divided among barge and rail, leaving shortsea shipping equal. With this new modal split, one can outline the number of containers that are transported through each mode. This, in turn, leads to a new amount of trucks, barges and trains necessary to carry away the freshly arrived cargo. Since it is unlikely that a barge or train will be loaded entirely with containers from the megaship, the number of vehicles necessary will be calculated twice – once with a load factor of 100% and once with a load factor of 60%.

After the required number of vehicles for inland transport has been established, the following step is determining what extra strain these would put on the exit roads. For trucks, this encompasses seeing if the road capacity is met as a result of the growth in the number of vehicles on the road, combined with the extra trucks needed for the new peak volumes and, if so, by how much it would increase the driving time. The road capacity is provided by Goemans et al. (2011) and data on road usage comes from Rijkswaterstaat (2019). The number of vehicles registered in the Netherlands is taken from CBS (2020). If in the new situation road usage exceeds capacity, the delay will be calculated Brueckner's framework. For barges, it is finding out if, and if yes, by how much they impact the travelling time to the hinterland in terms of berth time and waiting time in front of locks. Lastly, for trains, it encloses determining the current total of trains and whether the new, increased amount will put a significant strain on the number.

Evaluation of methodology

It is important to determine in what unit of measurement the additional cost will be expressed. Monetary value would be the most clear and intuitive one, but I foresee difficulties in specifying for instance a 45-minute delay of a container in its delivery to its final destination in euros. Hence, as an alternative, an expression in time seems more fit, as it is still rather intuitive and highly objective.

Furthermore, this manner of conducting research is based more on theory than on actual research. It was attempted to acquire an as high level of data as was possible, but it must be understood that a lot of information surrounding exact call sizes or crane productivity is considered sensitive and is therefore difficult to find.

Results

Number of containers

As said, the first point of focus is establishing the number of containers that is being handled at the Port of Rotterdam deep-sea terminals. This number is a product of the vessel size. The hypothetical

30.000 TEU vessel is 57,89% larger than the 19.000 TEU ship as calculated by ITF/OECD, as can be seen in formula (1). The accompanying increase in call size is computed by multiplying 57,89 percent point with 1,7, as was decided in the methodology. The results can be found in formula (2). This means that the number of TEUs which are being handled at the Port of Rotterdam is 98,41% higher than the previous 3.263 TEU, coming down to 6.474 TEU calculated in formula (3). In the year 2018, Rotterdam's TEU factor was 1,68, meaning that the current number of containers handled at the terminal is equal to 1.942. For the sake of continuity and ease, we will adhere to this TEU factor in this research, which means the number of containers handled when a 30.000 TEU vessel arrives, is equal to 3.854. For calculation, see formula (4).

$$\frac{30.000 - 19.000}{19.000} * 100\% = 57{,}89\% \qquad (1)$$

$$57{,}89\% * 1{,}7 \approx 98{,}41\% \text{ increase in call size} \quad (2)$$

$$3.263 \text{ TEU} * 1{,}9841 \approx 6.474 \text{ TEU} \qquad (3)$$

$$\frac{6.474}{1{,}68} = 3.854 \text{ containers} \qquad (4)$$

Consequences terminal

Logically, an important time-consuming factor of a larger container vessel for the terminal is the extra number of containers which must be offloaded. In formula (1), the increase in vessel size has been calculated already. Following UNCTAD's (2017) logic of a 1% increase in ship size leading to a 2,9% in time at berth, this time will increase by 167,88% (5), resulting in a new berth time of 63,2 hours (6).

$$57{,}89 * 2{,}9 = 167{,}88\% \; increase \qquad (5)$$

$$23{,}6 \; hours + 167{,}88\% = 63{,}2 \; hours \qquad (6)$$

Consequences hinterland

As stated earlier, the terminals capable of handling megaships are contractually bound to achieving a maximum of 35% of truck transport in the year 2035. This percentage is applicable only to the hinterland transport, therefore leaving shortsea shipping out of the equation. If the loss in road transport's share would be proportionally divided among inland shipping and rail transport, Rotterdam's modal split would develop in a way quite similar to the projection in *figure 12*. In order to get to 35% of truck transport in 2035, its share has to decline by just over 1% each year, starting in 2016, the year of the most recent, detailed modal split. In this same year, the ratio in the share of barge compared to train was 0.7735 to 0.2265. The loss in truck transport is divided according to this ratio among the two shipping modes.

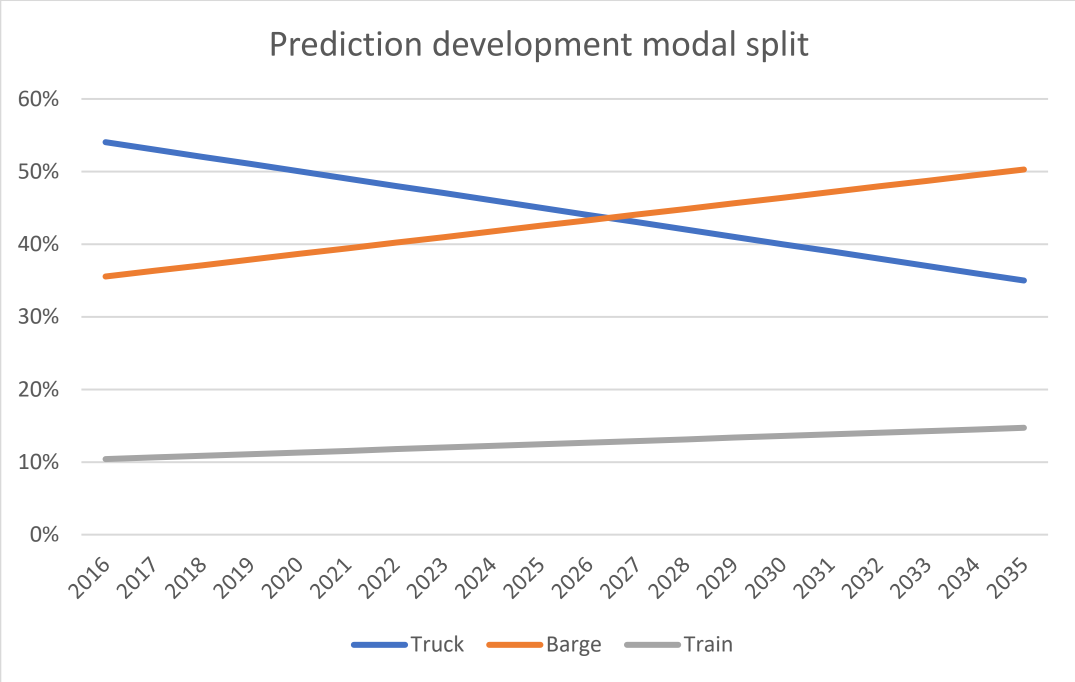

Figure 12 - Prediction development modal split. Source: own calculations.

When combining this shift with the percentage of goods transported through shortsea shipping, the new modal split is comprised of 31.2% truck transport, 29.4% of transport by barge, 8.6% by rail and 30.8% through the earlier mentioned shortsea shipping.

When applying the Port of Rotterdam's new modal split to the new number of containers, the additional volume of each transport mode can be easily calculated. With the split combined with the earlier calculated additional volume of 3.854 containers, the new number of containers per transport mode can be found in *table 2.* As stated before, the assumption is that one truck will transport one container, barges have a capacity of 120 containers (based on Ginckels, 2014) and trains can carry 48 (based on Rail Cargo, 2010). The number of additional vehicles necessary in order to transport the containers to the hinterland is also in *table 2*. This is calculated with a 100% load factor, meaning that a barge or train will be completely loaded with containers which have arrived with the 30,000 TEU vessel. Although this would be efficient for the container terminal, as the number of barges and trains is as little as possible, it is not very realistic. *Table 3* provides the more realistic image, based on a load factor of 60%.

Modality	Truck	31,2%	Barge	29,4%	Rail	8,6%	Shortsea	30,8%
No. of containers	1.202		1.133		331		1.187	
No. of vehicles	1202 trucks		10 barges		7 trains		N/A	
Vehicles/hour	19,02		0,16		0,11		N/A	

Table 2 - Vehicles per transport mode and hour at 100% load factor

Modality	Truck	31,2%	Barge	29,4%	Rail	8,6%	Shortsea	30,8%
No. of containers	1.202		1.133		331		1.187	
No. of vehicles	1202 trucks		16 barges		12 trains		N/A	
Vehicles/hour	19,02		0,25		0,19		N/A	

Table 3 - Vehicles per transport mode and hour at 60% load factor

As determined Goemans et al. (2011), a road's capacity is 2100 vehicles per hour per traffic lane. This number considers 15% of vehicles to be trucks. If this percentage turns out to be lower, the road's capacity increases. According to INWEVA, the dataset comprised of the road intensities in the Netherlands, measured by Rijkswaterstaat (2018), the busiest part of the A15 highway is between the nodes Vaanplein and Ridderkerk. At this particular stretch, an average of 8.165 vehicles passed the measuring point between 16:00 and 17:00 on a working day. Whereas this seems like a lot, the trajectory has six traffic lanes, making its theoretical capacity 12.600 vehicles per hour with 15% of trucks. However, out of the 8.165 passing vehicles, only 387 were trucks, which is equal to 4,7%. This means that the theoretical road capacity is even higher than 12.600 vehicles per hour, which is currently not met.

Before drawing conclusions, however, another factor must be considered, being the growth of the number of vehicles in the Netherlands. The Dutch Central Bureau for Statistics (CBS, 2020) provides the number of registered motor vehicles in the country. Between 2004 and 2018, this number has increased by an average of 1,35% per year. In order to thoroughly investigate the effect on the road, this growth should also be included. When the 1,35% is projected on the traffic on the A15, the new number of vehicles passing in the busiest hour is 8.853 of which 420 trucks, which still comes down to 4,7% of truck traffic. Despite including this general increase of traffic, the theoretical capacity of 12.600 vehicles per hour is still not met.

Based on the assumption that the outbound flow occurs at the same rate as the inbound one, if we were to add the extra trucks needed for the hinterland transport of the 30.000 TEU ship, the new ratio would be 439 trucks per 8.872 vehicles per hour, resulting in 4.9%. This is still way below the 15% benchmark considered in the calculation of the capacity, meaning it should not affect this in a negative way. Thus, even with the increased traffic intensity, the maximum road capacity is not met. Put differently, the additional number of trucks does not cause any extra delay in terms of road congestion or have any measurable time effect.

Table 2 also provides the extra number of barges necessary for hinterland transport, based on a 100% load factor. Once again assuming the outbound flow happens at the same rate as the inbound flow, one barge per six-and-a-quarter hours does not seem like a lot. If the load factor would be 60% instead of 100%, as is the case in *table 3*, the number of extra barges over a period of 63,2 hours would be 16, meaning one barge every four hours. As the locks of 'Sluis Weurt' already have an I/C-rate of 0,6, the waiting times for additional volume will add up exponentially. However, in practice, these effects will probably less negative, as Rijkswaterstaat (2010) notes that this factor is caused for a significant part by maintenance works at the river Meuse. It is highly likely that these works will be finished by the year 2025. As a result, the one foreseen bottleneck in the hinterland transport of barges turns out not to be a bottleneck after all.

The last mode of transport to be discussed is train haulage. As can be derived from *table 2*, the 30.000 TEU vessel will deliver 557 TEU to be transported by rail, which is equal to 331 containers when accounted for the TEU-factor. Combining this with the 48-container capacity as stated by Rail Cargo (2010), this comes down to a total of seven trains, considering a utilization rate of 100%. This is only three trains more than originally needed for the 19.000 TEU capacity ship. Currently, the Port of Rotterdam sees 434 railway shuttles depart each week (Port of Rotterdam, 2020). Three trains extra mean an increase of only 0,69% as compared to the current situation. If the load factor would be 60%, the number of trains needed is equal to twelve, which is an increase of six trains as compared to the 19.000 TEU container vessel with a train utilization rate of 60%. On a weekly basis, this means an increase of 1,38% in the number of departing trains.

Considering the fact that the Port of Rotterdam wants to steer away from road transport and wants to absorb this (partially) by freight trains, it is reasonable to assume there is enough capacity to do so. In fact, the port authority is investing hundreds of millions of euros to improve railway connections and punctuality (Port of Rotterdam, 2015b). Hence, it can be concluded that an increase of between 0,69% and 1,38% is possible without causing a strain on the capacity.

Interpretation

Beforehand, it was expected that the ever-increasing size of container ships would not cause disproportional strains for other modes of transport. This theoretical answer was based on three important factors. First is the fact that the negative effects as described in the theoretic framework seem to be mostly applicable on terminal operations and waiting times prior to the actual hinterland transport leg. Second were the different modes of hinterland transport: as the additional volume could be smeared out over four different modes, none of them would get into serious trouble. Lastly, for the 30,000 TEU ships to sail in a viable (i.e. highly utilized) way, calling frequency has to be lowered (van der Jagt, 2003; Imai et al., 2011; Davidson, 2015; Merk, 2018), giving the terminal the time to push the containers to the hinterland and avoid terminal congestion (Musso & Sciomachen, 2019). The results of this investigation seem confirm these expectations. It was calculated that the call size would increase with 98,41%. While this seems like a lot, in absolute numbers it comes down to just over 3.000 TEU. For a port with the infrastructure and capacities like Rotterdam, this turned out not to be a problem. At its busiest trajectory, road usage was still thousands of vehicles per hour under its maximum capacity. Similarly, the current main bottleneck for barges are maintenance works, which are well expected to be finished in the year 2025. For railway transport, the increase was limited to 1,38% as compared to the present situation. It seems then that the factors contributing to the theoretical expectation indeed caused the practical outcome.

What should be noted is that while the arrival of one 30.000 TEU vessel might not turn out to be problematic in the hinterland leg, it might become so if ships of this size would call on the Port of Rotterdam more often, thereby increasing the pressure on the (hinterland) supply chain. The same goes for if the call size turns out to grow with a factor larger than 1,7 relative to ship size, resulting in higher peak volumes. Similarly, a lower utilization rate of barges and trains results in more traffic on both the terminal as in the hinterland. Lastly, if terminal productivity would see a significant increase, the assumption that the outbound flow happens at the same rate as the inbound flow might put additional pressure on the transport chain.

Conclusion, limitations, and suggestions for further research

This research has been centered around the research question whether container mega-vessels will put a disproportional strain on the transport chain into the hinterland as a result of their higher peak volumes. The specific focus was on the transport leg of trucks and barges.

With the assumptions and variables used in this investigation, the answer to the research question is 'no, the strain on the hinterland transport chain is not disproportional'. Although the call size of a 30.000 TEU vessel increases with 98,41% as compared to a ship with a 19.000 TEU capacity, roads do not appear to get more congested as a result of an increased volume of containers, as they are still well under their maximum theoretical capacity during peak hours. Similarly, the transport leg of barges does not seem to be impacted as well, as the one identified bottleneck 'Sluis Weurt' is only a bottleneck due to maintenance works elsewhere. Lastly, the increase in train traffic seems to be neglectable.

However, some important remarks have to be made about this conclusion. First and most important of all, this research has a lot of uncertainty and is therefore based on a lot of assumptions. Whereas these assumptions are based on academic literature and actual numbers, they could turn out to be higher in practice. Most strikingly, a higher call size has a significant impact on the outcome of this paper.

This research assumes a constant outflow of goods after the container ship has been offloaded. This is not true to reality, as there are many issues to consider, such as vessels arriving late, limited berth space and peak hours at the terminal. As a result, the outflow may at times have a higher impact than projected here. Secondly, this research could not quantify the effect of being the first- or last port of call. If this were possible to do, the additional volumes the megaships offload could turn out to be significantly higher. Thirdly, it is also quite likely that the utilization of barges would be even lower than 60%, for example when they do not arrive empty at berth, or when the goods have a lot of different destinations, requiring more barges to get there.

It can be drawn from the above limitations that this subject is open to more research. One option would be to design a more detailed model of the terminal operations and potential delays there, such as containerships arriving too late, capacity problems with the loading and unloading of ships and the aforementioned peak hours causing additional issues. Another possibility is to add a time value to the possible delays. Moreover, this research is focused solely on the situation of the Port of Rotterdam, leaving the option wide open to conduct this study on other ports. Lastly, it is recommended to investigate the effect of being the first or last port of call in the Hamburg – Le Havre range in a quantitative manner.

Concluding, this is a study to determine whether there was noticeable effect in the arrival of a 30.000 TEU containership. Whereas this was not the case in this paper, the effect might be more present if the research would be conducted in a higher level of detail with more, hard to obtain data.

As a last remark I can say that even though the effect is not significant in this one case, this does not mean that container vessels can grow in an unlimited fashion, since sooner or later, the costs for other parties will actually start to rise sharply and even the shipping lines themselves will feel the consequences. As Panayides & Cullinane (2002), Notteboom (2004) and Kou & Luo (2016) noted, landside operations are vital in creating an ultimately successful network, with the potential of gaining a competitive advantage over rivals. It is now up to the shipping lines to do their part in ensuring that these landside operations can cope with the ever-growing volumes.

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