Transportation Planning and Technology

ISSN: 0308-1060 (Print) 1029-0354 (Online) Journal homepage: https://www.tandfonline.com/loi/gtpt20

In Search of the Link between Ship Size and Operations

Christa Sys , Gust Blauwens , Eddy Omey , Eddy Van De Voorde & Frank Witlox

To cite this article: Christa Sys , Gust Blauwens , Eddy Omey , Eddy Van De Voorde & Frank Witlox (2008) In Search of the Link between Ship Size and Operations, Transportation Planning and Technology, 31:4, 435-463, DOI: 10.1080/03081060802335109

To link to this article: https://doi.org/10.1080/03081060802335109

Published online: 22 Aug 2008.

Transportation Planning and Technology, August 2008
Vol. 31, No. 4, pp. 435–463

Routledge
Taylor & Francis Group

ARTICLE

In Search of the Link between Ship Size and Operations

CHRISTA SYS*,†, GUST BLAUWENS**, EDDY OMEY†, EDDY VAN DE VOORDE** & FRANK WITLOX‡

**Faculty of Applied Business, University College Ghent, Henleykaai, Gent, Belgium; **Department of Transport and Regional Economics, University of Antwerp, Prinsstraat, Antwerpen, Belgium; †SHERPPA, Ghent University, Tweekerkenstraat, Gent, Belgium & ‡Department of Geography, Ghent University, Krijgslaan, Gent, Belgium*

(Received 7 November 2006; Revised 27 June 2008; In final form 8 July 2008)

ABSTRACT Since 1990s the liner shipping industry has faced a period of restructuring and consolidation, and been confronted with a continuing increase in container vessel scale. The impact of these changes is noticeable in trade patterns, cargo handling methods and shipping routes, in short 'operations'. After listing factors influencing size, growth in container ship size is explained by economies of scale in deploying larger vessels. In order to quantify economies of scale, this paper uses the liner service cash flow model. A novelty in the model is the inclusion of +6000-20-foot Equivalent Unit (TEU) vessels and the distinction in costs between single and twin propeller units on ships. The results illustrate that scale economies have been – and will continue to be – the driving force behind the deployment of larger container vessels. The paper then assesses the link between ship size and operations, given current discussions about the increase in container vessel scale. It is found that (a) ship size and operations are linked; (b) optimal ship size depends on transport segment (deep-sea vs. short-sea shipping, SSS), terminal type (transhipment terminals vs. other terminals), trade lane (East-West vs. North-South trades) and technology; and (c) a ship optimal for one trade can be suboptimal for another.

KEY WORDS: Liner shipping; containership size; container operations; economies of scale

Correspondence Address: Christa Sys, Faculty of Applied Business, University College Ghent, Henleykaai 84, B-9000 Gent, Belgium. Email: christa.sys@hogent.be

ISSN 0308-1060 print: ISSN 1029-0354 online
DOI: 10.1080/03081060802335109

Introduction

History tells us that the liner shipping industry has been characterised by a number of profound changes, starting from the introduction of the container box in the early 1960s, the set-up of consortia and other operational agreements (1970–1980), and in the 1990s, the formation of (global) alliances. These alliances have made it financially possible to deploy bigger ships which, in turn, allow the economies of scale associated with such vessels (Ham, 2004; Stopford, 2004; European Commission, 2005; UNCTAD, various editions). The planned abolition of the European conferences in October 2008 puts the liner shipping industry on the threshold of a new era.

The maritime landscape, which plays a vital role in industrial and economic development, was redesigned by successive waves of consolidation. The first consolidation in the liner shipping industry took place around 1995. Ten years later a second consolidation round started. In Mid-June 2005, the liner shipping industry was shaken up by the takeover of Royal P&O Nedlloyd by Maersk Sealand (since known as Maersk Line). No doubt this merger will redesign the liner shipping industry and inevitably provoke others to follow, as can already be noted (Fossey, 1990; Brooks, 2000; Containerisation International, various editions). After all, liner shipping is an example of an oligopolistic market where interdependence is a key feature (Lipczynski *et al.*, 2005). The question becomes: Will the trend towards mega concerns affect the operations of liner shipping companies? If so, how?

The focus of this paper is to examine from an economic point of view the way ship size is linked with operations. The paper is divided into four sections. In Section 'Market Configuration' the configuration of market is explained. The next two Sections focus on the concept 'Optimal Ship Size' and 'Optimal Ship Operations', respectively. The Section 'The Link between Ship Size and Operations' outlines the link between both concepts. Finally, conclusions are drawn in the Section 'Conclusions'.

Market Configuration

Firstly, the world's pure cellular fleet capacity (or the capacity of container ships fitted throughout with fixed or portable cell guides for the carriage of containers, *OECD Glossary of Statistical Terms, 2008*) as at 1 January 2008 was assessed at 4312 vessels with a total nominal capacity of about 11 million 20-foot Equivalent Unit (TEU) (BRS, 2008). Assuming that all vessels are delivered as contracted and with the sustained minimum scrapping taking place, this carrying capacity is forecasted to increase by another 15.18% during 2009, 14% during

2010, 13.71% during 2011 and by 8.59% by 2012 (see Table 1 – Figures refer to 1 January of each year. The figures for the period 2009–2012 have been derived from the order book. As liner operators can still book orders for delivery in 2010, the figures for the period 2010–2012 are not yet definitive). The 10 million-TEU barrier was overstepped in 2007.

Secondly, we zoom in on the evolution of the world container fleet over two decades (see Table 1 – compiled with data from BRS, 2008 and Drewry Shipping Consultants, 2005). While the number of ships grew by a factor of five, the carrying capacity (TEU) increased at twice that rate. In combination these two aspects show that average ship size increased from about 1306 TEUs at the end of the 1980s up to 2533 TEUs (2008). Consultancy reports confirm that this trend of increased average ship size will continue. The trend forecast suggests that the average size will move to about 3300 TEUs in 10 years' time (Drewry Shipping Consultants, 2005).

In detail, Table 2 shows the distribution by size range of the newly delivered ships in the respective years (BRS, 2008). While in 1995, nine new vessels were deployed with a capacity in the size range of 5001–6000 TEUs, a decade later, 76 vessels were delivered with a capacity of over 5000 TEUs. Although the smallest size segments still account for the largest share, a shift towards larger ships is noticeable. Looking at

Table 1. Evolution of the cellular fleet 1988–2010

Year	Number of ships	Index	Carrying capacity (TEU)	Index	Growth %	Average ship size
1988	1151	100	1503244	100		1306
1998	2332	203	3875130	258		1662
1999	2512	218	4296511	286	10.87	1710
2000	2611	227	4525919	301	5.34	1733
2001	2735	238	4936737	328	9.08	1805
2002	2892	251	5540085	369	12.22	1916
2003	3033	264	6125493	407	10.57	2020
2004	3174	276	6667758	444	8.85	2101
2005	3347	291	7318184	487	9.75	2186
2006	3606	313	8258608	549	12.85	2290
2007	3943	343	9587306	638	16.09	2431
2008	4312	375	10921474	727	13.92	2533
2009	4798	417	12579049	837	15.18	2622
2010	5240	455	14340308	954	14.00	2737
2011	5600	487	16306339	1085	13.71	2912
2012	5788	503	17706885	1178	8.59	3059

the cellular ship deliveries for the period 2008–2011, one can conclude that this trend will continue (see Figure 1) (BRS, 2008).

Ultimately, the container liner shipping industry is currently undergoing a period of unprecedented structural growth, in terms of both volume and ship size. Table 3 shows the evolution of the biggest ships (listed by TEU) in the world, the information about the owner and the characteristics of the ship (i.e. length over all (length o.a.), beam, draught, TEU, Gross Register Ton (GRT), and Deadweight Tonnage (DWT) (compiled with data from www.answer.com and information from liner operators).

The impressive size growth – particularly during the last decade – is astonishing, especially when compared with the preceding period of 25 years. In the latter period (1970–1995) the vessel size tripled, while during the last 10 years it almost doubled.

The official number of TEU is not necessarily the same as the nominal number of TEU the ship can carry. In the column of the TEU characteristics in Table 3, the nominal values between brackets can be noted. Maersk Line for instance does not quote the TEU capacity of its ships in the same way as other liner shipping operators. Maersk Line quotes the maximum load capacity of their ships in terms of filled TEUs with a 14 tonne load (tare weight included). This will always result in a smaller TEU capacity than the true TEU capacity (i.e. the ship MS 'Axel Maersk' most likely has a capacity of 8650 TEU instead of the reported 7226 TEU).

Assuming that a 13,500-TEU vessel is soon to be deployed, how does this reflect on the problematic nature of draught and accessibility of ports (see Section 'Optimal Ship Operations')? Further research yields the following explanation: a containership cannot transport its nominal capacity, even if we are talking about empty containers. A hypothetical

Table 2. Number of ships newly deployed

Year Range in TEU	1990	1995	2000	2005	2006
1001–2000	31	51	43	47	95
2001–3000	16	16	20	44	71
3001–4000	4	13	7	7	24
4001–5000	7	22	18	40	35
5001–6000		9	23	34	20
6001–7000			5	3	13
7001–8000				7	5
8001–9000			4	24	33
9001–10,000				8	20
Total	58	111	120	214	316

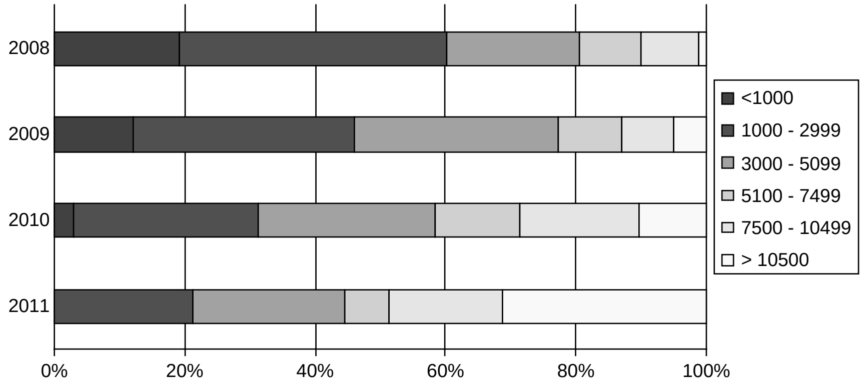

Figure 1. Cellular ship deliveries

example illustrates this point: suppose all 20-foot containers are filled with sand, and each container loaded up to a weight of $18t+2t$ (weight of the container) or $20t$. Multiplying the weight by the number of slots, viz 9580 TEUs, equals 191,600*t*, which exceeds the deadweight of the ship (11,5000*t* – see Table 3). Starting from its deadweight and using the Maersk Line rule of thumb, a 9580 vessel could transport about 8214 TEUs loaded (115,000*t*/14*t*).

Linking weight with trade lane, vessels on the Far East/Europe trade lane are fully loaded by TEU and not by weight. On the contrary, the African trade lane is characterised by heavy cargo (e.g. chemicals), so here the vessels are fully loaded by weight and not on slot capacity.

Besides the characteristics of cargo, the commercial aspect also plays an important role. In a very competitive environment on the one hand and with the forecasted risk of overcapacity on the other, it will become hard to sell all slots of these larger vessels. We can cautiously conclude that the problem of accessibility of ports is not an issue yet, as vessels are seldom fully loaded by weight and, in addition, main ports respond largely by intensive dredging investments (see Section 'Optimal Ship Operations').

The shift towards larger ships seems to continue, possibly even up to 18,000 TEUs (known as the Malacca-max vessels which refers to the maximum size and draught to transit the Strait of Malacca, a vital part of the Asian trade route). Although it is not clear if and when an 18,000-TEU containership with an allowable draught will be built, it is fairly certain that the recent surge in vessel size will not stop at the barrier of 11,000 TEUs. Technically there seem to be no limitations.

Table 3. The biggest ships (listed by TEU) in the world

Built	Name	Length o.a.	Beam (m)	Beam (TEU)	Draught	TEU	GRT	DWT	Owners
2006	Emma Maersk	394.00 m	56.40 m	17 (22)	16.00 m	11,000 (13,460)	n.n	173000	Maersk Line/Denmark
2006	COSCO Guangzhou	350.00 m	45.60 m	17	15.00 m	9580	105000	115000	China Shipping Container Lines
2005	MSC Pamela	336.70 m	45.60 m	18	15.00 m	9200	107849	109600	MSC/Switzerland
2004	CSCL Europe	334.00 m	42.80 m	17	14.50 m	8468	90465	101612	China Shipping Container Line
2003	OOCL Shenzhen	322.97 m	42.80 m	17	14.50 m	8063	89097	99518	OOCL/Hongkong
2003	Axel Maersk	352.10 m	42.80 m	17	15.02 m	7226 (8650)	93496	109000	Maersk Sealand/Denmark
1997	Sovereign Maersk	346.98 m	42.80 m	17	14.50 m	6600 (8050)	91500	104690	Maersk Line/Denmark
1996	Regina Maersk	318.24 m	42.80 m	17	14.00 m	6000 (7048)	81488	82135	Maersk Line/Denmark
1995	OOCL Hongkong	276.02 m	40.00 m	16	14.00 m	5344	66046	67637	OOCL/Hongkong
1991	Hannover Express	294.00 m	32.30 m	13	13.50 m	4639	53783	67686	Hapag-Lloyd/Germany
1988	Marchen Maersk	294.12 m	32.22 m	13	11.00 m	4300	53600	60639	Maersk Line/Denmark
1984	Louis Maersk	270.00 m	32.30 m	13	11.00 m	3390 (3700)	43392	53395	Maersk Line/Denmark
1981	Frankfurt Express	287.73 m	32.28 m	13	13.06 m	3430	57540	51540	Hapag-Lloyd/Germany
1972	Hamburg Express	287.70 m	32.20 m	13	12.04 m	3010	58088	47995	Hapag-Lloyd/Germany
1972	Tokyo Bay	289.32 m	32.26 m	13	13.00 m	2961	58889	47462	OCL then P&O/GB
1971	Kamakura Maru	261.00 m	32.20 m	13	12.00 m	2500	51069	35737	NYK/Japan
1970	Sydney Express	217.00 m	30.58 m	12	11.58 m	1665	27407	33350	Hapag-Lloyd/Germany
1969	Encounter Bay	227.31 m	30.56 m	12	9.00 m	1572	28800	28794	OCL then P&O/GB
1968	Hakone Maru	187.00 m	26.00 m	10	9.00 m	752	10423	14745	NYK/Japan

Optimal Ship Size

Wijnolst *et al.* (1999) states that the driving force is the creation of a competitive advantage through economies of scale. The Malacca-max design has an overall lower cost level of approximately 16% over the current largest container ships of 8000 TEUs. In a world of cut-throat competition, 16% can make a decisive difference. From a technological point of view, 18,000 TEUs can be considered as the maximal ship design, but it is not the optimal ship size.

Factors Influencing Size

Various technical studies have shown that the deployment of larger container ships is feasible and that there are neither technical limitations nor market obstacles to introducing them (Wijnolst *et al.* 1999; Akiyama *et al.*, 2002; Ham, 2004). Currently, further engineering is still needed regarding future Panamax vessels and new logistical concepts are required. The tremendous growth in ship size makes it necessary to look for a systematic explanation of the factors influencing the size of ships.

The driving variables were obtained by reviewing the relevant literature and from interviews with liner carriers and shippers. After listing the variables, it became clear that the criterion for cataloguing the driving key factors would be a synthesis of the different points of view of all players involved. In clockwise order this includes the shipper, the (port) authorities, technology, the terminal operators, the carrier and finally, though not least important, market-driven forces. The result of the driving variables pushing the vessel scale is shown in Figure 2.

From the viewpoint of the carrier, the response to the expanding market, the permanent strive for cost cutting, the formation of strategic cooperation, and most particularly the (global) alliances have fuelled the upsizing trend. Economies of scale, the engine that drives the scale of the container ship, exist when the unit costs of operating a ship decrease as the size of containerships increases. In a very competitive market new building orders for bigger ships provoke others to follow. These orders have not been solely placed by alliance members. In an attempt to maintain their market share by keeping pace with this level and type of investment, most major independent liner operators have also placed orders for such vessels.

In addition, other variables such as the increase in the worldwide demand for liner shipping, technological evolution (e.g. the development of the 45’ high cube/pallet wide containers), ongoing conversion of cargoes to containerisation, etc. have also contributed to the increase

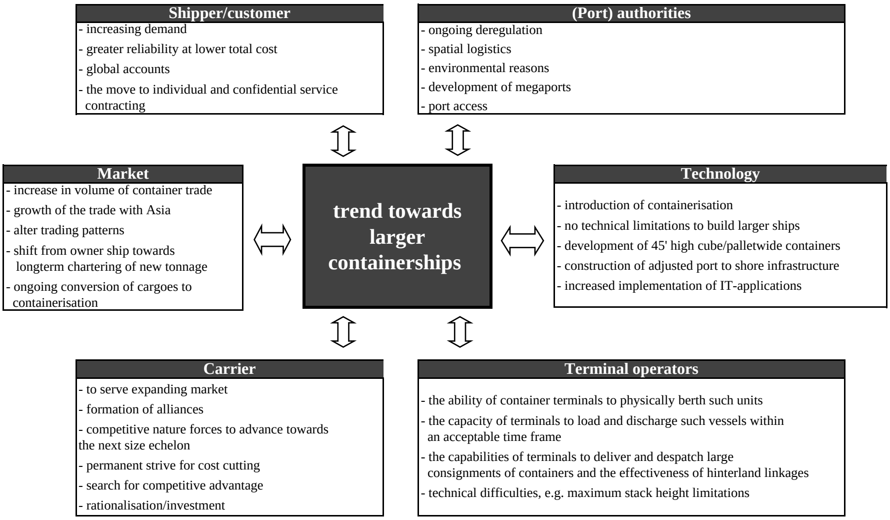

Figure 2. Influencing key factors

in container vessel scale. The economies of scale definitely form the main variable. But, without any doubt, the interaction between all factors plays a very important role in this upsizing movement.

Optimal (Ship) Size

In general, micro-economic theory links the size of a company to efficiency; that is to say, a size that minimises average long-run costs. Furthermore, the size of a business depends on the market that it is in. If demand is not sufficiently great, it is not possible to produce at the minimum efficiency level, even if it is technologically possible to take advantage of the economies of size.

Another approach refers to economies of scale, which are predominantly of a technical nature and which determines the optimal size of the firm (Baumol, 1982). However, organisational factors also have an influence on the optimal size, possibly creating diseconomies of scale, and thus changing the optimal size of the firm. Consequently, the balance between the predominance of economies of scale and the predominance of diseconomies of scale determines the optimum size of a company.

Size, a common denominator for ships expressing type as well as capacity (TEU), is singled out as the most important design variable or analytical tool for liner service optimisation.

Before the 1970s the theory was to use the largest ship possible that could be accommodated at both origin and destination ports (Heaver, 1968; Van de Voorde, 2005). Since then, the subject of optimal ship size has received a lot of attention from transport economists (Heaver, 1968; Goss, 1971; Kendall, 1972; Jansson & Shneerson, 1982, 1987; Talley, 1990; McLellan, 1997; Lim, 1994, 1998; Cullinane & Khanna, 1999, 2000; Stopford, 2004; Imai *et al.*, 2006). Nowadays, we know that other determinants, such as volume of trade, length of route, sailing frequency, the number of port calls, etc. also influence ship size. Regarding the number of port calls, an interesting question is: Is the reduction in the number of ports due to the dimensions of the ships or do liner operators in some cases decide to tailor their ship size to a port/region? The right answer probably lies somewhere in between.

A scan of the literature yields the following definitions:

Kendall (1972) describes the optimum size of a ship used on a particular route as the size which minimises total transport costs. By 'total transport costs' he does not only mean those costs incurred by the ship at sea, but also the related cost of the terminals at either end of the voyage (port costs – dredging, berthing, . . . , handling costs, storage costs). This definition already refers to the link with operations, which will be explored in Section 'The Link between Ship Size and Operations'.

According to Jansson and Shneerson (1982), optimal ship size is obtained by trading off economies of size in the hauling operations with diseconomies of size in the handling operations. In port, handling costs per ton increase with ship size, while hauling costs per ton at sea, on the other hand, decline with size. Talley (1990) defines optimal ship size as the containership size that minimises the cost per TEU moved per voyage leg (between two port calls) on a given route. Cullinane and Khanna (1999, 2000) and Stopford (2004) refer in their studies regarding optimal ship size to economies of scale as the determinant for optimal ship size.

Previous maritime studies provide an insight into the concept 'optimal ship size' but exclude from their model the costs linked with cargo handling, shore infrastructure, etc. (Heaver, 1968; Jansson & Shneerson, 1987; Cullinane & Khanna, 1999, 2000). Given the current expansion towards door-to-door transportation systems, recognition of these costs and their impact on logistic decisions (regarding waiting time, inventory, etc.) must be considered.

From the point of view of a profit-maximising liner operator, the notion 'optimal' is determined by minimising costs per TEU, given the current and forecasted demand. In the next section it will become clear that the optimum is rather a segment than a point estimation. Currently, due to technological advances and specialisation, optimal ship size on a particular route is equal to the number of containers a line can capture between port A and port B on a weekly fixed-day basis by minimising cost per TEU, at sea, in the port and hinterland connection, while still offering the greatest flexibility to liner operators in their movement toward logistic providers.

There are many different factors (e.g. number of ports, time in port, distance, etc.) that might determine optimal ship size and many different points of view of what optimal ship size really is. The fact is that minimising costs per TEU recurs as a crucial element. This point leads to the question: How can we identify the optimal containership?

The optimal containership size can be found by studying the economies of scale in deploying larger vessels. In order to quantify the economies of scale, this paper uses the liner service cash flow model of Stopford (2004). This model is based on a transatlantic round-trip voyage, assuming a hypothetical weekly service frequency, an 8500-mile distance, an average operating speed of 19 knots, seven port calls and a capacity utilisation of 80% outward and 90% return. The model consists of two levels. Level one constructs the six components of liner service costs (viz. service schedule, ship costs, port charges, container operations, container costs and administration costs). In the second stage the calculated costs are used in a cash flow model. The model was later updated by Notteboom (2000). In addition, he linked the days/portcall with ship size. Stopford's and Notteboom's calculations are limited to ships up to 6500 TEUs.

For an impact analysis of economies of scale, we focus on ship costs, more specific on the unit cost per TEU (expressed in terms of USD/day) by comparing different ship sizes. The unit cost per TEU (USD/day) is defined in the following way:

$$\text{Unit cost per TEU (USD/day)} = \frac{\text{operating cost (USD/day)} + \text{capital cost (USD/day)} + \text{bunker cost (USA/day)}}{\text{ship size (TEU)}}$$

Given the increase in container vessel scale, it is most interesting to enlarge the model with +6500-TEU vessels. In this paper the model has been expanded to include ship sizes up to the hypothetical 18,000 TEUs. Another novelty in the model is the distinction in costs between single and twin propeller units on ships. The use of single-propeller units on ships larger than 10,000 TEUs would require progressively longer engine rooms to accommodate such installations. Given the current structural implications it has been assumed, in our model, that ultra large containerships are equipped with a twin-propeller configuration. Ship owners opting for a twin configuration would have to be assured that operating costs would more than compensate for higher capital costs.

Two scenarios were computed. In the cost assessment of containerships exceeding current sizes, the assumptions of Stopford's model were, in a first stage, maintained and extrapolated (s1). Subsequently the cost calculation (s2) was repeated taking into account that:

- by the end of 2005, on the transatlantic trade, outward capacity utilisation was 68% and return capacity utilisation was 80% instead of 80 and 90%, respectively (Drewry Shipping Consultants, 2005);
- the average speed for vessels larger than 4500 is 21.5 knots rather than 19 knots;
- the moves per hour/crane are for the first three categories 30 moves/hour/crane, for the next three ship sizes 45 moves/hour/crane and for the remaining sizes 50 moves/hour/crane as the productivity of new cranes improves;
- the number of cranes increases gradually. In this calculation it is assumed that four cranes will be used for a 6500-TEU vessel, five cranes for the next two sizes and up to six cranes for the ultra-large container ships (ULCSs); and
- the capital cost is updated.

The data, processed in a standard spreadsheet application, were obtained from *The Drewry Annual Container Market Review and Forecast* (DSC, various editions) and from interviews with sales managers of top 10 liner carriers. The results of both calculations are shown in Table 4.

On closer analysis of the results of the first calculation (s1), we notice – not surprisingly – that savings are achieved by using bigger ships. The unit cost per TEU drops from 16.59 $/TEU/day for a 1200-TEU ship to about 6 $/TEU/day for a ship whose carrying capacity is 10 times

Table 4. Results of cost calculation – 2005

	Unit cost per TEU (USD/day)			
Ship size	Calculation 1		Calculation 2	
1200 TEU single propeller	16.59		15.10	
2600 TEU single propeller	11.06	–33.33%	10.10	–33.11%
4000 TEU single propeller	9.50	–14.10%	8.34	–17.43%
6500 TEU single propeller	7.45	–21.58%	6.63	–20.50%
7500 TEU single propeller	7.20	–3.36%	6.25	–5.73%
8500 TEU single propeller	7.02	–2.50%	5.97	–4.48%
10,000 TEU single propeller	6.52	–7.12%	5.63	–5.70%
12,500 TEU single propeller	6.02	–7.67%	5.45	–3.20%
10,000 TEU twin propeller	7.70		6.63	
12,500 TEU twin propeller	6.75	–12.34%	6.04	–8.90%
15,000 TEU twin propeller	5.97	–11.56%	5.73	–5.13%
18,000 TEU twin propeller	5.35	–10.39%	5.35	–6.63%

bigger (see Table 4) (1 US$: € 0.64). The rationale for this conclusion is that unit cost generally falls as ship size increases, because capital, operating and cargo handling costs – key elements in the economies of scale calculation – do not increase proportionally with capacity. For example, a 12,500-TEU ship only costs twice as much as a 5000-TEU ship, but carries more than two and a half times as many containers. Further increases in vessel size provide only limited unit cost reductions. Once the 7500-TEU barrier is exceeded, the economies of scale diminish very rapidly, which is in line with the results of the Malacca report (Wijnolst *et al.*, 1999).

Graphically, the economies of scale curve relates the unit cost per TEU (US$/day) on the vertical axis to ship size (TEU) on the horizontal axis (see Figure 3). Introducing the distinction between single vs. twin-propeller configuration results in a split economies of scale curve (see the dotted line in Figure 3).

Comparing the results of the size bracket [10,000 TEUs–12,500 TEUs] from a cost perspective, a liner operator will rather opt for a single-propeller than a twin-propeller configuration. It goes without saying a twin-propeller configuration is more costly (initial cost, maintenance, etc.). But then again, it also has some advantages: (a) the second propeller serves as a spare part; (b) increased manoeuvrability; (c) it economises on the number of tug boats, etc.

In the second scenario (s2), Stopford's assumptions were altered (as above). The results are also shown in Table 4 (second calculation – s2). The conclusion of the adjusted calculation does not diverge from the conclusion of the first. For the majority of vessel sizes the unit cost per

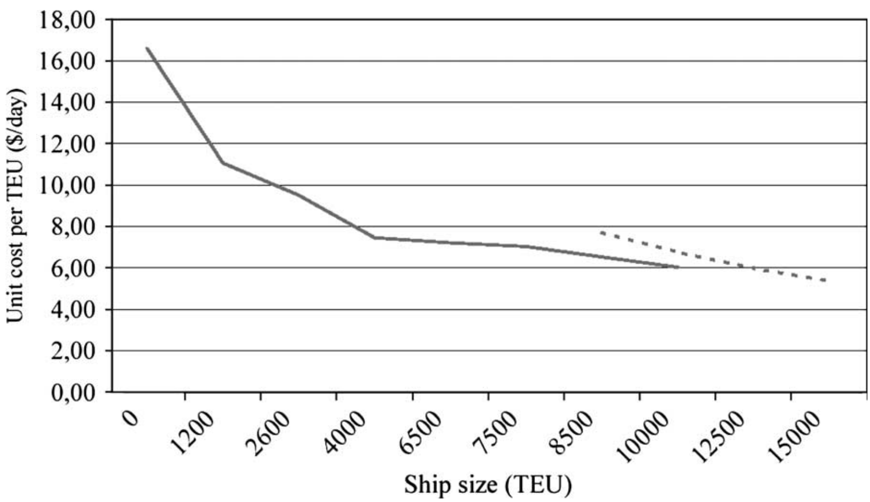

Figure 3. Economies of scale curve – s1

TEU is lower. Again, the cost falls sharply when sizing up towards 4000 TEUs, and in the larger categories the marginal return levels off. The results of both calculations are shown graphically in Figure 4.

The cost curve of the second calculation is situated below the curves of the first calculation. The marked full line corresponds with ship sizes fitted with a single propeller (i.e. 1200 TEUs–12,500 TEUs), while the marked dotted line shows the cost curve for ships equipped with a twin propeller (i.e. 10,000 TEUs–18,000 TEUs). The grey colour illustrates the economies of scale curve of the first calculation (s1), while the black curves show the results of the second calculation (s2) for both single (marked full line) and twin propeller (marked dotted line). By coincidence, the latter curve overlaps and continues the economies of scale curve of the first calculation (full grey line), giving the false impression that +12,500-TEU ships will be equipped with a single propeller. Again the curve becomes very flat and the optimal ship size seems to become very large.

When looking to minimise costs, a liner operator should opt for the largest ship available. But there is far more than this to take into consideration.

First, the determination of optimal ship size is undeniably linked to operational occurrence (see Section 'Optimal Ship Operations'/'The Link between Ship Size and Operations'). Secondly, the port-to-port cost saving will only be achieved if the vessel is fully utilised. Poor slot utilisation can have an impact on carriers' revenues and lead to lower profitability.

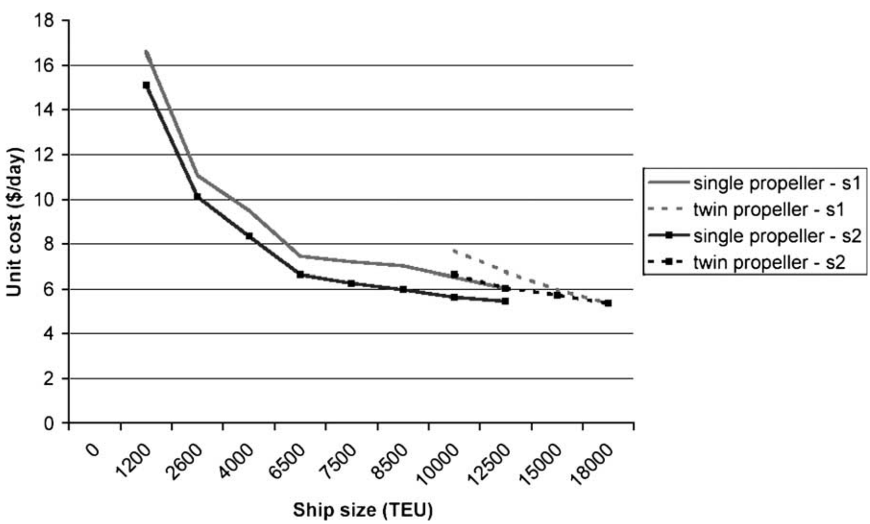

Figure 4. Economies in scale curve – s1 & s2

Furthermore, the deployment of larger ships will also increase an operator's cost base as additional sales and marketing staff may have to be employed, particularly if new trades are targeted to provide the additional cargo necessary to load the vessels and if operations are reconfigured.

Eventually, if the additional feeder, transhipment and landside distribution costs are taken into account, the cost per TEU will hypothetically increase for 12,500-TEU, 15,000-TEU and 18,000-TEU vessels. The shape of the economies of scale curve (see Figure 4) is likely to change into a U-shaped curve (see Figure 5). If this proves to be the case, the size bracket [10,000 TEU–12,500 TEU] appears to be the optimum, under the assumptions that the carrier operates efficiently and that there is sufficient volume on a particular trade.

This latter assumption cannot be ignored. Returning to the starting point, the cost calculation is based on a transatlantic round-trip voyage. The long-term prognosis for this trade, according to Drewry Shipping Consultants, is not very promising, with growth in both directions forecast to be in the 2 to 2.5% range for the foreseeable future (Drewry Shipping Consultants, 2005). Even though a liner operator wants to reduce unit costs (i.e. to achieve economies of scale) and to increase income (i.e. to gain greater market power), on the transatlantic trade lane smaller ships will be put in service compared with the other major line routes (see Section 'The Link between Ship Size and Operations'). Thus features such as demand, space for future volume growth and cargo imbalances also need to be examined.

Another important issue is the infrastructure needed at ports to accommodate large ships. The trend toward increased size of containerships presents challenges not only for liner operators, owners,

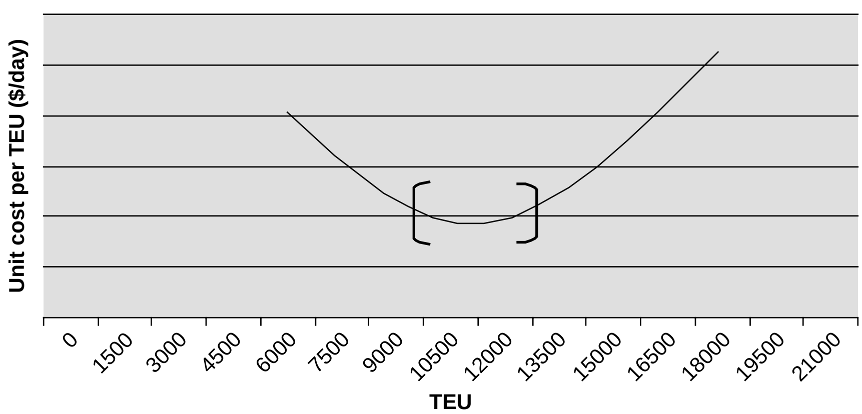

Figure 5. Interval estimation of optimal ship size

designers and classification societies, etc, but especially for operational managers. This brings us to a discussion of the impact of vessel scale increase on operations.

Optimal Ship Operations

Optimal ship operations should be interpreted in a broader sense than ship operational management. Optimal operations include:

- linking economic centres by choosing the right route with the best number of port calls, taking into account the possibilities of feeder and hinterland connections;
- a reasonable frequency: this should be interpreted for the liner operator as, for example, offering a weekly fixed-day service with the smallest number of ships employed. Setting up a weekly service on the Europe-Far East line will require the deployment of seven to eight ships; for the transpacific, five vessels employed is sufficient;
- an efficient agency network;
- a sufficient number of stevedores providing a reliable service;
- good logistical support; and
- acceptable port conditions (i.e. port entry charges – port and canal dues, frequency reduction, pilotage, etc. if applicable, acceptable time-windows, etc.).

In other words, optimal operations involve all aspects geared towards minimising cost. The impact of previously listed aspects should be integrated into the outline of costs (e.g. the impact of frequency on waiting time cost, inventory cost, etc.) (Witlox & Vandaele, 2005; Blauwens *et al.*, 2006).

Clearly, the central question regarding optimal ship size cannot be studied without reference to operations. In the decision process, liner operators take into account potential implications on ports by deploying ever-larger vessels.

In the past, ports and terminals have responded to size increases by making large and rapid investments in infrastructure in order to cope with these new vessel sizes. Until now they could provide whatever capacity to ensure that the vessel only stayed in port for a brief period. But the movement to the next size echelon has struck terror into the hearts of terminal operators (Stopford, 2002).

Opting for minimisation of the number of port calls (see Section 'The Link between Ship Size and Operations'), container shipping alliances, as well as independent lines, put pressure on domestic ports to keep skylines. Moreover, the movement towards larger ships confronts the port authorities with a number of pressing issues with regard to investing in stronger tugs; deepening and/or widening approach channels, port and turning basins; environmental and regulatory constraints; expansion projects; organising traffic (deepsea – shortsea – barges); etc.

At present, the limiting factor is water depth in ports and navigable waterways. Rumour has it that in future the limiting factor will no longer be vessel draught but rather vessel length (i.e. turning circle). An indication can be found in the expansion plans of the Bremerhaven Basin in Germany. Extra limiting factors will be air draft, bending moment and torsion of the vessel.

Returning to water depth, the current 14m-scantling design draught of +6000-TEU ships already poses problems. Table 3 shows that since containerisation vessel draught has climbed gradually from 9m up to 16m. It also clearly shows the changes in design, concentrating on length, followed by beam and design draught. As ships get deeper, a number of ports will be faced with restrictions on their capacity to handle them (e.g. East Coast US ports). Table 5 shows draught of the top 20 container ports and some secondary ports in alphabetical order. Note that the maximum draught should be taken with a pinch of salt. In practice the draught is smaller (i.e. Antwerp: 14m). In addition, Table 5 does not take into account the sequence of the port in a loop. The draught criterion maybe less determined for the fifth port of the loop.

Bearing in mind that Table 5 is just a snapshot, two scenarios are possible: (a) for future ULCS's the list becomes more limited. This, in its turn, will encourage the further development of a selected number of big transhipment hubs for containerships, which will cause fierce competition between ports and terminals wishing to become one of these few gigahubs (i.e. Tanjung Pelepas vs. Singapore); or (b) main ports/terminals will remain the focus of large-scale major dredging and

Table 5. Draught of container ports – 2005

Port	Draught	Port	Draught	Port	Draught
Amsterdam	14m–15m	Hong Kong	12.2m–15m	Rotterdam	10.65m–13.5m
Antwerp	7.5–16.7m	Kaoshiung	12m–15m (*)	Seatle	9m–15m
Bremerhaven	14.6m	Laem Chabang	14m	Shanghai	9.4m–12.5m
Busan	11m–15m	Long Beach	11m–15.2m	Shenzhen	6.5m–14m
Dubai	14m	Los Angeles	n/a	Singapore	8.9m–15.3m
Dunkirk	12.5m	Marseille	14.5m	Tacoma	15.24m
Felixstowe	9.75m–15m	New York	11m–13.5m	Tanjung Pelepas	15m
Gioia Tauro	12.5m–14m	Port Kelang	10.5m–13m	Tokyo	12m–15m(**)
Hamburg	14.5m	Quingdao	7.2m–14.5m	Zeebruges	15m–16m

*Four terminals with a draught of 12m, 1 of 13m, 14 of 14m and 3 of 15m.

** >Five terminals with a draught of 15m.

port infrastructure developments to cater to them, while other ports/ terminals will need to focus on niches (Fairplay, 2005; Lloyd's List, 2004).

The latter scenario suggests that port and terminal operators must take action and, moreover, continue to respond by investing in terminals and in larger ship-to-shore handling equipment. Taking into account that the next generation of quay cranes with their ever greater outreach ($\pm$65m) and lift capacity will cause higher loads on the wheels, quay walls must be stronger, and this has implications on quay wall construction methods, a serious concern for all container ports (Drewry Shipping Consultants, 2001).

In addition to investment decisions about ship-to-shore equipment, terminal operators are also confronted with an increased quantity of TEU handling, partly due to their clients' enormous growth in tonnage. As their clients grew – in tonnage as well as in market power – terminal operators had to follow, if they wanted to carry on independently from any shipping line. Terminal operators have to be extremely cost-conscious, as the handling rate remains the principal factor for the liner operator when selecting a port and an operator. From this point of view, the advent of ever-larger container vessels necessitates port decisions regarding the container yard area, higher yard stacking, terminal automation, improved gate system, reduced container dwell times, security and safety issues, environmental aspects (e.g. the EU habitat directive), the depth of berth, etc.

Berth time is an ever more critical aspect. A lot of equipment and work force are required when such a mega-vessel arrives. Can a terminal handle these ships cost-effectively? Will the handling cost remain relatively constant? Over time as vessel size increased, berth productivity (moves/vessel/hour) became ever more important to guarantee that vessels could adhere to their sailing schedule. The operating system enabling these high productivities is the so-called 'direct straddle carrier system'. A fully automated yard management and operation planning system is necessary to exploit the potential of the straddle carrier. Terminal operators also need to consider decisions regarding new IT and communication systems, Internet applications, etc. with regard to this operating system.

Another question emerges: Is handling a 12,500-TEU vessel comparable to the handling of two 6000-TEU ones? To answer this question, one needs to know what is required to cater to an ULCS or vessels with a nominal capacity in excess of 10,000 TEU. Table 6 compares the requirements concerning berth length, depth alongside, etc. for both ship sizes (revealed from interviews (2005) and Rizvi, 2003).

Besides longer/deeper berth dimensions and a bigger terminal area, wider vessels will require container terminals to invest in longer cranes

Table 6. Terminal requirements

	6000 TEU	12,500 TEU
Berth length	350m	450m
Depth alongside	14m	15.5–16.0m
Approach channel depth	14m	18.0–19.0m
Terminal area	16.0 ha per berth	22.5 ha per berth
Gantry cranes	45m outreach/45 cycles per hour	63m outreach/45 cycles per hour

that can handle +20-container-wide vessels. The main aspect is rather the number of gantries (or port cranes used to load and discharge containers from vessels able to be positioned by moving along rail track) and straddle carriers (or wheeled vehicle designed for loading containers onto or unloading them from a trailer, and carrying them to and from a stacking area, *Port Glossary*) a terminal operator must have at its disposal when a large ship arrives. An excess of terminal handling equipment will jeopardise the overall cost-effectiveness. Furthermore, practise teaches us that the capacity/crane is not the constraining factor; it is rather the system bringing the containers under the gantry crane that plays a key role in the productivity of handling a ship. Depending on the clauses stipulated in the terminal contract, three to five container cranes are used simultaneously for one 6000-TEU vessel. Up to six cranes have to be put into action to load/unload a +12,500-TEU ship. These vessels have to be served in the shortest possible time (typically less than 24 hours, depending on the volume of the cargo). At the same time operations on other vessels must not be hampered by a lack of equipment due to the operations on the ULCS. More and faster container handling is necessary just to keep up with vessel upsizing; otherwise extended port time will destroy the rationale for bigger ships. Thus ship size has a number of effects on container operations.

Whereas, the beam or the number of rows of containers affects the outreach of cranes, the length of ships influences the quay length. Given a quay length of 1000m, two ships of 6000 TEUs can be catered to at the same time. In future a 12,500-TEU ship and, say a 6000-TEU ship can easily be put into action alongside such quay length. Consequently, this will require a significant increase in productivity of terminals.

When dimensions and capacities of the equipment are considered, the impact of the ULCS on the terminal is rather minor. Vessel size has no influence on terminal transport equipment and stacking area design. But what about the size of the terminal? The parameter 'size' is less important, because a containership hardly unloads all its containers in one port. The impact difference between 2x6000-TEU vessel deployment and a 12,500-TEU will be determined by the hinterland (offtake of the containers) and whether or not the terminal is a dedicated terminal, rather than by the size of the terminal. Port operations will not be a bottleneck for their deployment, provided large terminals are called at. However, it seems likely that hinterland connections are becoming a significant factor, as a consequence of the move towards a door-to-door transportation system.

In order to maintain acceptable container line schedules and to compete successfully with smaller container ships, main liner operators are becoming more and more involved in extended partnerships with terminal operators. The huge scale of investment required for container handling operations favours these closer relationships. Besides infrastructure, operational managers are confronted with other issues, such as:

- the lobby of environmental groups against competitiveness and growth of large terminals;
- the containership loading problem;
- lack of qualified people;
- 24/5 or 24/7 availability of the customs office depending on the country;
- hinterland transportation operations; and
- direct service vs. the trend towards hub-and-spoke operations. A hub is the central transhipment point in a transport structure, to which traffic from many ports is directed and from where traffic is fed to other areas/ports (referred as spokes). Given the growing importance of transhipment, 12,000 TEU capacity will most likely be deployed between hubs. Note that the trend towards hub-and-spoke operations is located in the East-West trade, and less in the North-South trade. Moreover, it does not exist in the African trade.

Until now, the trend in the East-West Transpacific trade has been to call direct at as many ports as possible in different loops. In Europe, the biggest ships generally call at two or three Mediterranean ports and around four in the North-West of the continent. The advantages are threefold, keeping transit times and roundtrips as short as possible, limiting expensive feeder operations only to outports and finally, allowing the shipper the advantage of direct port calls. As ship size continues to increase, various studies (Cullinane & Khanna, 2000; Rijsenbrij, 2001; Ham, 2004) forecast that liner shipping companies in search of cost reduction and faster transit times will reduce the number of port calls in favour hub-and-spoke global networks, with mother and feeder services integrated to serve the container trade. This upsizing movement in the main trades creates a corresponding increase in both number and size of feeder vessels. This cascading effect is probably the most important application of scale economies in the container business

(Stopford, 2004). However, other questions arise: will the lower slot cost outweigh the higher feeder cost for ships above 10,000 TEUs? Have we already reached the point at which additional feeder and inventory costs outweigh any further savings in slot costs on main line vessels? Tariffs diverge strongly, depending on the destination variables such as distance, degree of competition, expensive/cheap ports and surcharges such as bunkering adjustment factor (BAF), International Ship and Port Security (ISPS), etc. One thing is certain: what matters is the total cost of the network.

Finally, the logistics of the container flow itself will become more important. Are these flows large enough to maintain container-shipping services with very large ships with a reasonable frequency, knowing that each container transported requires two others, one in the port of origin and one in the port of destination?

The Link between Ship Size and Operations

It is obvious that ship size and operations are linked, but to what extent? After expounding the experience of the sector through interviews, considering the cost price of bigger vessels – chartered or owned – and taking into account the operational process, cost-effectiveness will probably not increase by deploying such ships. There are three arguments to consider:

First, various studies (Cullinane & Khanna, 1999; Ham, 2004) state that larger ships will have access to fewer ports due to the limited draught of the ports (see Section 'Optimal Ship Operations'). The number of port calls by the post-Panamax vessel will be reduced as long as the additional costs for feeder and intermodal connections are lower than the savings from fewer port calls. However, currently this is hardly the case for ship sizes up to 9700 TEUs calling at North European ports. For example, an analysis of the CMA CGM's French Asia Line (FAL) tells us that in 2006 this liner operator gradually replaced the 6500-TEU ships by new ones with a capacity of 8450 TEUs with the same port rotation (Shanghai, Ningbo, Yantian, Hong Kong, Port Kelang, Suez, before calling at Malta and continuing to Le Havre, Rotterdam, Hamburg, Zeebrugge and Southampton) (see Table 7) (Compagnie Maritime d'Affrètement – Compagnie Générale Maritime abbreviates to CMA CGM). Starting in July 2007, the number of port calls in this service increased (+4).

Since August 2006, eight vessels of 9400–9600-TEU capacity have been deployed on the Far East liner service (FAL2) with the liner operator China Shipping Container Line (CSCL). The port rotation is Ningbo, Shanghai, Yantian, Hong Kong, Port Kelang, Le Havre, Rotterdam, Hamburg, Zeebrugge, Port Kelang and back to Ningbo.

Table 7. Overview French Asia Line (FAL)

French Asia Line							
Service name	FAL1			FAL2	FAL3	FAL4	FAL5
Year	jan/06	jul/06	jul/07	aug/06		jul/08	oct/09
Vessel type	6500 TEU	8450 TEU	8450 TEU	9400/9600 TEU	6400/6700 TEU	9700 TEU	11,000 TEU
Port call							
Beirut					×		
Chiwan			×		×		
Dalian			×				
Hamburg	×	×	×	×	×	×	
Hong Kong	×	×	×	×			
Jeddah					×		
Khor Al Fakkan			×				
Le Havre	×	×	×	×	×		
Malta	×	×	×				
Nansha						×	
Ningbo	×	×	×	×	×		
Port Kelang	×	×	×	×		×	
Qingdao					×		
Rotterdam	×	×	×	×	×	×	
Shanghai	×	×	×	×		×	
Southampton	×	×	×		×		
Suez	×	×	×	×			
Tiajin Xingang			×				
Xiamen					×	×	
Yantian	×	×	×	×	×	×	
Zeebrugge	×	×	×	×	×	×	
Number of ports	12	12	16	10	11	8	
Cooperation				50–50 China Shipping Container Line (CSCL)		50–50 China Shipping Container Line (CSCL)	

With the launch of the FAL2 Malta (12m average draught), Southampton (with a 12.6m channel depth) and the ports in the Arabic Gulf were excluded from this rotation. Under the denominator of providing optimum port coverage, FAL 4 (July 2008) and FAL 5 (October 2009 – 11,000 TEUs) are added to the existing FAL network, linking Asia and Europe (FAL1, FAL 2 & FAL3). The launch of the new service, FAL5 will coincide with the process of enlargement, since CMA CGM will in the same year take entities of 11,000 TEUs into service.

Knowing that on the world's densest maritime routes nearly all main ports are considering expansion plans, we assume that for the deployment of +10,000-TEU ships a revision of major loops will result in a reduction in the number of port calls. This trend by no means complies with the preferences of shippers who favour more ports, more routes, shorter transits, greater frequency and all this with a lower freight rate. Economies of scale are the driving force behind the trend of containerships calling at a limited number of big ports. This policy will, therefore, increase transhipment costs as well as the risk of longer transit time for containers that have to be transhipped and relayed, whether by feeder vessel or overland. But how long will carriers be able to follow a strategy of restricting the number of entry ports into Europe to provide opportunity for consolidated freight flows? And what about the impact on service levels? Or are shippers pleased with a lower freight rate for slow moving containers?

Second, not all terminals are dedicated terminals. To unload such large ships three to five gantry cranes are required. Dedicated terminals will organise the process of unloading so that a ship can leave the port as quickly as possible. But will other terminals have the same strategy? Will they only concentrate on the big ships or not?

Third, containerships with higher container capacities have to sail at higher speeds than those with lower capacity, because they need more port time. This is the reason why ship speed is of such enormous importance to large container ships. An hour's time loss in port would require on average a four-knot increase in transit speed to meet the scheduled arrival time. The very large single-propeller containerships cannot reach the required service speed with their current main engines. Large ships, certainly those above 12,000 TEUs, will need twin propellers, and this will logically increase maintenance and fuel consumption. Fuel consumption rises exponentially with increased speed. A rule of thumb: a 10% increase in speed results in about a 30% increase in fuel consumption (www.prads2004.de).

Furthermore, there are financial implications. A ship with a capacity of 10,000 TEUs only has a reduced slot cost with the assumption that the capacity is fully utilised. It is clear that these ships will be deployed on the Far East trade (Far East – Europe route and Far East – USA route). Knowing that to exploit a route on the Far East, a liner operator needs seven to eight ships for a weekly service and the capital cost of a 10,000-TEU ship is about US$ 130 million (end 2005), it is quite obvious that only the main liner operators will be able to finance such ships.

Nor can the loading problem be ignored. A liner operator cannot operate a loop with one loading port and one discharging port. If this were the case, a weekly service would be impossible because the presence of more than one ship at the terminal would hinder operational speed. Imagine a loop with three loading ports and three discharging ports. Will it be possible to load a ship with a huge number of containers in each loading port and to discharge the containers in the right discharging port without repositioning containers on the ship or by way of the quay? And what will be the projected cost of repositioning? Moreover, how will a liner operator fill ULCS not once but with a reasonable frequency, preferably weekly? And will the ship in that first discharging port be expected to take in additional cargo for the next destination in order to keep it at full charging capacity?

These arguments confirm the link between ship size and operations and also confirm that ship size influences operations, creating diseconomies of scale (e.g. increased cost of transhipment,...). It is obvious that (optimal) ship size goes hand in hand with (optimal) operations. This brings us to the question: Is there an optimal ship size?

Until the mid-1980s, size was limited by the dimensional constraints of the Panama Canal (length 294 m and width 32 m), which strongly influenced the development in containership size. For a long time the market levelled off at the maximum ship size of 4500 TEUs. This was undoubtedly the reason why this was labelled as 'optimal ship size' for more than a decade. Note, due to technological reconfiguration, the capacity of new Panamax vessels is pushed above 4500 TEU – the so-called high capacity Panamax vessels. In future the planned expansion of the Panama locks will definitely cause another revolution in the global liner shipping industry and eliminate the distinction between Panamax and wider-than-Panamax vessels.

The 2003–2006 ordering craze has fuelled speculations on future ship size. CEOs of big carriers give different statements. CMA CGM indicates 9500 TEUs as the optimal ship size. According to them deploying such ships is the best strategy without reducing the number of ports (www.cmacgm.com). This trend towards ever-larger vessels is not followed by all top 25-carriers. APL, CSAV/Norasia, PIL, Wan Hai and ZIM do not (yet) have ships larger than 7500-TEU vessels on order. Will this be the optimal strategy or will they jump immediately towards +10,000-TEU vessels?

Clearly 'the' optimal ship size does not exist. It will evolve according to *transport segment* (deep-sea vs. short-sea shipping, SSS), *terminal concept*, *trade lane* and *technology*. These parameters – or four T's – are taken into account. First, a distinction is made between terminals which operate solely as transhipment hubs (e.g. Gioia Tauro, Algéciras, etc.) and other terminals, where hinterland throughput plays an important role (e.g. Antwerp, Rotterdam, Hamburg, etc.). Hub terminals will be marked by operational activities focused on the quayside area, whereas other terminals will focus more on backyard area or even both. Second, the determination of optimal ship size cannot be studied separately from a trade route (volume, port accessibility). Container business covers a spectrum of different trades. There are about 1500 liner routes. The industry divides the trade routes into three groups: East-West trades, North-South trades and intraregional cargo. The different routes are marked by a different volume and therefore the global liner operator requires a portfolio of different ship sizes. Ultimately, as larger ships enter the market, a shift towards these ships can be expected, as they are more cost-effective with reference to the routes.

Table 8 gives an overview of the optimal ship size with the parameters of transport segment, type of terminal, trade lane, and phasing-up of larger ships. This overview is based on the results of Section 'Optimal (Ship) Size' and on extrapolation of the demand, cost and technology parameters. At present neither 15,000-TEU nor 18,000-TEU ships have been built, but for the purpose of the present study we are already simulating the consequences of their existence. Since preparations to widen the Suez Canal have already begun, the arrival of those ships in the next 10 years is a serious possibility. Undoubtedly, this ship size will be the minority in the fleet portfolio of the main liner operators.

Assuming that the main liner companies will continue to invest in larger tonnage, the size of a typical container ship on the *Europe-Asia* trade lane will shift first towards vessel sizes varying between 7500 TEUs and 12,500 TEUs. Within the portfolio of the fleet, one expects that the number of vessels varying between 7500–9500 TEUs will form the majority (read: be the optimal ship size segment). The vessels will be powered by a single propeller and will offer operators, compared to a 4500-TEU ship, potential cost savings of about 35% (see Section 'Optimal Ship Size'). It is likely that the upcoming giant container ships will be single-propeller vessels. Due to economic reasons twin-propeller vessels are currently not competitive (i.e. increased maintenance, fuel consumption, . . .). By 2012, the largest ships on the Europe/Asia/Europe and the transpacific trade lanes will be 15,000-TEU twin-propeller, rising to 18,000 TEUs. Few vessels of the future Panamax size, which will be able to load at least 22 containers across the weather deck, will enter service during the latter part of this decade, once the ports/terminals operating companies have made the necessary investments in new equipment (cranes,. . .), berths, etc. to handle them. Ever-larger vessels will most likely constitute a minority within the fleet portfolio.

The optimal ship size will be found around 12,500-TEU capacity. This vessel does not only offer economies of scale, but also environmental benefits (reduced emissions, improved fuel consumption, etc.). In the long run, optimal ship size will probably shift towards the 12,500–15,000-TEU segment, taking into account the expected growth of China and India. The same trend is expected for the *transpacific trade*. The last main trade, though not the least important, is the

Table 8. Optimal ship size linked to optimal operations

	Transport segment	Deepsea					SSS
	Terminal type	Hub+hinterland				Hub	
	Trade lanes	Main trades			Other		
Technology	Eu/Asia/Eu	Intra Asia	Transatlantic	Transpacific	North/South		
2005 – up to 10,000 TEU	7500–9500	1000–1500	3000–5500	7500–9500	1500–3000	7500–12,500	1500
2012 – up to 15,000 TEU	10,000–12,500	1500–3000	3000–5500	10,000–12,500	3000–4500	7500–15,000	3000
>2012 – up to 18,000 TEU	12,500–15,000	1500–3000	4500–6500	12,500–15,000	5500–6500	7500–18,000	4500

Intra-Asia trade. The smaller ports in this region are fed with vessels up to a capacity of 1500 TEUs. Given the increased volume, optimal ship size will gradually increase. A noticeable trend is the takeover of this trade by the main liner operators. Recently two feeder operators have filed a petition of bankruptcy.

The *transatlantic trade* is quite another story. Most of the reflections concerning future seaport development depend heavily on estimations of future demand for freight transport, a major element. Generally, the demand is expected to grow continuously. But, as cargo volumes on the transatlantic route evolve at a slower pace and no real durable growth margin is noticeable, the optimal ship size is currently situated in the range between 3000 and 5500 TEUs, according to the deployed ship sizes. In line with the trend on the other two major trade lanes and under the assumption of sufficient volume, the optimal ship size for the transatlantic route is expected to be located in the 4,500–6,500-TEU segment by 2012.

Other trades will be served with smaller ship sizes. The main constraints here are trade volume and port accessibility. On the *North-South routes*, the optimal ship size today is about 3000 TEUs. Hamburg Süd, a major player on these routes, started deploying ships with a capacity of 5500 TEUs. According to them this capacity is the optimal ship size for this trade, taking into account the volume of trade and especially the accessibility of ports in South America. These 'true giants' (e.g. the Monte Rosa, a 5500-TEU container freighter with the largest reefer capacity) represent the beginning of a new era for the South American trade. +10,000-TEU freighters cannot/will not be handled in, for instance, South American ports. Ports on the North-South trade lanes are advised not to invest in large facilities. These ports are facing pressure to upgrade, as vessel sizes on these routes are also growing due to a cascade effect. The optimal ship size will steadily rise to 4500 TEUs followed by a shift to the 5500–6500-TEU segment after 2012.

The capacity of a terminal solely operating as a hub port needs to evolve hand in hand with the growth of container ship size. Here the feeder network gains importance. Consequently, the focus of the optimal ship size in deep-sea operations will shift towards the optimal ship size in short sea operations (SSS).

The existing range of vessels deployed on the *intraregional routes* diverges between 1000 TEUs and 3500 TEUs. Here the optimal ship size is expected to increase repeatedly with +1500 TEUs largely due to the cascading effect, but also because of the development of hub-and-spoke systems (see Section 'Optimal Ship Operations').

Conclusions

The liner shipping industry is an increasingly important and attractive transport market segment. Nowadays, this industry is marked by (increased) containerisation, globalisation, consolidation, deregulation, rationalisation and (intensified) competition. These have radically changed the liner shipping industry and helped to fuel progress towards larger ships.

The central question of this paper was to analyse the link between ship size and container operations.

Firstly, this paper dealt with the question of the driving variables behind the growth in size of the containership. Evidently, the deployment of the new generation of container vessels is largely due to economies of scale which are based on the assumption that a good utilisation of the larger vessels can be achieved. Scale economies have been – and will continue to be – the driving force behind the deployment of larger container vessels. Neither the desire to maximise profit nor the impact of the other variables can be ignored.

Secondly, the economic analysis of the concept of 'optimal containership size' was studied, allowing the following conclusions to be drawn:

- the economies of scale curve is rather a split curve (single propeller vs. twin propeller);
- for a long time the market levelled off at the maximum/optimal ship size of 4500 TEUs, while nowadays a shift of the optimal ship size towards larger vessel scale is noticeable: economies of scale still exist for +8000 TEUs (see Figure 3 – Section 'Optimal Ship Size');
- the operating cost (especially feeder cost) and the landside distribution costs should be integrated in the cost model; and
- consequently, the split economies of scale curve will likely turn into a U-shaped curve.

Thirdly, the size of the future post-Panamax ships challenges not only the liner shipping companies, but also the ports and terminals businesses. Ports and terminals have responded and still respond to size increases by making large investment plans. This is the case because the main limiting factor is the water depth in ports and navigable waterways besides the length of the vessel, the airdraft, etc. Furthermore, it is quite obvious that the operation of bigger vessels raises terminal, intermodal and commercial issues.

Finally, throughout this paper it has become clear that (optimal) ship size and (optimal) operations cannot be studied separately. Both concepts develop hand in hand. It has been shown that the determination of the optimal ship size in relation to operations depends on the 4T's-Transport segment; Terminal type; Trade lane; and Technology.

Acknowledgements

The authors wish to thank the editor-in-chief for his comments, and acknowledge the anonymous referees for their constructive criticism and helpful suggestions that contributed to the overall quality of this paper. All remaining errors are the responsibility of the authors.

References

Akiyama, A., Horn, G. & Wong, K. M. (2002) *Structural design challenges of ultra large container ships,* in: Pacific 2002 International Maritime and Naval Expo & Conference, Sydney, January 29–February 1.

Baumol, W. (1982) *Contestable Markets and the Theory of Industry Structure* (New York: Harcourt Brace Jovanovich).

Blauwens, G., Vandaele, N., Van De Voorde, E., Vernimmen, B. & Witlox, F. (2006) Towards a modal shift in freight transport? A business logistics analysis of some policy measures, *Transport Reviews*, 26(2), pp. 239–251.

Brooks, M. R. (2000) *Sea Change in Liner Shipping: Regulation and Managerial Decision-Making, in a Global Industry* (Oxford: Pergamon Press).

BRS (2008) *Shipping and Shipbuilding Markets* (Neuilly sur Seine: Barry Rogliano Salles).

Containerisation International, various editions (London: Informa Maritime & Transport).

Cullinane, K. & Khanna, M. (1999) Economies of scale in large container ships, *Journal of Transport Geography*, 33(2), pp. 185–208.

Cullinane, K. & Khanna, M. (2000) Economies of scale in large containerships: Optimal size and geographical implications, *Journal of Transport Geography*, 8(3), pp. 181–195.

Drewry Shipping Consultants (2001) *Post-Panamax Containerships – the Next Generation* (London: DSC Consultants).

Drewry Shipping Consultants (2005) *The Drewry Annual Container Market Review and Forecast 2004/2005* (London: DSC Consultants).

Drewry Shipping Consultants (2006) *The Drewry Annual Container Market Review and Forecast 2005/2006* (London: DSC Consultants).

Drewry Shipping Consultants (2007a) *The Drewry Container Market Review – 2006/2007* (London: DSC Consultants).

Drewry Shipping Consultants (2007b) *Ship Operating Costs Annual Review and Forecast – 2006/ 2007* (London: DSC Consultants).

European Commission (2005) *The Application of Competition Rules to Liner Shipping* (Luxembourg: DG Comp).

Fairplay (2005) *Port and Terminals Guide – 2005–2006* (London: Fairplay publications).

Fossey, J. (1990) Top 20 Carriers Consolidate, Containerisation International, June, pp. 46–51.

Goss, R. O. (1971) *The Economies of Size in Dry Bulk Carriers* (London: HMSO).

Ham, J. C. (2004) The feasibility of megacontainer vessels, *International Journal of Transport Economies, Engineering and Law*, 25/26, pp. 89–98.

Heaver, T. D. (1968) *The Economics of Vessel Size* (Ottawa, Canada: National Harbour Board).

Imai, A., Nishimura, E., Papadimitriou, S. & Liu, M. J. (2006) The economic viability of container mega-ships, *Tranportation Research Part E-Logistics and Transportation Review*, 46(1), pp. 21–41.

Jansson, J. O. & Shneerson, D. (1982) The optimal ship size, *Journal of Transport Economies and Policy*, 16(3), pp. 217–238.

Jansson, J. O. & Shneerson, D. (1987) *Liner Shipping Economics* (New York: Chapman and Hall).

Kendall, P. M. (1972) The theory of optimal ship size, *Journal of Transport Economies and Policy*, VI(2), pp. 128–146.

Lim, S. (1994) Economies of container ship size: a new evaluation, *Maritime Policy and Management*, 21(2), pp. 149–160.

Lim, S. (1998) Economies of scale in container shipping, *Maritime Policy and Management*, 25(4), pp. 361–373.

Lipczynski, J., Wilson, J. & Goddard, J. (2005) *Industrial Organisation, an Analysis of Competitive Markets* (Essex: Prentice Hall).

Lloyd's list (2004) *Ports of the World – 2004* (London).

McLellan, R. G. (1997) Bigger vessels: How big is too big?, *Maritime Policy and Management*, 24(2), pp. 193–211.

Notteboom, T. (2000) Logistieke ontwikkelingen in het voorland-achterland continuüm (Antwerp: unpublished PhD dissertation).

OECD Glossary of Statistical Terms, online available http://stats.oecd.org/glossary/ – consulted on 21 June 2008.

Port Glossary, online available http://www.portofantwerp.com – consulted on 21 june 2008.

Rijsenbrij, J. C. (2001) *Impact of tomorrows ships on landside infrastructure*, TOC2001.

Rizvi, Z. (2003) The containership: How big?, *IAPH Conference*, Durban.

Stopford, M. (2002) Is the drive for ever bigger containerships irresistible? in: *MD Clarkson research, Lloyd's List Shipping Forecasting Conference*, 26th April 2002.

Stopford, M. (2004) *Maritime Economics* (London: Routledge).

Talley, W. K. (1990) Optimal containership size, *Maritime Policy and Management*", 17(3), pp. 165–175.

UNCTAD (various editions) *Review of Maritime Transport* (Geneva, Switzerland: United Nations).

Van de Voorde, E. (2005) What future the maritime sector? Some considerations on globalisation, co-operation and market power, in: Kanafani, Adib and Katsuhiko Kuroda (Eds) *Global Competition in Transportation Markets: Analysis and Policy Making, Research in Transportation Economics*, pp. 253–277 (Amsterdam, The Netherlands: Elsevier JAI).

Wijnolst, N., Scholtens, M. & Waals, F. (1999) *Malacca-Max. The Ultimate Container Carrier* (Delft, The Netherlands: University Press).

Witlox, F. & Vandaele, E. (2005) Determining the monetary value of quality attributes in freight transportation using a stated preference approach, *Transportation Planning and Technology*, 28(2), pp. 77–92.