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Reference:

van Hassel Edwin, Meersman Hilde, Van de Voorde Eddy, Vanelslander Thierry.- Impact of scale increase of container ships on the generalised chain cost

Maritime policy and management - ISSN 0308-8839 - 43:2(2016), p. 192-208

Full text (Publisher's DOI): <http://dx.doi.org/doi:10.1080/03088839.2015.1132342>

To cite this reference: <http://hdl.handle.net/10067/1315000151162165141>

Impact of scale increase of container ships on the generalised chain cost

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Abstract

In recent years, an increase in the size of the container ships could be observed. The question is how these larger ships will influence the total generalised costs from a port of loading to a destination in the European hinterland. The second question is whether a scale increase of the container ships on other loops, such as a loop from the United States to Europe, has the same impact on the generalised chain costs as on the loop from Asia to Europe. A derived question is which element of the total chain has the highest importance, and whether this balance varies as ship size changes.

In this paper, a model is developed that allows answering the above research questions. The model is designed to simulate the cost of a complete loop of a container ship and of a chain that uses that same loop. For the chain cost simulation, the maritime part is determined by the loop. From the ports of loading and unloading, the port container handling and the hinterland transportation costs are also integrated. The model also allows calculating the total chain cost from a point of origin (either a hinterland region or a port) to a destination point (also a port or a hinterland region). An actual container loop of a container shipping company can be introduced in the model. An application is made to two existing container loops, namely from Asia respectively the United States to Europe. It turns out that changing ship does indeed lead to economies of scale, but also that the impact is larger on the Asia-Europe connection than on the

US-Europe connection. Furthermore, the maritime component has the biggest share in the total chain cost, but as ship size increases, the shares start getting closer to each other.

This research contributes to the existing literature in two ways. First of all, it quantifies the impact of the scale increase of container ships throughout the total chain. Secondly, this is done from a bottom-up engineering modelling approach.

Keywords: Maritime logistics chains, ports, hinterland transportation, container ships, scale increase

1. Introduction

In recent years, an increase in the size of the container ships could be observed. The average ship size has grown from 1,500 TEU per ship in 1996 to 3,200 TEU in 2013 (Figure 1). The currently largest container ships (8,000+ TEU) did not exist in 1996, and in 2013 there are 469 of those largest container ships representing a 4,693,040 TEU capacity. These larger ships (up to 18,000 TEU) have been mainly deployed in the loops from Asia to Europe. The orderbook in 2013 contains an additional 214 large container ships (8,000+ TEU) representing an extra 2,483,879 TEU loading capacity (Clarkson Research Services Limited, 2013). These ships will be added to the existing container fleet.

The question is how these larger ships will influence the total generalised costs from a port of call to a destination in the European hinterland. More in particular, the question is how the potential cost decrease per TEU during the maritime part of the chain will trade off with the total chain cost (including next to the maritime also the port and hinterland cost).

Figure 1: Evolution of container ship size

Source: based on data from Clarkson Research Services Limited (2013)

In this paper, a model is developed that allows calculating the impact of an increase in container ship size on the total generalized chain costs from a point of loading landside, via a port and maritime transport to another port and a point of unloading in a different hinterland. The generalized cost concerns costs to all actors involved, hence not only out-of-pocket costs, but also costs related to for instance speed and reliability. This means that the generalised cost is calculated as the sum of the total transportation cost plus the opportunity cost (determined by the transportation time and the value of time). For each part of the chain (maritime, port and hinterland) the generalized cost will be calculated, and through this also the total chain cost. Therefore, the model must take into account the total supply chain, including maritime transport, the port processes and hinterland transport and the linkages between those three. The main reason to lay the emphasis on the supply chain is that container liners and ports will compete along these supply chains. This is illustrated in Figure 2. The chain with the lowest overall generalised cost will be the most successful chain.

With this chain approach, it is possible to calculate whether the effects of economies of scale on the maritime part of the chain still have a positive impact on the total chain, including the port and hinterland sections; or whether they trade-off negatively in these other two sections, and what the resulting balance is.

Within this research, the two main research questions are:

- 1) What is the impact of a scale increase of container ships on the total generalised chain cost?
- 2) How does the increase of container ship size influence the cost ratio between the different chain elements (maritime, port and hinterland)?

Figure 2: Supply chain view on port competition

Source: Meersman en Van de Voorde (2012)

In order to answer these two research questions, first, a literature review is made in section 2. Next, a chain model is developed in section 3, which allows calculating the generalised cost of a several chains with different ship sizes. This model will be applied to two different container loops (Far East – EU and U.S. - EU) in section 4, focusing on chains having Europe as destination points, entering Europe through one of the Hamburg – Le Havre range ports. Finally, conclusions are drawn in section 5.

2. Literature review

In this research, the main focus is on the logistics chain, which consists of three main blocks, namely maritime shipping, ports and hinterland transportation, which are brought together into a logistics chain.

There is a large number of research initiatives concerning maritime transport, ports and port hinterland operations and the costs associated to them. It is not the aim to give a complete overview of this large body of literature. Reference is made to the work of Heaver (2006) where such an overview is given, stating that the port is part of larger logistics chains. This shows that the chain idea in relation to ports is not new and it shows the importance of integrating the various processes in the same chain. Modeling such an integrated chain, with the aim of applying the model to testing for economies of vessel scale, is exactly the aim of this paper.

A more classical but very relevant research is that by Jansson and Schneerson (1982). The book offers a detailed view on the manufacturing theory and application of queuing theory to seaports in order to calculate congestion and cost functions. Queuing is crucial to include in the model as it impacts on the interfaces between the maritime, port and hinterland segments.

Yeo et al. (2014) make a fuzzy logic analysis of port selection and port attractiveness from a shipping company point of view. They apply the method to the Northeast-Asian container ports, but the discovered selection criteria are relevant too to other port contexts, and for inclusion in a chain port cost structure component analysis.

Cullinane and Khana (2000) did research on the effects of economies of scale in the container industry. This research uses data from existing vessels (up to 8,000 TEU). It is very difficult to extrapolate this data for ships larger than 8,000 TEU. There is however a study on a larger, hypothetical, 18,000 TEU container ship, called Malacca-max container ship (Wijnolst et al., 1999). Both papers have in common that they include the port process of the ships in their analysis. In our proposed research, besides incorporating the port process, also the hinterland transport will be taken into account. The results of these studies will be used as benchmarks for the current research. Another relevant study on the optimal size of a container ship is by Sys et al. (2008). In this paper, it is determined till which size economies of scale can be achieved. It was concluded that this point is around 12,500 TEU's. However, it is there pointed out that the optimum size of a vessel 1) is not limited to a fixed point but that there is a range in which the optimum is located, and 2) it is not only determined by the efficiency to be achieved by a larger ship, but that other issues, such as circulation frequency, number of port calls and availability of sufficient demand also are very important aspects.

In Paz et al (2014), the further growth of container ship size is researched based on a Delphi method. The final conclusion of the research was that further growth of the ship size is related to the physical port characteristics (draught of the port waters, manoeuvring space in the port, quay wall length etc.). This research underlines the importance of integrating the port (including all its physical parameters) and the maritime transport in one total model. With respect to the hinterland transportation cost per transport mode, reference is made to Blauwens et al. (2012) where a generic cost model is used for the calculation of transportation costs. This cost model includes cost items related to the distance (kms transported) and cost items related to the transport time (hours consumed). This general model can be used for all three inland transport modes. In Grosso (2011), research was conducted on intermodal transportation for port hinterland transport in the corridor from Antwerp to Genoa. Within that study, the out-of-pocket costs for road, rail and inland waterways are determined. In this paper, a similar methodology will be used for the hinterland model. For all these modes of transport, also the intermodal costs, such as transshipment at an inland terminal, are taken into account. In Kronbak and Cullinane (2011), a visual representation of different port hinterlands is given. In that research, also a part of the maritime element and the port process is taken into account. However, in that study, these chain elements are simplified and differences in costs between ports are not (yet) taken into account. Also for the hinterland, only road haulage is taken into account, while in our research also rail and inland navigation transport are considered.

Along the side of the ship owners, there was in the past period a scale increase, initially through horizontal cooperation and/or mergers and acquisitions, and later on through ship owners

focusing on the terminal operations and hinterland transport. This is the result of the growing thinking in terms of complex logistics chains, in which each link should contribute to the optimization of the chain. The result was an increased market power of the shipping companies, through the market power of the total supply chains that they control (Meersman et al, 2010; Lam and Van de Voorde, 2011).

A further paper that is of interest with respect to integrating between chain segments is that of Moon and Woo (2014), who analyse the impact of reduced port dwell times on operational efficiency of ships. Through a system dynamics approach, they find out that more efficient port operations indeed contribute to better ship efficiency.

3. Modelling approach

3.1 Overview of the methodology

A model is developed that allows calculating the generalised chain cost from a selected point of origin, via a predefined container loop to the destination point. The model has been coded in C# and uses Microsoft Excel (data) and JMP11 (maps) as output formats. In order to calculate the chain cost, first, a container liner loop has to be defined. A loop is defined as a circle route of a ship from one port to the next - it has no beginning nor an end. This loop will determine the maritime part of the chain. Figure 3 presents the general overview of the developed model. The model is built up as a route builder for ships. This route builder connects different aggregated hinterlands via a route of ports (bold lines). The aggregated hinterlands are defined as a summation of different smaller geographical areas, such as NUTS-2 regions in Europe. In the aggregated hinterland, at least one but mostly more ports are located that can serve the same set of hinterland areas. Examples of aggregated hinterlands are mainland Europe or the United States. Once a ship is selected, the main dimensions (and related costs) are known. Based on the physical characteristics of the ship, a set of ports which can accommodate the selected ship are available. At current, the model encompasses 42 ports in total, on which the loop can be set up (see section 3.3).

Each port has a set of terminals which in their turn have an own set of characteristics, such as: allowable draught, navigation channel to enter the port, locks (if available), number of container cranes, etc. Per terminal, the total port entering cost can be determined. The reason to determine these costs at a terminal level is that port dues, tug boat cost, pilotage cost, etc. can differ between the different terminals in the same port (see section 3.4).

From each terminal in a port, the hinterland distances via road, rail and inland waterways (if available) are incorporated in the model. The distances are determined from each terminal in the

ports located in the aggregated hinterland to the different hinterland areas. The hinterland areas for now are defined as NUTS-2 regions¹ in Europe and in Great Britain. For the other aggregated hinterlands, introducing the hinterland areas is part of future research and model development. Using the hinterland distances, it is possible to calculate the hinterland cost per mode from a terminal to a hinterland destination by using generic cost functions (see section 3.5).

Figure 3: Structure of the model for a loop

Source: Own figure

A chain is defined as a route from a hinterland area in a specific aggregated hinterland to another hinterland area in another aggregated hinterland. A chain therefore has a beginning and an end. In order to calculate the generalised chain cost from a point a origin to a destination point, the model must not only calculate the generalised cost during the maritime phase, but it must also take into account the generalised cost of a container during the port phase (port dues, pilotage, container handling, time, etc.) on both chain sides, and the cost of transporting a container from a port to a hinterland destination on both chain sides. In Figure 4, the overview of the model is given when a chain calculation is made.

Figure 4: Structure of the model for a chain

Source: Own figure

As mentioned before, not all the aggregated hinterlands are yet fully developed. At this stage, the aggregated hinterland of mainland Europe and the UK are fully developed. In the example of Figure 4, the left side aggregated hinterland has no hinterland areas in the model. Therefore, it is not possible to select a point of origin there for now. In order to solve this problem in the current model structure, a port in that specific aggregated hinterland has to be chosen as a point of origin (for example Hong Kong in the aggregated hinterland of Asia). The aggregated hinterland in which the start of the chain lies is called the aggregated *from* hinterland, whereas the hinterland in which the end of the chain is defined is called the aggregated *to* hinterland. If a hinterland is part of the selected loop but is not selected to be an aggregated *from* or a *to* hinterland, then only the maritime cost is taken into account. In the aggregated *to* hinterland, all the possible chains are calculated. This means that from all the ports, that are part of the loop and that are located in the aggregated *to* hinterland, the port cost and the hinterland cost from the ports to all hinterland

¹ Nomenclature of Territorial Units for Statistics. NUTS-2 regions are areas where between 800,000 and 3,000,000 people are living. Usually, these are the provinces of the European Member States.

areas are calculated (250 NUTS-2 region in Europe). Due to the fact that all possible combinations are calculated, it is also possible to determine the lowest chain cost from a port of origin to all the different hinterland regions, including which ships, sailing routes, ports of call and hinterland modes to be chosen.

3.2 Input parameters

The input for the chain model consists of four main elements. The first desired input is a selection of an existing container loop. Secondly, a specific vessel needs to be selected that will sail within the selected loop. Thirdly, the size of the considered European aggregated hinterland must be chosen². The last element which requires input is the value of the goods transported in the containers. All these elements are further elaborated in the next sections. Based on this input, it is possible to simulate an existing container loop or to build one by oneself.

3.3 Ship model

The maritime model consists of three main parts: a routing module, a design module and a cost module. These three components are merged into an integrated maritime ship model. In the routing module, a maritime distances database was built to connect all the available 42 ports to each other. The design module is used to determine the technical parameters of the ship. Based on the results from the routing and the design module, the transport cost can be calculated in the cost module.

In the route model, complete loops from port to port are pre-programmed. The distances are determined by making use of AXSmarine (2013). These distances together with the given sailing speed will determine how long a specific trip will take and this will influence the level of the maritime costs.

The second major component of the model is the technical design model. In this model, the technical characteristics of the vessel are determined. The design model aims at designing a container ship with very limited "user input". The user input is limited to the desired main dimensions of the ship. This tactical design will contain information on the main ship characteristics, such as overall dimensions (L, B, T, D, C_b ³), installed power (including fuel consumption), propeller and bow thrusters, construction of the hull (based on Lloyd's) and tank plan (fuel, ballast and sludge). For each vessel size, it is possible to design a ship. These technical parameters of the ship are needed to determine whether a specific ship can enter a specific port, subject to for instance draught restrictions, quay lengths, etc.

² There is a choice for a core hinterland (direct hinterland of the ports in the Hamburg – Le Havre range) and the total hinterland.

³ L = Length of the ship, B = the width, T = the draught, D = the depth and C_b = the block coefficient

The design model that has been developed is a parametric design model. Several methodologies were developed in the past to design a ship, as indicated in section 2. In this paper, an engineering approach is chosen (Watson, 1998). This will allow designing different ships (even larger than 18,000 TEU) with the same methodology. The design model is programmed in a combination between Excel macros (calculations) and Rhino 4.0 (graphical output).

The last component that is included in the maritime model is the cost model. In this sub-model, all the relevant cost components are determined. These costs are split up into three main sub-groups (Drewry, 2005): operational cost, voyage cost and capital cost.

The operational cost of the ship size j (OC_j) is again split up into five different elements, which are all taken from Drewry (2005) and indexed to 2012 values by applying index numbers (Equation 1): crew (CC_j), insurance (IN_j), consumables (CON_j), repair and maintenance ($R\&M_j$) and management and administration ($M\&A_j$).

$$OC_j = (CC_j + IN_j + CON_j + R\&M_j + M\&A_j) \cdot \frac{DIST_k}{V_j} \quad (1)$$

All these costs are calculated on the basis of the size of the ship and calculated as a cost per hour. $DIST_k$ is to total sailed distance in nm for a given loop k and V_j is the speed of ship j in knots,

The voyage costs of ship size j (VC_j) are calculated based on Equation 2, including fuel (FC_j), lubricants (LUB_j), canal dues (CD_j) and port dues ($PD_{i,j}$).

$$VC_j = (FC_j + LUB_j) \cdot \frac{Dist_k}{V_j} + CD_j + PD_{i,j} \quad (2)$$

The fuel cost is determined by the cost of one tonne of fuel and by the fuel consumption of the ship. The latter has been calculated in the technical design model by using resistance predictions (Holtrop and Mennen, 1978), propeller calculations based on the Wageningen B-series propellers (Oosterveld en van Oossanen, 1975) and the engine characteristics (Wärtsilä data). The same goes for the cost of the lubricants. The channel dues for passing the Suez Canal are taken from the original published data.

The capital costs of ship size j ($CapC_j$) are determined by Equation 3, where $INTER_j$ is the interest cost and DEP_j the depreciation of the ship j . T_k is total time in days that a ship will spend on selected loop k .

$$\text{CapC}_j = (\text{DEP}_j + \text{INTER}_j) \cdot \frac{365}{T_k} \quad (3)$$

The total time includes the sailing time at speed V_j and the total port time in all ports. The port time in the Hamburg – Le Havre ports is calculated in the port model while the port time for the “other” ports is for now set at two days. As more specific data become available, these can be inserted. In order to calculate the depreciation and the interest, the price of the ship needs to be known. In Malligian (2006), a simple but effective model was developed to determine the newbuilding cost of a container ship based on the size (dwt) of the ship.

Finally, the generalised costs for the maritime component per TEU is calculated with Equation 4, in which $\text{GC}_{j,i,l}$ is the generalised cost per TEU for the maritime component per TEU with ship j from port of origin l to port of destination i .

$$\text{GC}_j = \frac{\text{OC}_j + \text{VC}_j + \text{CapC}_j}{N_{\text{TEU}}} + \text{VoT} \cdot T_{o,i} \quad (4)$$

N_{TEU} is the number of transported containers on ship size j and $T_{o,i}$ is the total maritime time from port O (origin) to port i in the Hamburg – Le Havre range.

3.4 Port model

A number of actors are involved in the port process. The process starts with a shipping company calling at a port and is ending with the hinterland transport company that will pick up the cargo at the terminal to transport it to the hinterland. This means that sailing in the port area to the different terminals is incorporated in the port model. There are several operators in the port process that will either work together in a chain (from top to bottom), or compete with each other (terminals). This means that it is possible to form as many chains as there are terminals in a port. These chains will have a large number of the total port cost items in common, such as the port dues (imposed by the port authority), pilotage and towage. But there are also differences among port costs. These are reflected by the different prices charged by the various terminals, and/or by different sailing distances in port to the terminals. This has been taken into account in the developed model.

All the relevant cost components that a ship owner will bear when a ship will enter a port are taken into account. The total port cost is built up of three different cost components: port shipping cost, port authority cost and the third party cost.

The port shipping cost is related to operating the vessel in the port. The port shipping costs are composed of the crew costs and the operating and maintenance costs of the ship while the ship is in a port (i.e. fuel consumption during the port stage and crew cost while the ship is at port). All these costs are made a function of the size and type of the ships that will enter the port.

The port dues are the dues that have to be paid by the ship owner to the port authority. Each port has its own system of setting charges, and hence, their value and the way of calculating them will vary from port to port. For each of the ports in Europe (10) and the UK (6), these costs have been modelled.

The last cost element are the third party costs. Three different types of third party cost are used in this research. First, there is the price to be paid for the use of a tug boat (depending on vessel type and size). Secondly, there is the price to be paid for the use of pilotage. The last element is the cargo handling cost. This is the price that has to be paid for handling the cargo in the port.

A generic port model has been developed which is built up from different container terminals. These terminals are connected by shared port infrastructure (locks and waterways). The different processes that take place in the port, and that are important for the treatment of a ship, are included in the developed model. This was done by applying queuing theory in the port process. There is queuing to pass the tide window, to pass a lock⁴ and there are queues at the terminals. Through queuing theory application, the linkages between different chain elements with varying capacity is taken into account. At the terminals, the process of loading and unloading the ships is modeled. First, the ship has to sail from the entrance of the terminal to the quay wall. The ship is moored and containers will be handled. The handling time is related to the number of cranes per ship length deployed and the nominal handling rate of the cranes. If more containers are handled (due to the increase in ship size) or when more container ships enter a terminal, the total handling time will increase. Therefore, the diseconomies of scale with increasing ship size in port is taken into account. So with this model, it is possible to calculate the total time and cost per ship for each terminal in the port and thus the generalised cost during the port phase.

3.5 Hinterland model

A hinterland model is developed that will be used to calculate the hinterland transport cost from the selected container terminals in the selected ports to in total 250 European hinterland regions, according to the mentioned NUTS-2 classification. The generalised costs of three different transportation options (road, rail and inland waterways) are calculated.

⁴ In reality, there will be no real queue in front of the locks. The ship's speed will be adjusted so that the ship will arrive at the lock when it can be handled. If there are a lot of ships that have to pass a lock, the speed has to be reduced further which will imply congestion. This additional time (congestion) will be modeled via a queue model.

In this model, the distances are determined from the various container terminals in the selected ports to the hinterland destinations. For all these regions, the distances for the direct road connections (to the centre of the region) and the inland shipping and rail connections to the various inland terminals are determined, hence explicitly including intermodal hinterland transportation. Also distances from the inland terminals to the centre of the various NUTS 2 regions are determined. These data was made available by the Port of Antwerp.

In Equation 5, the generalised cost per hinterland transportation mode can be calculated. GC_i is the generalised cost of transport mode i , OPC_i are the out-of-pocket costs of transport mode i , $C_{handling}$ are the handling costs per TEU, U_i is the total hinterland travel time and VoT is the value of time.

$$GC_i = OPC_i + C_{handling} + U_i \cdot VoT \quad (5)$$

On the basis of Grosso (2011), it is possible to calculate the out of pocket cost with a function that is based on time cost (h) and distance cost (d). This cost model is given in Equation 6 (Blauwens et al. 2012).

$$OPC_i = u_i \cdot U_i + d_i \cdot D_i \quad (6)$$

In this formula, u_i represents the time cost coefficient of mode i , U_i is time for mode i , d_i is the distance cost coefficient of transport mode i and D_i is the distance via mode i .

The time costs are the costs incurred by an inland transport mode as a result of the time passing by. These costs do not depend on the mere time spent by a transport mode, but on the total travel time (including waiting / congestion and loading and unloading). Also, the value of time is included and is set equal to the opportunity cost during the transport. The values of the goods in a container are difficult to determine, but O'Sullivan (2010) provided an overview of these values as a function of the different ports in which containers are loaded. The distance costs are added to the time cost and only depend on the actual moving through a hinterland transport mode. Fuel costs are a typical component of the distance charges. The distances needed in this calculation are obtained from the network model (3.5.2).

4. An Application to two existing container loops

With the developed model, two research questions stated in section 1 will be tested, each related to the two different case studies mentioned. The first case study is an application on the Far East – Europe trade. The second case study will focus on a liner route from the East Coast of the U.S. to Europe.

4.1. The Far East – Europe trade

In this first case study, for answering the first research question, a container loop of CMA-CGM is used (FAL 1 loop) (CMA-CGM 2013a). On this loop, ships with a loading capacity of 13,100 TEU are deployed that will sail at a speed of 22.5 knots and an occupation rate set at 80% of the nominal capacity. If the import port is set at Shanghai, the total generalised chain costs per hinterland region can be calculated.

In this analysis, the ship size varies from 4,000 TEU to 18,000 TEU. For each ship size, the total generalised chain cost is calculated, as is the ratio between the sea, port and hinterland costs. Since in the model, the generalised chain cost is calculated per hinterland region, a change in ship size will have an impact on all these regions. In order to create suitable graphs, an “average” of the 250 hinterland regions is determined. This “average” will be based on the hinterland container distribution per hinterland region from the six main container ports in the Hamburg – Le Havre range. The resulting container distribution can be observed in Figure 5. In this figure, it can be observed that most hinterland containers have a destination in the regions near the six main container ports.

Figure 5: Hinterland destinations for the Hamburg – Le Havre range ports (2014)

Source: Own figure based on data from Antwerp Port Authority

For each hinterland area, a weighting factor is calculated based on the total amount of containers that are transported to that specific region (f_j). When these factors are calculated, the total average chain cost can be calculated with Equation 7, in which AGC_i is the average chain cost from origin port i and $GC_{i,j}$ is the generalised chain cost from origin i to hinterland destination j :

$$AGC_i = \sum_{j=1}^n f_j GC_{i,j} \quad (7)$$

Figure 6 shows that the average generalized chain cost decreases as larger container ships are deployed. This decline is levelling off for vessels larger than 10,000 TEU. There is still a decline, but the decline is smaller compared with an increase in ship size from 6,000 TEU to 10,000 TEU. This is because the port cost component is only slightly influenced by the size of the ship, while the hinterland cost is not at all influenced by the size of the ship⁵: the latter cost remains constant. Therefore, the decrease in cost in the maritime part of the chain cannot be fully absorbed by the total chain.

⁵ In figure 6, there are two lines: an import and an export line. The difference between them is small. The reason for this is that the destination is set to be same as the import port. Also, the model chooses for each cargo flow the chain with the lowest generalized cost. This means that different ports in the Hamburg-Le Havre range are selected for the import and the export flows.

Figure 6: Influence of ship size on the average generalised chain cost

Source: based on own calculations

In order to calculate the composition of the different chain elements, Equation 8 is applied. In this formula, ACC_i are the average contribution per chain component from origin I to the total hinterland and the $CC_{i,j}$ is the percentage of the contribution of a chain element to the total chain cost from origin i to destination j .

$$ACC_i = \sum_{j=1}^n f_j CC_{i,j} \quad (8)$$

When Equation 8 is applied, the composition of the different chain elements can be calculated as a function of the ship size. The results of these calculations can be observed in Figure 7.

From Figure 7, it can be concluded that the average contribution of the sea component decreases from 68% for a ship of 4,200 TEU to 48% when a ship of 17,900 TEU is deployed. The influence of the hinterland is increasing if the size of the vessel is increasing (from 19% to 30%). These are averages and there are clear differences per hinterland region. The contribution of the port phase increases from an average of 14% to 22%. There is a clear trend where the contribution of the maritime part of the chain is decreasing while the importance of the port and the hinterland phase increases.

Figure 7: Composition of the generalised chain cost (import)

Source: based on own calculations

At this moment, average ships of 13,100 TEU are deployed on this loop. For the current situation, it can be seen that the contribution of the sea component is still the highest (54%). If larger vessels are used, this share will decrease. When ships of 18,000 TEU are deployed, the contribution of the maritime component will decrease to 48%, while the contribution of the port and the hinterland phase will increase to 22% and 30% respectively. These ships are now being constructed and being deployed (Marco Polo of CMA-CGM and the 3E's of Maersk).

4.2. East Coast U.S – Europe trade

The second loop that is being analysed, for answering the second research question, is the loop from the East Coast of the U.S. to Europe. For this case study, the CMA-CGM loop (Liberty bridge loop) is used (CMA-CGM 2013b).

On this loop, ships with an average slot capacity of 4,600 TEU are deployed (CMA-CGM). For the calculations, the ship speed is set at 22 knots and the ship is loaded up to 80% of its slot capacity. During the analyses, the port of origin is set at Miami. For this loop, the same kind of calculation is made as for the loop from the Far East to Europe. In Figure 8, the influence of the increase in ship size on this loop can be observed.

Figure 8: Influence of ship size on the average generalised chain cost

Source: based on own calculations

This figure shows that the average generalized chain costs decrease as the ship size increases, just like is the case on the Far East – Europe loop. However, this decline is levelling off as vessels larger than 4,400 TEU are deployed. This is due to the fact that the impact of the port and hinterland components is growing when larger vessels are being deployed.

There is an additional, green line in Figure 8. This line indicates the maximum ship size that can be deployed on this loop. The maximum allowable draft is still limited to 13 meters. This depth threshold is caused by the ports on the East Coast of the U.S. Therefore, on that route, no ship larger than 7,200 TEU can be deployed. So with the current infrastructure of the ports along the East Coast of the U.S., the ship size on this loop can be further increased from 4,400 to 7,200 TEU. The average generalized chain costs will then decrease from €1,019 to €931 per TEU (a decrease by 8.6 % compared to the current situation, in 2012 values).

If the port infrastructure of the U.S. ports is increased, for example as a result of the opening of the new Panama Canal, larger vessels can be used. As a result, the average chain costs can decrease further to €883 per TEU (a decrease of 13.3 % compared to the current situation).

In figure 9, the composition of the different chain elements is again calculated for this loop.

Figure 9: Composition of the generalised chain cost

Source: based on own calculations

From this figure, it can be observed that the average contribution of the sea component decreases from 58% when a ship of 2,200 TEU is deployed to 40% when a ship of 9,700 TEU is used. The influence of the hinterland is increasing if larger ships are deployed on this route (from 24% to 34%). The contribution of the port phase increases from 18% to 26%. The port phase has the lowest contribution to the total chain costs also with increasing vessel sizes.

At this moment, vessels averaging 4,400 TEU are used in this loop. For the current situation, the share of the generalized sea and hinterland costs is almost as large (48% for sea compared to 30% for the hinterland). So, for this loop, the hinterland and the port phase have a major influence on the total generalized chain costs and this influence increases when larger ships are being deployed.

5. Conclusions and further research

In this paper, the impact of the increase in container ship size on the generalised chain cost is researched. Also, the impact of a changing ratio between the three main chain elements (maritime, port and hinterland) was taken into account. In order to answer the research questions, a chain model was developed and was applied to two case studies.

Based on the results of the calculation of the two case studies, it can be concluded that the total generalised chain cost will decrease if larger ships are deployed. The decrease in chain cost is large when most of the generalised chain cost is determined by the maritime part of the total chain. This is especially the case for the liner route from the Far East to Europe. On this trade, the maritime part of the chain is the most dominant element of the chain. But now that the ships are increasing in scale, this dominant position is decreasing. As a result, the influence of the port and more even the hinterland is increasing. When ships of 18,000 TEU are deployed, the influence of the port and the hinterland phase are as large as the influence of the maritime section.

It is important to realise that most containers that are transported to the hinterland will have a destination near the six main container ports with a high concentration of containers in The Netherlands and Belgium and in the German Ruhr area. This means that the impact of the hinterland costs is relatively limited due to the fact that the covered hinterland distance is limited. A consequence is that the cost incurred during the port phase becomes more important.

On the liner route from the East Coast of the U.S. to Europe, the generalised chain cost also decreases with increasing ship size, although this decrease is smaller when ships larger than 4,000 TEU are being deployed, than in the Far East to Europe case.

The calculations have shown that the impact of scale increase is different on different routes. It is therefore necessary to treat each liner route separately. This will have two consequences.

First of all, the importance of the location and the availability of hinterland connections of a port towards its hinterland will increase. This can have a huge impact on port competition. It may seem that due to the increase of the scale of the container ships, port selection and competition could be more determined by the hinterland and the port phase rather than by the maritime part.

This aspect can be of great importance if the draught limitations of the ports at the East Coast of the U.S. will be increased due to the opening of the new Panama Canal. If larger ships can be deployed on the loop from the U.S. to Europe, the influence of the hinterland on the total generalised chain cost increases. Therefore, also the port competition in Europe can be influenced in this specific loop. Ports that are located further inland, such as Antwerp and Hamburg, can obtain a large competitive advantage.

Secondly, the shipping company is the most dominant player in the total chain. It will incur most of the cost. However, its position will decrease due to the deployment of larger ships. It can therefore be expected that shipping companies want to increase their power in the total chain by acquiring or establishing hinterland transportation companies. This vertical integration can be very important when deploying larger container ships if the shipping company wants to maintain its dominant position in the total chain.

The current research will be extended in the future. Extensions are planned in depth, in order to provide a more refined and qualified answer for specific trades, vessels, ports, etc., and in width, so as to cover more routes, ports and hinterland areas. When these extensions are implemented, a more refined and extensive analysis can be made for more trades, and looking at the impacts of specific chain cost elements. Furthermore, applying a similar chain approach to other commodity types (dry bulk, liquid bulk, etc.) can be very useful.

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