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Flexibility in Port Selection: a Quantitative Approach using Floating Stocks

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Abstract

Ports provide a number of logistical choices concerning storage, onward transport, and postponement. We investigate the routing flexibility offered by ports with a central location with respect to the hinterland. This flexibility is investigated using an illustrative case in which a number of alternative strategies are evaluated by means of simulation. Detailed cost data was used for the illustrative case. The combination of a simulation model and detailed cost data allows us to quantify the value of the rerouting flexibility. A combination of using regional distribution centers and a European Distribution Center results in the lowest cost per container.

Keywords: Supply chain, Floating Stock, Intermodal Transport, Port Selection, Inventories.

1 Introduction

Academic research on ports has evolved from a focus on the physical infrastructure to the supply chain perspective, where a port is seen as a node in the supply chain network. Robinson (2002) promotes the paradigm of ports as elements in value-driven chains and contrasts this paradigm with previous paradigms such as the morphological framework (ports as places), the operational efficiency framework (ports as operating systems), the economic principles framework (ports as economic units), and the governance and policy framework (ports as administrative units). One aspect that has received little explicit attention is the role of ports as natural locations where multiple logistical choices are available regarding storage, onward transport, and postponement. Containerization has lowered the cost of transport and increased the speed of cargo handling through the use of a single, standardized type of load unit. It also allows rerouting standard cargo.

The configuration of the logistics for a supply chain of fast-moving consumer goods such as consumer electronics or sports shoes involves many choices. These products are relatively expensive and have to reach the markets quickly but at a limited cost. The demand is that large that standardized containers can be used for the sea transport. Many manufacturers are located in Asia, particularly China, and the main markets for these goods are in Western Europe and the USA. Transportation from China to the markets is mostly done by sea, using standardized containers, as the costs for this mode of transport are low and the volumes large. If we look at the situation in Western Europe, we see several ports that are both close to the demand regions and able to handle the larger container ships. The focus of this paper is on the factors that influence the selection of these ports and in particular on the value provided by the flexibility of ports with a central location with regard to the hinterland.

If demand is less than a full container load, then it is not possible to store the goods in the transport unit (container); storage and handling would be required at a (European) distribution center. The sea transport from Asia to Europe is followed by inland transport by barge, train or truck. The container terminals provide some short-term storage capacity; while this terminal storage is intended to decouple the stages of the intermodal transport chain, it can also be used to postpone the routing decision (i.e., to which demand region the container will be shipped). This flexibility can be used to accommodate demand variations between regions. To ensure fast delivery to customers in the face of long supply chains, safety stock has to be held close to the demand region. This safety stock has to be stored at a physical location such a container terminal or a distribution center, incurring storage costs. Throughout the supply chain, one also incurs holding costs (the products tie up capital and depreciate in value over time). Both the location for and the amount of safety stock should therefore be carefully selected to minimize these costs.

The contribution of this paper is to quantify the routing flexibility that can be provided by ports with a central location. This makes the paper unique in the literature (see section 3). We use a case to illustrate our approach. The rerouting flexibility is used to some degree in practice at an operational level, where it is known as container rerouting.

This paper is structured along the following lines. We first formulate some hypotheses. Next, we review the academic literature, focusing on port selection and inventory control. We formulate an illustrative case (section 4) which provides the basis for numerical experiments using simulation (sections 5 and 6). With these experiments we evaluate the performance of the strategies and present the outcomes (section 7). We then present the results of a sensitivity analysis to assess the robustness of the outcomes (section 8). We close with a discussion of the results and the conclusion.

2 Hypotheses

We formulate the following hypotheses regarding the application of intermodal transport and distribution chains for a long sea-transport to a continent (e.g. the China–Europe route).

1. Ports with a central location with regard to the hinterland have a competitive edge due to greater flexibility in (re)routing traffic.
2. The value of this flexibility depends on the value of the products and the demand uncertainty.

We investigate these hypotheses using an illustrative case. The analysis is generic but the illustrative case provides more insight into the consequences. For this case we have gathered realistic data; we use real ports but aggregate the customers to demand regions that are represented as a point. The cost structure for the road haulage is based on the road distances covered; the cost data are based on consultation with practitioners as well as academic and professional literature. For the shipping network, we used expert judgements.

We use a simulation model to compare the effects of various strategies for the illustrative case. Simulation was selected as an evaluation method because some of the strategies we want to evaluate can not be analyzed analytically. This case study focuses on Western-Europe but the approach can also be applied to other regions. The simulation model was verified using a set of test cases.

3 Literature Review

In the academic literature the topics of shipping networks, logistics planning and inventory policies are most commonly studied separately. In this paper, we apply the concept of floating stocks to the transport of fast-moving consumer goods (FMCG) from Asia to Western Europe. The floating stocks concept draws on the areas of transportation and inventory control: in addition to the literature on port selection, we will therefore briefly recapitulate relevant transportation and inventory control literature.

3.1 Transportation

We will first look at the topic of port competition, followed by the topic of port selection, and the role of container terminals.

The geographical location of ports and demand regions on a continent are important factors in port selection. For the Asia-Western Europe route, one could argue that offloading cargo in Southern Europe would be beneficial for the carriers as this would shorten the trip time. The main disadvantages of this approach are that there are few ports that can handle the larger container ships and that most of the cargo would be far from the demand region. Therefore, most cargo from Asia to Western Europe is discharged in the Hamburg-Le Havre range in North-Western Europe; from the ports in this range, the main demand regions in Western Europe can be reached within days. Thus, one should also look at the connectivity of a port; when there is choice amongst multiple ports in a region, the position of that port in the transport network becomes an important characteristic. When routing most cargo through a single or a small number of ports, there is also the possibility of postponement; cargo can be rerouted at a fairly late moment in the transportation process. Offloaded cargo that is stored in a container terminal can be rerouted as demand shifts across regions. A port with good connectivity and support for multiple modes of transportation will be a more attractive choice. Port selection is an issue for both carriers (as part of the network design) and shippers (as part of the transport choice decision process). In this paper we take a supply-chain perspective and will thus focus on the transport choice rather than the network design.

3.1.1 Port competition

Chang and Lee (2007) provide an overview of the literature on port competition. They note that port competition has risen in prominence as a result of containerization and identify five main topics: governance, performance, cooperation, competitive policy, and port selection factors. In their review of the literature on port selection, they conclude that most studies have focused on the shippers rather than on other stakeholders. The methodologies that were applied to performance evaluation tended to be quantitative; cooperation was researched using conceptual, descriptive and case studies research; qualitative surveys were used for studies on governance and port selection. For the latter, surveying shippers and port authorities are popular methods. Several papers use this method to determine the factors that influence port selection and port performance (see for example Tongzon (2002)); Yeo et al. (2008) used literature review and a regional survey to find determinants of port competitiveness in Korea and China. They group the determinants into seven main categories (port service, hinterland condition, availability, convenience, logistics cost, regional center, and connectivity). The last category, connectivity, partially matches our flexibility (in terms of land distance, connectivity to major shippers, and efficient inland transport network). They also mention terminal free dwell time (as part of the logistics cost) as a significant factor for port selection.

Notteboom and Rodrigue (2005) argue that inland distribution is an important factor in port competition. They propose that regionalization expands the hinterland reach by linking the port more closely with inland freight distribution centers. Notteboom and Rodrigue (2008) indicate that terminal managements skills (software and know how) and hinterland size are key to productivity gains for container terminal operators. They also signal the development of multi-port gateway regions such as those in the Hamburg and Rotterdam–Antwerp regions and the integration of ports, liner shipping networks and hinterland transport.

Veldman and Bückmann (2003) use a logit model to forecast a port's market share in terms of container throughput, based on demand choice models. The logit model was used for an economic analysis of the port-extension project "Maasvlakte-2" in Rotterdam. Their approach includes model and route choices but at an aggregate level only. In line with the regionalization trend described by Notteboom and Rodrigue (2005), they focus on the European end; the Hamburg-Le Havre range. The analysis is limited to the factors of shipping costs for a route, the transit time, and the frequency of service. In their paper, the authors note that carriers use "the same tariff to each of the continental seaports".

3.1.2 Port selection

In his seminal paper on port selection, Slack (1985) argues that the traditional criteria such as port equipment appear to have relatively little influence on the port selection process. The flexibility of hinterland transportation is discussed only in an indirect fashion (for example, as 'number of sailings' and 'possibility of intermodal links', (Slack, 1985)). Some papers do touch on this topic; consider de Langen (2007), in which the port selection process for cargo destined for Austria is considered. In that paper, the flexibility of onward transport for imports gave the port of Rotterdam an edge over competing ports due to the possibility of barge traffic; there is a choice between fast and expensive transport (by road) and slower but less expensive transport (by inland waterways). In Wiegmans et al. (2008), the focus is on the selection of ports and terminals in the Hamburg–Le Havre range; for both decisions, the availability of hinterland connections is a key determinant (the methodologies employed were literature review, interviews with industry practitioners and application of decision-making theory). The immediacy of consumers (large hinterland) is found to be a determinant for the port selection.

3.1.3 Transportation choice

Meixell and Norbis (2008) provides a review of the transportation mode choice and carrier selection literature. The academic literature is categorized by topic, methodology, and challenges. They note the low use of simulation and interviews as methodologies. McGinnis (1989) classifies the models of freight transportation choice as classical economic, inventory-theoretic, trade-off, and constrained optimization, and identifies the variables involved in transportation and non-transportation costs through a review of empirical literature. (Flexibility is not mentioned.) The approach in our paper has elements of the inventory-theoretic and constrained optimization models. Naim et al. (2006) is one of the few papers that discuss flexibility in transportation. Starting from the use of flexibility in the field of manufacturing, they perform a synthesis of the literature to identify the key components of transport flexibility. The flexibility as used in our paper would classify as external (i.e., provided by transportation providers to customers), volume (range of and ability to accommodate changes in transport demand), delivery (range of and ability to change delivery dates) and access flexibility (ability to provide extensive distribution coverage).

3.1.4 Container terminals

The role of container terminals in supply chain logistics from the perspective of the terminal operator is discussed by Panayides and Song (2008). They identify four key variables for the integration of terminal operators in the supply chain: information and communication systems, value-added services, multimodal systems and operations, and supply chain integration practices. van der Horst and de Langen (2008) acknowledge the important role of hinterland transport (with costs often exceeding that of the maritime transport) and focus on the coordination between seaport actors involved in hinterland chains. Mangan et al. (2008) provide an overview of port-centric logistics.

The introduction of ever larger vessels causes a concentration of traffic to larger ports. This in turn creates hub and spoke networks with feeder ports. 'Lean' supply chains with relatively long lead times and predictable demand cause a focus on cost-effective storage capabilities; 'leagile' supply chains with long lead times and unpredictable demand lead to postponement of manufacturing/assembly. Olivier et al. (2007) signal the development of container terminal from cost centers to profit centers: increasingly, container terminals are operated by transnational companies, and while Asian companies have come to dominate the global terminal business, the European carriers have taken the lead in delivering total logistics packages. The shift from cost centers to profit centers may negatively affect the free dwell time.

Christiansen et al. (2004) present an overview of ship routing and scheduling literature. They distinguish routing (sequences of ports to be visited) and scheduling (timing the sequences) within network design. They do not mention port selection issues.

3.2 Inventory

In this paper we do not consider transport on its own, but take a supply chain perspective; we look at the total system of inventory and transportation facilitites to satisfy customer demand. Supply chain responsiveness can be obtained by fast transport and by keeping inventories close to customers. Normally, inventories are stored in distribution centers (DC's) which have fixed cost elements: setting up a DC requires an investment up-front and annual costs for operation that are incurred irrespective of the volume of inventory kept.

We consider a form of inventory speculation, which is appropriate for low customer order-to-delivery time and high-delivery frequency (Wallin et al. (2006), Pagh and Cooper (1998)). Inventory speculation is also identified as the method of choice by Baker (2007), if supplier lead times far exceed customer lead times.

Many papers in the area of supply chain strategies are qualitative in nature and do not provide quantitative results (such as Pagh and Cooper (1998)). The floating stock concept (Ochtman et al., 2004), in which intermodal transfer points are used as short-term storage locations for advance deployment of stock, attempts to find a middle ground between speculative and postponed logistics in the terminology of Pagh and Cooper (1998) (see their figure 6). In this concept, the geographical layout of the demand region and the available transport infrastructure are exploited to delay the final choices until retailer demand materializes. Ochtman et al. (2004) apply this to a case within Europe; they use simulation to numerically evaluate the performance of several stock deployment and transport strategies. Pourakbar et al. (2007) provide a mathematical analysis of the floating stock distribution concept; they present two mathematical models to analyze the floating stock policy with backlogging allowed and determine the optimal shipping time of containers through intermodal routes.

Baker (2007) discusses the role of inventory and warehousing in international supply chains, the role of decoupling points, and distribution centers; he maps 13 different supply chains from six companies, including some FMCG supply chains, on the basis of a survey.

Huggins and Olsen (2003) present an analytical model that takes the expediting and holding costs into account but their expediting cost model is fairly simple (fixed cost plus a linear function of volume) and they don't include lead times.

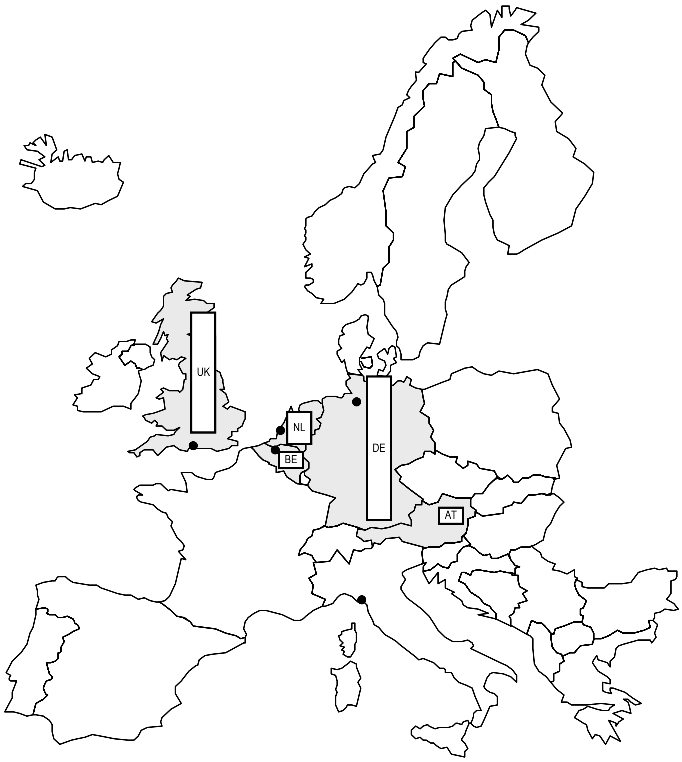
3.3 Summary of literature review

Most papers on port competition and selection are qualitative in nature and focus on identifying the key variables. Few papers approach this from a quantitative angle. The flexibility aspect has received some attention in the transportation literature, but again mostly from a qualitative perspective.

The main trends we synthesize from the literature are the shift towards terminal management and hinterland size as determinants for productivity gains for container terminal operators, the regionalization of ports, the advent of "port-centered logistics", and the development of hub-and-spoke networks. When combined with the industry trends towards ever larger container vessels and a reduction in the number of ports called, we conclude that an approach that can quantify the routing flexibility of a port could be a valuable tool in the port selection decision process.

4 Illustrative Case

In this case we consider a supplier of fast-moving consumer goods (FMCG) with variable demand, such as DVD-players, LCD televisions, sports shoes, or clothing. The supplier is typically located in China (for the case study, we will use a supplier close to the port of Shanghai). The goods are shipped in containers via Shanghai to Western Europe. (See figure 1.) We distinguish five demand regions: Austria (AT), Belgium (BE), Germany (DE), The Netherlands (NL), and the United Kingdom (UK). Here we limit ourselves to these five countries to limit the



Region	Ratio	Interarrival time in days ($1/\lambda$)
NL	2.1	4.3
BE	1.2	7.3
DE	8.9	1.0
UK	7.4	1.2
AT	1.0	8.9

Figure 1: Map of Western Europe with ports and Relative demand per region

amount of data to analyze. (A larger case has also been evaluated and we will return to this topic in the discussion section.)

For the distribution in Western Europe, we are faced with a choice of ports and storage locations. We consider five ports (La Spezia in Italy, Antwerp in Belgium, Hamburg in Germany, Rotterdam in The Netherlands, and Southampton in the United Kingdom) that are able to meet the following requirements: they are physically close to the demand regions, they feature in Asia to Europe container shipping schedules, and they are visited by large to very large container ships. The frequency for the Shanghai–Rotterdam and Shanghai–Hamburg connections is high and costs are (comparatively) low. For the Shanghai–Antwerp and Shanghai–Southampton connections, the frequency is lower but the costs are identical to the Rotterdam and Hamburg connections (Veldman and Bückmann (2003) confirm that the tariffs for the continental ports are identical). The frequency for the Shanghai–La Spezia connection is low and the costs are higher.

The demand ratios for the regions are based on the 2007 Gross Domestic Product (GDP) per country, based on the April 2008 World Economic Outlook Database (International Monetary Fund (2008), see figure 1). So, for example, the demand for Germany is approximately four times the demand for the Netherlands and eight times the demand for Austria and Belgium. The demand is modeled by a Poisson process at each location; the interarrival time between demands (customer orders in units of a full container) thus follows a negative-exponential distribution function. The parameters for the distribution function for each demand region are based on the demand ratios and are listed in the table next to figure 1. The size of an order is always one full container or TEU (twenty-foot equivalent unit).

Given this geographical layout of the demand regions and ports, we can determine which port has the most ‘central’ location. The parameters are the distance from each port to the demand regions, the cost per trip, and the volume for these links. Using these parameters we can calculate the average cost to deliver a container from a port to the demand regions. Using the road distances from each port to each demand region and the truck transport cost model that we used for this case (v.i.), we can compute this average cost per trip. Antwerp has the lowest average cost, at \$764, closely followed by Rotterdam at \$839; Hamburg, Southampton, and La Spezia trail at \$994, \$1,049, and \$1,396 respectively. On the basis of this calculation, Antwerp and Rotterdam are the best candidates to locate a central distribution center.

Taking the location of the ports and the demand regions into consideration, we now formulate a number of alternative layouts or strategies. In the first strategy the containers are shipped from China to the port closest to demand regions. From these ports the containers are then transported by road to distribution centers located in the

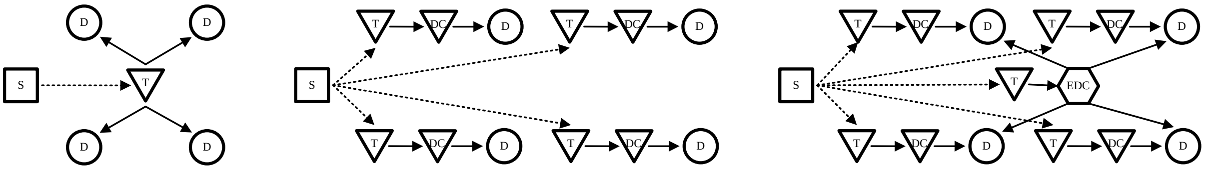


Figure 2: Diagram of centralized (left), Decentralized (middle), and EDC (right) Strategies. (S indicates Supplier; T–container terminal; DC–distribution center; D–demand region. Solid lines represent truck transport and dashed lines represent ship transport.)

demand regions. Some safety stock is required in these DC's to secure fast delivery. We will refer to this strategy as the decentralized strategy ("DEC"). (Figure 2 provides a schematic representation of the strategies; "S" represents the supplier in China, "T" the container terminals, "DC" the distribution centers, and "D" the demand regions. In this diagram, dashed lines represent sea transport and solid lines are use for land transport by truck.)

Alternatively, we can pool all demand and fulfill it from a central location. In this centralized strategy ("CEN") the containers are shipped to a container terminal at a port with a central location (for this case we selected Rotterdam). Customer demand is fulfilled by road transport from the central location; we keep some safety stock at this location to ensure fast delivery.

The centralized strategy uses the container terminal for temporary storage. This is fine if the dwell time is short; if the dwell time is longer, then this may present problems (especially higher costs). Both the centralized and the decentralized strategies depend on moving the load unit (container) as-is; there is no opportunity to rebatch the goods into smaller units for regions with lower demand. We therefore define a third strategy that includes a European Distribution Center. In this strategy (labeled "EDC") we will ship most containers to the ports closest to the demand region; onward transport to the distribution centers in the demand regions is done by truck. Safety stock is kept at the European Distribution Center, which we located close to the port of Rotterdam, and at the distribution centers in the demand regions.

Most stock is held at distribution centers, except for the centralized strategy. In the centralized strategy we use the container terminal as a storage location. In this strategy the demand from all regions is pooled. We expect the average dwell time of a container to be short and can thus take advantage of terminal free time (which is also mentioned by Slack (1985) as a relevant port selection criterium). In the DEC and EDC strategies the dwell times will be longer; stock is therefore stored at distribution centers located close to the demand regions.

The main performance indicators are the fraction of orders fulfilled within a preset time limit (three days) as a measure of responsiveness, and the total cost per container. The total cost per container includes the costs of shipping, inland transportation, handling, storage (at terminals and distribution centers), and holding (depreciation). We hold sufficient safety stock to ensure that 95% of orders are fulfilled within the preset limit. To minimize the cost associated with this safety stock (both storage and holding costs), we need to determine the inventory levels that will satisfy the order fulfillment requirement while minimizing the overall cost per container. Secondary indicators are the lead time, as an indicator of supply chain responsiveness, the residence times, and the inventory levels.

In this model we use a continuous-review base-stock policy with parameters (S-1,S) as we assume the absence of economies of scale in container transport for ordering more than one container. These parameters are defined for each storage location (terminal or DC). When an order for a container is placed, a replenishment order is initiated. Orders are fulfilled from either the on-hand stock or from the virtual (in-transit) stock; the former is shipped immediately, the latter is shipped when the stock arrives at the storage location.

4.1 Costs

The transport network consists of a number of storage locations such as warehouses, distribution centers, and container terminals. The storage locations are connected via transport links. The transport links are either shipping links (sea-going vessels) or trucking links (land transport using trucks). We do not consider barge or rail transport to limit the complexity of the model.

To determine the total cost of transporting a container to the customer, we introduce the following variables:

L the set of transport links

S the set of storage locations

t_i^t the time (in days) is takes to transport an individual container on transport link i.

c^1_j cost of handling incoming goods at storage location j.

c^2_j cost of handling outgoing goods at storage location j.

c^s_j cost of storing a container at location j for one day.

t^s_j the time (in days) a container is stored at location j (this includes the time for handling at arrival and departure).

t^f_j free dwell time for a container at location j.

c^t_i the cost of transporting a container along transport link i.

c^h the holding cost per day for a single container.

The total cost per trip for a container can then be formulated as:

$$\sum_{i \in L} c^t_i + (t^t_i \times c^h) + \sum_{j \in S} c^1_j + (t^s_j \times c^h) + (max(t^s_j - t^f_j, 0) \times c^s_j) + c^2_j$$

The total cost can vary for each individual container because the times a container is stored or transported (t^s_j and t^t_i) can vary, depending on the strategy selected. In this formulation, some of the t^t_i and t^s_j will be zero (for transport links and for storage locations that were not used). The time a container is stored at a location will vary, depending on the time required to arrange for pickup by truck or on the sailing schedule.

4.2 Inventory model

The base scenario of our illustrative case can also be analysed with the METRIC model (Sherbooke, 2004). In the METRIC model a multi-echelon inventory chain is considered with a central depot and several bases where demand occurs. Demand at each base is modeled by a Poisson process. The bases apply a (S-1,S) model for stock replenishment. Every base has a leadtime for replenishments from the central depot, which can reorder at a supplier. The output of the METRIC model comprises the service level (fraction of customers supplied in time) as well as the distribution of the inventory level as function of the base stock levels. In our case the bases are the demand region DC's and the central depot is the EDC or central port. We applied the METRIC model to verify our simulation model and the results were within the confidence bounds. As it is very difficult to accommodate other demand distributions in the METRIC model and to accommodate for the free time at terminals, we have chosen for simulation as evaluation method.

5 Simulation Model

The simulation model was implemented in the Java programming language, using the open-source SSJ discrete-event framework (L'Ecuyer et al., 2002). The configuration for a particular experiment is specified in a spreadsheet file. This includes the transport network, inventory locations, the costing parameters, and the experimental setup (warm-up time, length of a run, and the number of replications). This implementation facilitates easy experimentation without having to modify the Java source code. (Tables 1–3 are near verbatim copies from these spreadsheets.)

The simulation model tracks each container individually from creation (at the factory), through transport and storage to the final delivery at the customer. This tracking allows for detailed calculation of the costs (transport, storage, holding).

The source for this simulation model totals around 6,500 lines of code. It takes ten seconds on a 2.4 Ghz Intel Core 2 Duo processor to run 30 replications of six years each. The number of replications and the length per run were set to these values to get small confidence intervals on the statistical outputs. (For example, the 95% confidence interval on the 'average total cost' statistic is approximately 0.1 percent.)

6 Experimental Setup

6.1 Decentralized strategy (DEC)

In the first scenario we ship the goods directly from China to the port closest to each demand region. The safety stock is held at distribution centers close to the local ports; the level of safety stock required is determined by repeatedly running the simulation model and increasing S until the order fulfillment requirement (95% of orders is delivered within three days) is met for each location. (For this scenario, it is possible to determine the parameters

Table 1: Network Links for Decentralized Strategy (DEC)

From	To	Modality	Duration (days) t_i^t	Cost ($ per TEU) c_i^t	Interval (days)	Distance (km)	City
China vendor	Shanghai port	truck	0.5	150			
Shanghai port	La Spezia port	ship	19.0	1580	14		
Shanghai port	Antwerp port	ship	21.0	1340	7		
Shanghai port	Hamburg port	ship	21.0	1340	3.5		
Shanghai port	Rotterdam port	ship	21.0	1340	3.5		
Shanghai port	Southampton port	ship	21.0	1340	7		
La Spezia port	DC in AT	truck	1.1	920		920	Vienna
Antwerp port	DC in BE	truck	0.1	79		20	
Hamburg port	DC in DE	truck	0.1	79		20	
Rotterdam port	DC in NL	truck	0.1	79		20	
Southampton port	DC in UK	truck	0.1	79		20	
DC in AT	Customer AT	truck	0.1	79		50	Vienna
DC in BE	Customer BE	truck	0.1	130		130	Liege
DC in DE	Customer DE	truck	0.4	580		580	Nuremberg
DC in NL	Customer NL	truck	0.1	100		100	Amersfoort
DC in UK	Customer UK	truck	0.2	330		330	Manchester

Table 2: Network Links for Centralized Strategy (CEN)

From	To	Modality	Duration (days) t_i^t	Cost ($ per TEU) c_i^t	Interval (days)	Distance (km)	City
Supplier China	Shanghai port	truck	0.5	150			
Shanghai port	Rotterdam port	ship	21.0	1340	3.5		
Rotterdam port	Customer AT	truck	1.2	1200		1200	Vienna
Rotterdam port	Customer BE	truck	0.2	250		250	Liege
Rotterdam port	Customer DE	truck	0.9	710		710	Nuremberg
Rotterdam port	Customer NL	truck	0.1	150		150	Amersfoort
Rotterdam port	Customer UK	truck	1.3	1212		780	Manchester

for the inventory policy analytically (f.e., using the method discussed by Chopra and Meindl (2004) on p.326), but in more complicated scenarios this becomes more difficult; thus, we have chosen the same approach throughout.)

We assume there are sailings from Shanghai to Rotterdam and from Shanghai to Hamburg twice a week; Antwerp and Southampton are visited once a week, and La Spezia once every fortnight. While the frequencies of all carriers on these routes combined may be higher, an individual client of a carrier will usually be limited to the sailings offered by that carrier. For each demand region, we have selected a location for the average customer (listed in the 'City' columns below) to determine transport distances, and thus times and costs. (See table 1 for the details of the links in the network.) It takes two days to unload a container in a port, stack it in the yard, get cleared through customs, and arrange onward truck transport to a DC. The time to arrange transport from a DC to the customer is included in the order generation process.

6.2 Centralized strategy (CEN)

The second scenario routes all transports through a centralized port, in this case a container terminal in Rotterdam. Using the container terminal eliminates extra handling times and costs when compared to storing in a European Distribution Center, even though the storage costs can be high. Onward transport from Rotterdam to the demand regions is by truck. The details of the transport network links are listed in table 2.

6.3 EDC strategy (EDC)

In this scenario, the goods are shipped to the regional ports close to the demand regions. Some stock is kept at distribution centers close to these regional ports and an additional safety stock is kept at a European Distribution Center (EDC) in Rotterdam. Fulfillment from the EDC to the customers is via truck. (See table 3 for details.) Storing at an EDC implies extra handling costs; for long dwell times, storing at an EDC is cheaper than at a terminal. We do not explicitly consider the fixed costs of an EDC or regional warehouse.

Table 3: Network for European Distribution Center Strategy (EDC)

From	To	Modality	Duration (days) t_i^t	Cost ($ per TEU) c_i^t	Interval (days)	Distance (km)	City
The first six rows are identical to the CEN *strategy (see table 1)*							
La Spezia port	DC in AT	truck	1.1	920		920	
Antwerp port	DC in BE	truck	0.1	79		20	
Hamburg port	DC in DE	truck	0.1	79		20	
Rotterdam port	DC in NL	truck	0.1	79		20	
Southampton port	DC in UK	truck	0.1	79		20	
DC in AT	Customer AT	truck	0.1	79		50	Vienna
DC in BE	Customer BE	truck	0.1	130		130	Liege
DC in DE	Customer DE	truck	0.4	580		580	Nuremberg
DC in NL	Customer NL	truck	0.1	100		100	Amersfoort
DC in UK	Customer UK	truck	0.2	330		330	Manchester
Rotterdam port	EDC	truck	0.1	79		20	Rotterdam
EDC	Customer AT	truck	1.2	1200		1200	Vienna
EDC	Customer BE	truck	0.2	250		250	Liege
EDC	Customer DE	truck	0.9	710		710	Nuremberg
EDC	Customer NL	truck	0.1	150		150	Amersfoort
EDC	Customer UK	truck	1.0	1212		780	Manchester

6.4 Cost parameters

For the cost associated with stocks, we specify the holding costs and the storage costs separately ((Chopra and Meindl, 2004) refer to these as the ‘cost of capital’ and the ‘occupancy costs’). Here, the holding cost is the money spent to maintain a stock of goods, excluding the cost of storing those goods. For this case, the holding costs are based on a cargo of approximately 2,000 DVD players per container valued at $45 each. This means that the total value of a single container is $91,250. At an interest level of 8%, the holding cost per container per day c^h is then $20.

The storage costs c_j^s are 10 dollar per TEU per day, 5 free days for the container terminals (t_j^f); at 5 dollar per TEU per day, no free days for the European Distribution Center; and at 6 dollar per TEU per day, no free days for the regional DC’s. The regional DC’s are more expensive due to fewer economies of scale than the EDC.

The container terminal handling charges are based on expert opinion at $120 for Antwerp, $140 for Rotterdam, $160 for Hamburg, and $180 for La Spezia and Southampton[1].

6.5 Transport parameters

The costs for truck transport are based on a simple model that is linear in the distance covered. The cost is $1 per TEU per kilometer, with a minimum of $79 per trip. (These parameters were based on expert opinion; Notteboom (2004) cites a range of $0.8 to $2 per TEU-kilometer for inland haulage per truck.) These parameters are used to calculate the c_i^t for the truck transports.

The distances from the terminals to the customers were estimated using the ‘Driving Directions’ feature of Google maps (Google, 2008); a sample of these distances was verified using the Microsoft AutoRoute 2007 software package. The travel times for trucks (t_i^t) have been calculated using the Dutch regulations for driving/rest-times, an average speed of 80 km/hr and a one-hour overhead per trip.

The tariff for shipping one TEU from Shanghai to ports in the Hamburg–Le Havre range is 1340 dollar per TEU (c_i^t for shipping routes); there is a 20% premium for the Shanghai–La Spezia route. For trips between the European continent and the UK, we include in the inland transport costs the cost of a channel tunnel crossing, which is $432 one way (based on tariff from the Eurotunnel website).

7 Experimental Results

The experiments consist of 30 replications of six years; before the start of each replication the system is warmed-up by ordering and delivering the base-stock level for each location. Here, we report the means over the number of

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[1] As we did not have data for La Spezia and Southampton, we have selected the highest charge (Hamburg) and added a small premium to model the lack of economies of scale. No terminal handling charges were defined for the Shanghai terminal because they would not cause any difference in the results.

Table 4: Inventory Policy Parameter (S)

Location	DEC	CEN	EDC
DC in AT	7	-	4
DC in BE	8	-	4
DC in DE	32	-	21
DC in NL	10	-	7
DC in UK	30	-	21
Rotterdam terminal	-	69	-
EDC (Rotterdam)	-	-	18
	87	69	75

Table 5: Overview Results (averages per container)

Totals	Unit	DEC	CEN	EDC
Avg. Lead Time	days	0.5	1.0	0.7
Avg. Handling Cost	\$/TEU	164	140	159
Avg. Holding Cost	\$/TEU	759	618	663
Avg. Storage Cost	\$/TEU	71	29	40
Avg. Shipping Cost	\$/TEU	1352	1340	1349
Avg. Transport Cost	\$/TEU	660	980	740
Avg. Total Cost	\$/TEU	3006	3106	2951

replications; more detailed statistics, including the 95% confidence intervals and 90% quantiles are available in a separate technical report.

We have run the simulation model for the three strategies described above (DEC, CEN, and EDC). The order-up-to levels (parameter S of the inventory policy) are listed in table 4. The order-up-to levels were determined by repeatedly running the model, increasing S if necessary, until the fraction of orders that could be fulfilled within three days exceeded 0.95 for all regions. For the EDC strategy, we determined the order-up-to levels by starting with no EDC stock and determined the required stock levels for the other DC's. We then increased the EDC level by one unit (container) at a time; for each EDC level we decreased the local levels until we found the minimum level necessary to meet the order lead time requirement. We selected the setting with the lowest total cost.

The inventory required to meet this requirement is smallest with the centralized strategy (CEN); as expected, pooling demand clearly has a significant impact on the level of stock required. The results of the EDC strategy exhibit a similar effect with regard to the pooling of the safety stock; this strategy has the additional benefit of a lower average lead time because most of the stock is held closer to the demand regions.

For easy comparison, we have calculated the average lead time and costs; these reflect the differing demand volumes per region. These indicators are listed in table 5. (More details of the results, including standard deviation and confidence intervals, are in the appendix on page 15.) The average lead-time is the number of days it takes to fulfill an order from the demand region. The cost parameters are the average costs per container. The EDC strategy has the lowest average total cost; the centralized strategy has the highest total cost and the longest lead-time; the savings in holding costs and storage costs due to pooling are offset by higher inland transport costs. In this case, the trips to the UK demand region are relatively expensive due the additional charges for the channel tunnel. The decentralized strategy has the best performance in terms of the lead time; this is expected as the inventory is held close to the demand regions at the regional DC's.

If we look at the overall cost per container delivered to the customers (table 6), we can see that centralized strategy lowers the costs most for regions with relatively low demand (Austria and Belgium); the cost savings for regions with high demand are more modest in comparison to the decentralized strategy. The EDC strategy leads to an increase in storage costs (as this strategy does not take full advantage of the free dwell time at the container terminals) when compared to the centralized strategy but this is balanced by a reduction in the inland transport costs.

The lead times per demand region (i.e., the time between the moment of ordering by the customer and the actual delivery to the customer) are in line with expectations (table 7). (More details of the results, including standard deviation and confidence intervals, are in the appendix on page 15.) As the inventory levels were set on the basis of the fulfillment requirement (95% fulfillment within three days), we can expect the best performance from the strategy that places most of the stock closest to the demand region. The centralized strategy has a higher average order lead time: the stock is now further from the demand regions and final delivery from the central stock to the customer by truck takes longer than delivery from the regional port.

Table 6: Cost per Customer

Customer	Total Costs			Transport Costs		
	DEC	CEN	EDC	DEC	CEN	EDC
Customer AT	4371	3483	3897	1149	1350	1209
Customer BE	3118	2516	2687	359	400	391
Customer DE	3006	2989	2977	809	860	841
Customer NL	2779	2414	2602	329	300	337
Customer UK	2870	3491	2935	559	1362	727
	Storage Costs			Holding Costs		
	DEC	CEN	EDC	DEC	CEN	EDC
Customer AT	223	28	110	1239	624	877
Customer BE	177	30	68	1122	607	763
Customer DE	42	29	27	655	620	614
Customer NL	107	29	63	863	604	722
Customer UK	59	29	36	732	620	660

Table 7: Lead Times (in days)

Customer	DEC	CEN	EDC
Customer AT	0.4	1.4	0.8
Customer BE	0.3	0.4	0.6
Customer DE	0.6	1.1	0.8
Customer NL	0.4	0.3	0.3
Customer UK	0.5	1.1	0.6

The EDC strategy fulfills most orders from the regional distribution centers and some orders from the European Distribution Center. The inventory policy settings for this strategy place a modest amount of stock at the EDC and significant amounts at the regional DC's (table 4); the lead time is thus longer than the lead time of the DEC strategy but shorter than the lead times of the CEN strategy. The lead time increases most for the demand region that is furthest from the EDC (Austria) as more orders are fulfilled by a long truck trip from the EDC.

For the CEN strategy, the average dwell time at the container terminal is within the terminal free time at 4.8 days (see table 8; the 95% quantile just exceeds the free dwell time at 5.2 days). (More details are in the appendix on page 16.) This is reflected in lower storage costs (table 6).

8 Sensitivity Analysis

We have performed a sensitivity analysis to investigate the robustness of the outcomes. We have focused on the holding costs, the inland transport costs, the demand functions, and the free time for container terminals. Table 9 contains the total cost for each scenario of the sensitivity analysis results. In the 'absolute' column, the best performing strategy (indicated with the value '0') is used as a benchmark for the other strategies. The

Table 8: Residence Times (in days)

Location	DEC	CEN	EDC
DC in AT	32.5	-	16.8
DC in BE	29	-	12.3
DC in DE	7.1	-	3.0
DC in NL	17.8	-	10.8
DC in UK	9.3	-	4.7
Antwerp terminal	2	-	2
Hamburg terminal	2	-	2
La Spezia terminal	2	-	2
Rotterdam terminal	-	4.8	2
Shanghai terminal	2.7	1.8	2.5
Southampton terminal	2	-	2
EDC (Rotterdam)	-	-	10.8

Table 9: Overview of Sensitivity Analysis (total cost per TEU)

	Relative to base case			Absolute		
	DEC	CEN	EDC	DEC	CEN	EDC
Base Case				+55	+155	0
Holding Cost 5	-19%	-15%	-17%	0	+206	+16
Holding Cost 10	-13%	-10%	-11%	+8	+179	0
Holding Cost 40	+25%	+20%	+22%	+151	+110	0
Holding Cost 100	+101%	+80%	+90%	+465	0	+25
Demand Erlang(2)	-4%	-1%	-2%	+18	+179	0
Demand Erlang(9)	-7%	-3%	-5%	0	+213	+9
Inland Transport 2$/km	+14%	+22%	+16%	+6	+349	0
Free dwell time 0 days	+1%	+1%	+1%	+57	+149	0
Free dwell time 2.5 days	-	-	-	+57	+157	0
Free dwell time 7.5 days	-	-	-	+55	+154	0
Free dwell time 10 days	-	-	-	+55	+151	0
40 ft container	-8%	-16%	-15%	+222	+87	0

'relative' column shows the relative differences of each scenario when compared to the base case. The EDC strategy has the lowest total cost for most scenarios. The exceptions are the extreme holding cost scenarios and the less variable demand (Erlang(9)). The decentralized strategy is most sensitive to the demand distribution function; as the demand becomes less variable, it becomes easier to meet demand from the decentralized stocks. Overall, the performance of the simulation model appears to be sensitive to the holding costs and the demand functions.

8.1 Holding costs

In our base case, the holding cost is \$20 per TEU per day; for the sensitivity analysis, we have also run the model with values of \$5, \$10, \$40, and \$100 per TEU per day to reflect two lower and two higher valued scenarios. Changing the holding costs will only affect the 'Holding Cost' and 'Total Costs' outputs. As the holding costs increase, the strategies (CEN and EDC) that include pooling benefit. For the lowest holding costs of \$5 per TEU per day, the disadvantage of higher overall inventory for the decentralized strategy is offset by lower inland transport costs. As the holding costs increase, the EDC strategy offers a nice balance between inventory pooling and lower inland transport costs caused by keeping some inventory closer to the demand region. Finally, for the highest holding costs of \$100 per TEU per day, the centralized strategy provides the lowest total costs; the higher inland transport costs from the central location to the demand regions are offset by savings in the holding costs due to pooling. Conversely, the average cost per container increases significantly for the decentralized strategy as this strategy does not feature any pooling.

8.2 Inland transport costs

For the base case, we use a tariff of \$1 per TEU-km for inland (road) transport. As Notteboom (2004) mentions a range of \$0.8 to \$2 per TEU-km, we have also done an experiment using the upper limit of this range, \$2 per TEU-km. (In line with Notteboom (2004) we assume that there are no economies of distance.) The tariff per TEU-km has the biggest impact on the centralized strategy as it uses the most and the longest truck transport trips. The difference between the EDC and the DEC strategy is now very small. The EDC strategy could additionally benefit from a location adjacent to the terminal. If the EDC could be reached by the terminal transporters, the transport from the terminal to the EDC could be performed at the discretion of the terminal operator. This could benefit both the costs of the move (even a short move by truck costs \$79) and the operation of the terminal itself as it would allow the terminal operator to schedule these moves away from peak times. (Consider, for example, the Distripark concept used at the Maasvlakte in Rotterdam (United Nations (2002), p.44); a site directly adjacent to the ECT container terminal with a dedicated internal transport track.)

8.3 Demand function

In the base case, we modeled demand using the familiar negative-exponential distribution function for the order interarrival times per region. This distribution function generates a large proportion of very short interarrival times. The negative-exponential function is a specific case (shape parameter $k = 1$) of the more general Erlang distribution function. To examine the sensitivity of the simulation results for the demand function, we have done two additional experiments with the Erlang distribution function with the shape parameter value set to $k = 2$ and $k = 9$. For higher values of the shape parameter, the proportion of very short interarrival times will diminish; in essence, the order arrivals will be more evenly distributed over time, modeling more predictive demand.

The Erlang distribution function can model the sum of a number of exponential distributions; thus, the $k = 2$ and $k = 9$ cases are a model for a number (two, nine) of customers within a demand region. For this analysis, the second parameter of the Erlang distribution (the scale parameter θ) was set to have the same mean for all three functions ($k\theta$ is constant).

The order-up-to parameter S was determined separately for each distribution function. The stock required to meet the lead time constraint (95% of orders delivered within three days) is lower for higher values of the shape-parameter k. As k increases, the scale parameter θ decreases ($k\theta$ is constant). This implies that the variance ($k\theta^2$) decreases. All strategies benefit in a similar way; holding and storage costs are reduced. With more predictable demand (higher values of k), the DEC strategy benefits most: the safety stock required drops from 87 ($k = 1$) to 77 ($k = 2$) and 68 ($k = 9$) units (for CEN and EDC this numbers are 69-65-61 and 75-72-67, respectively). Less variable demand reduces the advantage of the strategies that involve pooling, making the decentralized strategy that places the inventory close to the demand regions the most attractive in term of total cost per TEU. (for $k = 9$, the total costs per TEU are $2,802 (DEC), $3,015 (CEN), and $2,811 (EDC)).

8.4 Free dwell time on terminal

The influence of the free dwell time at the container terminals was tested for 0, 2.5, 5, 7.5, and 10 days. The analysis showed that the free dwell time on container terminals has little influence on the overall cost level unless the free dwell time is less than the time required for handling and arranging onward transportation (in our case, less than two days). This is, however, unlikely to happen in practice. The differences in storage costs between 2.5 and 10 days of free dwell time are $9, $13, and $7 per TEU for the DEC, CEN, and EDC strategies; the differences between no free dwell time and 2.5 days of free dwell time are $38, $30, and $38 respectively.

8.5 40ft container

If the inland transport costs do not depend on the size of the container, then it would be attractive to use 40ft rather than 20ft containers. To analyze the impact of this change, we have run the base case configuration with all the settings adjusted for the use of 40ft containers (assuming that the shipping tariff for a 40ft container is twice that of a 20ft container). The data for this experiment in table 9 have been scaled back to TEU. As expected, the strategies with longer truck transport trips benefit most from this change. Looking at the detailed data (which is not listed in the table), we see that the handling and inland transport costs per TEU decrease whereas the holding and storage costs increase.

9 Central Location

Our initial calculation in section 4 indicated that Rotterdam and Antwerp have the most central location. To further investigate this, we have performed some additional experiments with Antwerp, Hamburg, Southampton, and La Spezia as the ports for the centralized strategy. Table 10 displays the outcomes. In line with our initial calculation, the total costs for Antwerp and Rotterdam are lowest; Antwerp has the lowest total costs due its more central location, in spite of the lower sailing frequency (once a week rather than twice a week for Rotterdam and Hamburg). The low frequency of sailings to La Spezia means that a higher level of safety stock has to be kept. Combined with a higher shipping rate, the total costs are therefore higher. The geographical position of La Spezia means that the order lead time is also significantly higher. Hamburg benefits from the higher frequency of sailings (the same as Rotterdam); the less central geographical location means that the inland transport costs are higher. The transport costs from Southampton are impacted by the cost of using the Euro Tunnel for transport to the European mainland.

10 Discussion and Conclusion

From our study, ports with a central location with respect to the hinterland in a region or on a continent enjoy a competitive advantage; when cargo is shipped to such a port, it can be redirected before arrival, when unloaded and stacked in the container terminal or when stored in a (European) distribution center. The value of this flexibility depends on the hinterland (where does the demand originate) and the value of the products. In this paper we have

Table 10: Comparison of Different Ports for Centralized Strategy

	Unit	Rotterdam	Antwerp	Hamburg	Southampton	La Spezia
S for central terminal	TEU	69	74	70	76	90
Avg. Lead Time	days	1.0	1.0	1.0	0.9	1.6
Avg. Handling Cost	\$ per TEU	140	120	160	180	180
Avg. Holding Cost	\$ per TEU	618	661	627	677	810
Avg. Shipping Cost	\$ per TEU	1340	1340	1340	1340	1580
Avg. Storage Cost	\$ per TEU	29	29	32	35	78
Avg. Inland Transport Cost	\$ per TEU	980	912	1142	1199	1544
Avg. Total Cost	\$ per TEU	3106	3062	3302	3430	4192

looked at a sample supply chain in which Rotterdam is used as an example of a port that can offer this type of flexibility. We used a simulation model to quantify the value of the flexibility.

The port selection criteria that are discussed in the literature are rather abstract. We provide a more precise, quantified interpretation of criteria such as flexibility, location, shipping frequency, and charges. The results of our simulation model for the case show that the free dwell time of the container terminal does not have a large impact on the total cost provided the free time does allow sufficient time for the onward transport to be arranged. For the centralized strategy, the average dwell time is just below the terminal free dwell time. Although terminal operating companies might want to reduce the free dwell time in order to reduce yard congestion, they would thereby also endanger the potential for the terminal to be used as a temporary storage location. If the yard is very congested, then a setup such as the Distripark Maasvlakte in Rotterdam (United Nations, 2002) could provide a solution: an off-terminal location that is linked to the terminal via a dedicated internal track. The transport costs to the Distripark can be significantly lower than truck transport to an external distribution center.

The flexibility that is offered by ports with a central location with regard to the hinterland enables pooling of safety stock. This flexibility is useful when there is variation in demand across the regions. With highly predictable demand, it would be more beneficial to keep stocks close to demand regions. However, with less predictable demand or with a high variation in demand across regions, pooling stocks at ports with a central location and a good transport network becomes more attractive. This pooling opportunity provides ports with a central location and a good hinterland transport network with a competitive edge. The regions with relatively low demand can then benefit from the safety stock that is also used for the regions with relatively high demand. The pooled demand reduces the average residence time of the stock; this in turn reduce storage cost and especially holding costs.

In the illustrative case study, we have looked at two variations of centralization. The centralized strategy uses a container terminal for temporary storage. Within the case setup, the dwell times are such that the storage costs remain low because we can take advantage of the free dwell time. This strategy has a slightly higher average cost per container than the decentralized strategy; however, as the value of the goods increases (and thus the holdings costs), the pooling advantage of the centralized strategy enables it to outperform the other two strategies. The EDC strategy has the lowest total cost per container and a shorter lead time than the centralized strategy. As demand variance was reduced, it became more attractive (cheaper) to hold more stock in the regional DC's and the role of the EDC was reduced. The storage costs for the EDC are such that it is a more attractive choice for stock with longer dwell times. The sensitivity analysis indicates that this strategy is attractive for moderately high holding costs; for very low holding costs, the decentralized strategy is preferred, and for very high holding costs, the centralized strategy performs best. Additionally, the EDC enables value-added logistics and less than full container shipments to regions with lower demand. These options are not available for the centralized strategy as the stock remains in the load unit (container) and they are less efficient if implemented in all the regional distribution centers (for the decentralized strategy).

In the illustrative case, we have looked at a limited number of ports and demand regions to enable a clear presentation of the results. Using the same methodology, we have also evaluated a larger case that includes 15 demand regions (the regions from the base case plus Denmark, the Czech Republic, France, Spain, Portugal, Switzerland, Poland, and Hungary) and nine ports (the ports from the base case plus Barcelona, Le Havre, Marseille, and Trieste). Initial analysis has shown that the results match the results of the base case.

The geographical layout of Western Europe provides a number of ports in the Hamburg–Le Havre range with a beneficial, central location that facilitates the centralization approaches included in our model. The East coast of the USA has somewhat similar characteristics; ports such as Savannah, Norfolk, Baltimore, and New Jersey serve an overlapping hinterland and most industrial areas in the Eastern USA can be reached by truck within three days. The addition of the new set of locks for the Panama canal (planned for 2014) which can handle larger and longer ships may cause a shift from using the West Coast ports with onwards transport by rail to the East Coast to using the East Coast ports. The carriers and their customers will then face a new port selection problem. Once the shipping tariffs for the new routes to the East Coast are known, customers could employ the model presented in this paper to evaluate their options.

An obvious extension would be to include barge and train transport. This would require a fairly detailed model of the hinterland transport network for these modes as well as accurate costing data. The location of a port in relation to these transport networks could, however, be an important factor in the overall flexibility of (re)routing traffic and could thus be worthwhile.

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Appendix: Detailed Results

In this appendix we list the detailed statistical outputs of the simulation experiments for the three strategies. In the tables below the mean (or average) across replications, the standard deviation, minimum and maximum values, the half width (half of the 95%-confidence interval for the mean), and the number of replications is listed for each statistic. All statistics are reported per container.

Overview Results

name	avg	std	min	max	hw	num
DEC Strategy						
Avg. Lead Time	0.53	0.04	0.44	0.60	0.02	30
Avg. Total Cost	3006	10	2976	3024	4	30
Avg. Transport Cost	660	3	654	668	1	30
Avg. Handling Cost	164	0	163	164	0	30
Avg. Holding Cost	759	8	737	773	3	30
Avg. Shipping Cost	1352	1	1350	1353	0	30
Avg. Storage Cost	71	2	65	76	1	30
CEN Strategy						
Avg. Lead Time	1.01	0.04	0.94	1.12	0.02	30
Avg. Total Cost	3106	10	3078	3121	4	30
Avg. Transport Cost	980	4	972	988	1	30
Avg. Handling Cost	140	0	140	140	0	30
Avg. Holding Cost	618	6	600	627	2	30
Avg. Shipping Cost	1340	0	1340	1340	0	30
Avg. Storage Cost	29	3	21	33	1	30
EDC Strategy						
Avg. Lead Time	0.69	0.06	0.57	0.82	0.02	30
Avg. Total Cost	2951	7	2930	2963	3	30
Avg. Transport Cost	740	4	733	747	1	30
Avg. Handling Cost	159	0	158	159	0	30
Avg. Holding Cost	663	6	645	673	2	30
Avg. Shipping Cost	1349	0	1348	1350	0	30
Avg. Storage Cost	40	2	35	43	1	30

Lead Times

For the lead times per customer, we include the 90% percentile.

name	avg	std	min	max	hw	num	90q
DEC Strategy							
Customer AT	0.4	0.2	0.1	0.7	0.1	30.0	0.6
Customer BE	0.3	0.1	0.2	0.8	0.0	30.0	0.5
Customer DE	0.6	0.1	0.5	0.8	0.0	30.0	0.7
Customer NL	0.4	0.1	0.2	0.8	0.0	30.0	0.6
Customer UK	0.5	0.1	0.3	0.6	0.0	30.0	0.6
CEN Strategy							
Customer AT	1.4	0.1	1.3	1.5	0.0	30.0	1.5
Customer BE	0.4	0.1	0.3	0.5	0.0	30.0	0.4
Customer DE	1.1	0.0	1.0	1.2	0.0	30.0	1.1
Customer NL	0.3	0.0	0.2	0.4	0.0	30.0	0.4
Customer UK	1.1	0.1	1.1	1.3	0.0	30.0	1.2
EDC Strategy							
Customer AT	0.8	0.2	0.4	1.2	0.1	30.0	1.1
Customer BE	0.6	0.2	0.3	1.0	0.1	30.0	0.8
Customer DE	0.8	0.1	0.7	1.0	0.0	30.0	0.9
Customer NL	0.3	0.1	0.2	0.5	0.0	30.0	0.5
Customer UK	0.6	0.1	0.5	0.8	0.0	30.0	0.8

Residence Times

The results for the residence times include the 90%, 95%, and 99% percentiles.

name	avg	std	min	max	hw	num	90q	95q	99q
DEC Strategy									
DC AT	32.5	3.9	26.7	42.9	1.5	30.0	36.8	40.3	42.5
DC BE	29.0	3.9	22.5	37.1	1.5	30.0	34.3	35.4	36.7
DC DE	7.1	0.6	5.6	8.2	0.2	30.0	7.8	8.0	8.1
DC NL	17.8	1.8	14.1	22.1	0.7	30.0	20.0	20.7	21.9
DC UK	9.3	0.6	8.2	10.3	0.2	30.0	10.2	10.3	10.3
Antwerp port	2.0	0.0	2.0	2.0	0.0	30.0	2.0	2.0	2.0
Hamburg port	2.0	0.0	2.0	2.0	0.0	30.0	2.0	2.0	2.0
LaSpezia port	2.0	0.0	2.0	2.0	0.0	30.0	2.0	2.0	2.0
Rotterdam port	2.0	0.0	2.0	2.0	0.0	30.0	2.0	2.0	2.0
Shanghai port	2.7	0.0	2.7	2.8	0.0	30.0	2.8	2.8	2.8
Southampton port	2.0	0.0	2.0	2.0	0.0	30.0	2.0	2.0	2.0
CEN Strategy									
Rotterdam port	0.0	0.0	0.0	0.0	0.0	30.0	0.0	0.0	0.0
Rotterdam-terminal	4.8	0.3	3.9	5.3	0.1	30.0	5.2	5.2	5.2
Shanghai port	1.8	0.0	1.7	1.8	0.0	30.0	1.8	1.8	1.8
EDC Strategy									
DC AT	16.8	2.1	13.6	22.2	0.8	30.0	19.5	19.7	21.5
DC BE	12.3	1.8	8.5	16.4	0.7	30.0	15.3	15.8	16.3
DC DE	3.0	0.2	2.4	3.4	0.1	30.0	3.3	3.4	3.4
DC NL	10.8	1.1	8.6	13.4	0.4	30.0	12.2	12.6	13.2
DC UK	4.7	0.3	4.3	5.2	0.1	30.0	5.0	5.1	5.2
Antwerp port	2.0	0.0	2.0	2.0	0.0	30.0	2.0	2.0	2.0
Hamburg port	2.0	0.0	2.0	2.0	0.0	30.0	2.0	2.0	2.0
LaSpezia port	2.0	0.0	2.0	2.0	0.0	30.0	2.0	2.0	2.0
Rotterdam port	2.0	0.0	2.0	2.0	0.0	30.0	2.0	2.0	2.0
Shanghai port	2.5	0.0	2.4	2.6	0.0	30.0	2.5	2.5	2.6
Southampton port	2.0	0.0	2.0	2.0	0.0	30.0	2.0	2.0	2.0
EDC Rotterdam	10.8	1.1	8.0	12.7	0.4	30.0	12.4	12.5	12.7

Costs

DEC Strategy

name	avg	std	min	max	hw	num	75q	90q
Total Costs								
Customer AT	4371	104	4217	4632	39	30	4416	4503
Customer BE	3118	101	2948	3328	38	30	3199	3254
Customer DE	3006	16	2968	3036	6	30	3017	3025
Customer NL	2779	46	2683	2891	17	30	2796	2838
Customer UK	2870	16	2840	2896	6	30	2881	2893
Transport Costs								
Customer AT	1149	0	1149	1149	0	30	1149	1149
Customer BE	359	0	359	359	0	30	359	359
Customer DE	809	0	809	809	0	30	809	809
Customer NL	329	0	329	329	0	30	329	329
Customer UK	559	0	559	559	0	30	559	559
Handling Costs								
Customer AT	180	0	180	180	0	30	180	180
Customer BE	120	0	120	120	0	30	120	120
Customer DE	160	0	160	160	0	30	160	160
Customer NL	140	0	140	140	0	30	140	140
Customer UK	180	0	180	180	0	30	180	180
Holding Costs								
Customer AT	1239	80	1120	1440	30	30	1273	1339
Customer BE	1122	78	991	1283	29	30	1183	1226
Customer DE	655	12	626	678	5	30	663	669
Customer NL	863	35	790	949	13	30	876	909
Customer UK	732	12	709	752	5	30	740	750
Shipping Costs								
Customer AT	1580	0	1580	1580	0	30	1580	1580
Customer BE	1340	0	1340	1340	0	30	1340	1340
Customer DE	1340	0	1340	1340	0	30	1340	1340
Customer NL	1340	0	1340	1340	0	30	1340	1340
Customer UK	1340	0	1340	1340	0	30	1340	1340
Storage Costs								
Customer AT	223	24	187	283	9	30	234	255
Customer BE	177	23	138	225	9	30	196	208
Customer DE	42	4	33	49	1	30	45	47
Customer NL	107	11	84	133	4	30	111	120
Customer UK	59	4	52	65	1	30	61	64

CEN Strategy

name	avg	std	min	max	hw	num	75q	90q
Total Costs								
Customer AT	3483	21	3450	3538	8	30	3500	3509
Customer BE	2516	21	2460	2551	8	30	2530	2538
Customer DE	2989	9	2972	3007	3	30	2994	3001
Customer NL	2414	19	2375	2455	7	30	2425	2432
Customer UK	3491	13	3464	3514	5	30	3502	3510
Transport Costs								
Customer AT	1350	0	1350	1350	0	30	1350	1350
Customer BE	400	0	400	400	0	30	400	400
Customer DE	860	0	860	860	0	30	860	860
Customer NL	300	0	300	300	0	30	300	300
Customer UK	1362	0	1362	1362	0	30	1362	1362
Handling Costs								
Customer AT	140	0	140	140	0	30	140	140
Customer BE	140	0	140	140	0	30	140	140
Customer DE	140	0	140	140	0	30	140	140
Customer NL	140	0	140	140	0	30	140	140
Customer UK	140	0	140	140	0	30	140	140
Holding Costs								
Customer AT	624	15	603	663	5	30	636	642
Customer BE	607	15	568	629	5	30	616	621
Customer DE	620	6	608	632	2	30	624	628
Customer NL	604	13	578	632	5	30	612	617
Customer UK	620	9	601	636	3	30	627	632
Shipping Costs								
Customer AT	1340	0	1340	1340	0	30	1340	1340
Customer BE	1340	0	1340	1340	0	30	1340	1340
Customer DE	1340	0	1340	1340	0	30	1340	1340
Customer NL	1340	0	1340	1340	0	30	1340	1340
Customer UK	1340	0	1340	1340	0	30	1340	1340
Storage Costs								
Customer AT	28	7	17	45	3	30	34	37
Customer BE	30	7	13	41	3	30	34	37
Customer DE	29	3	24	35	1	30	31	33
Customer NL	29	6	17	43	2	30	33	35
Customer UK	29	4	20	36	2	30	32	36

EDC Strategy

name	avg	std	min	max	hw	num	75q	90q
Total Costs								
Customer AT	3897	54	3807	4024	20	30	3933	3970
Customer BE	2687	42	2593	2779	16	30	2710	2747
Customer DE	2977	8	2956	2988	3	30	2983	2987
Customer NL	2602	26	2544	2668	10	30	2611	2631
Customer UK	2935	13	2908	2960	5	30	2944	2953
Transport Costs								
Customer AT	1209	8	1193	1224	3	30	1215	1218
Customer BE	391	3	382	397	1	30	393	394
Customer DE	841	1	837	843	0	30	842	842
Customer NL	337	1	336	339	0	30	338	338
Customer UK	727	9	702	739	4	30	736	739
Handling Costs								
Customer AT	171	1	169	174	0	30	172	173
Customer BE	125	1	124	126	0	30	126	126
Customer DE	155	0	155	156	0	30	155	155
Customer NL	140	0	140	140	0	30	140	140
Customer UK	172	0	172	174	0	30	173	173
Holding Costs								
Customer AT	877	41	808	975	15	30	906	933
Customer BE	763	34	689	837	13	30	783	813
Customer DE	614	7	597	624	2	30	619	622
Customer NL	722	20	676	774	8	30	729	745
Customer UK	660	8	643	678	3	30	666	670
Shipping Costs								
Customer AT	1529	7	1516	1542	3	30	1533	1538
Customer BE	1340	0	1340	1340	0	30	1340	1340
Customer DE	1340	0	1340	1340	0	30	1340	1340
Customer NL	1340	0	1340	1340	0	30	1340	1340
Customer UK	1340	0	1340	1340	0	30	1340	1340
Storage Costs								
Customer AT	110	13	90	140	5	30	118	128
Customer BE	68	10	47	90	4	30	73	84
Customer DE	27	2	22	29	1	30	28	29
Customer NL	63	6	49	79	2	30	65	69
Customer UK	36	2	31	41	1	30	37	39

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