# A THEORY OF OPTIMUM SHIP SIZE

By P. M. H. Kendall*

There has been a phenomenal increase in the sizes of sea ships during the last twenty years. It has long been assumed that normal trade practice is to use the largest ship that can be accommodated at both origin and destination ports and that happens to be available at the time required. However, there is now a considerable body of evidence to suggest that volume of trade, length of route and value of product are the primary determinants of ship size, and consequently of sailing frequency and number of visits to a port.

The effect of these factors is obscured by traditional practices in such matters as port-of-call operation, general cargo procedures, handling equipment on board ship and the way in which various trades are organised and operated. In addition there are seasonality of trade effects and constraints at both port and shipyard which must be considered.

The optimum ship size theory discussed in this paper has been developed to explain the macro-economics of some aspects of shipping practices for dry bulk cargo. Nevertheless, the general concepts and principles appear to have far wider applicability. Some of these implications are described later in this paper.

In more recent work related to the mechanism of industrial location for the so-called sea port industries, account has been taken of part-loaded ships, port constraints and backhauling. For those readers wishing to read further on these matters a number of references have been listed at the end.

## NEED FOR THE THEORY

The need for understanding the major determinants of ship size is not hard to establish. The amount of capital involved in the development, operation, insurance and servicing of large ocean-going vessels is now being approached by the investment necessary in cargo handling and storage and in the harbour works to accommodate them. With rapid change still occurring in sizes of trading ships, incorrect investment decisions can be very costly, and a proper understanding of the mechanism at work can reduce the investment risk considerably.

It has been known for some time that economies of scale exist in sea shipping and that, for a given annual tonnage of freight to be carried, the longer the sea voyage the more these economies can be utilised. Conversely over a given route the larger the annual tonnage carried the larger can be the ships to carry it economically. However, these factors in themselves do not satisfactorily explain the current ship

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*This paper is based in part upon work done for the National Ports Council by the author while he was a member of Management Sciences Ltd. The views expressed are his own.

size patterns. What, it was asked, in practice further restrains ship sizes from being as large as ports can accommodate?

In the short term, longer turnround time in port will penalise the larger ship; but in the longer term faster handling equipment can overcome this difficulty. Similarly, whereas port costs could have handicapped the larger ships in the past, the port costs per ton have, if anything, tended recently to favour the larger ships.

As ships become larger there are indeed economies at sea, but on the quayside there are substantially larger stocks of product. If the capital investment and other costs of holding this stock are included, a realistic balance is found to exist, depending not only upon volume of product but also upon its value. The higher the value of the product the greater the penalty in large stocks, and the lower the best size of ship to achieve minimum total cost of transport. This element of the theory is in accordance with common experience, which indicates that it is the lower value products which are carried in the large bulk carriers.

The next two sections of this paper describe first the conceptual development of the model for the optimum ship size, and secondly its applicability in different circumstances.

## DEVELOPMENT OF THE THEORY

### Optimum Ship Size

The optimum size of ship used on a particular route will be that which minimises the total transport costs. These costs should include not only those incurred by the ship at sea, but also the related cost of the terminals at either end of the voyage. The total sea transport cost, as it affects differences in sizes of ships, includes:

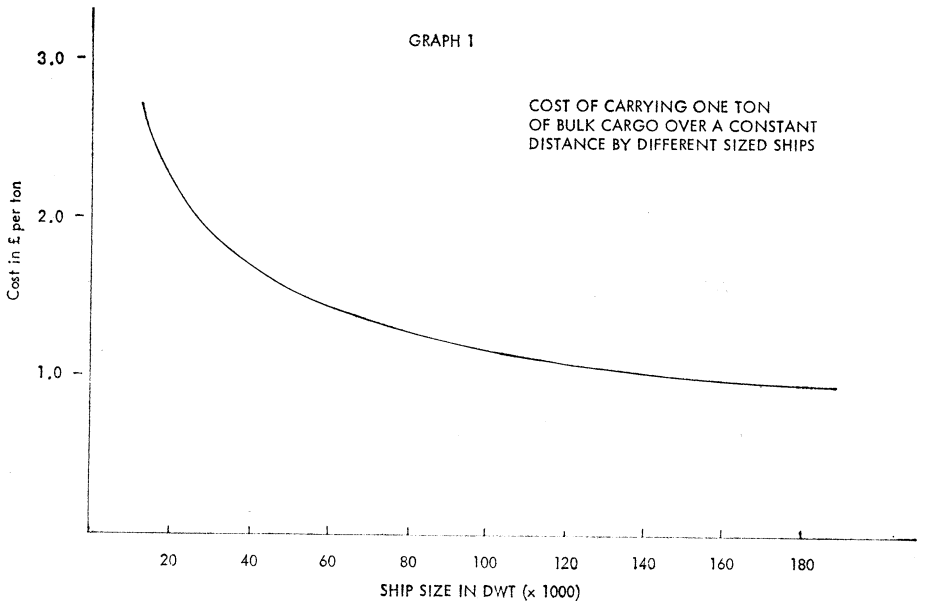
(i) Ship costs—comprising capital charges and running costs;
(ii) Terminal costs—comprising:
  (a) Port costs—dredging, berthing, locks, etc.;
  (b) Product handling costs;
  (c) Storage costs.

Each of these costs must now be examined in detail to determine the precise effect of each upon optimum ship size.

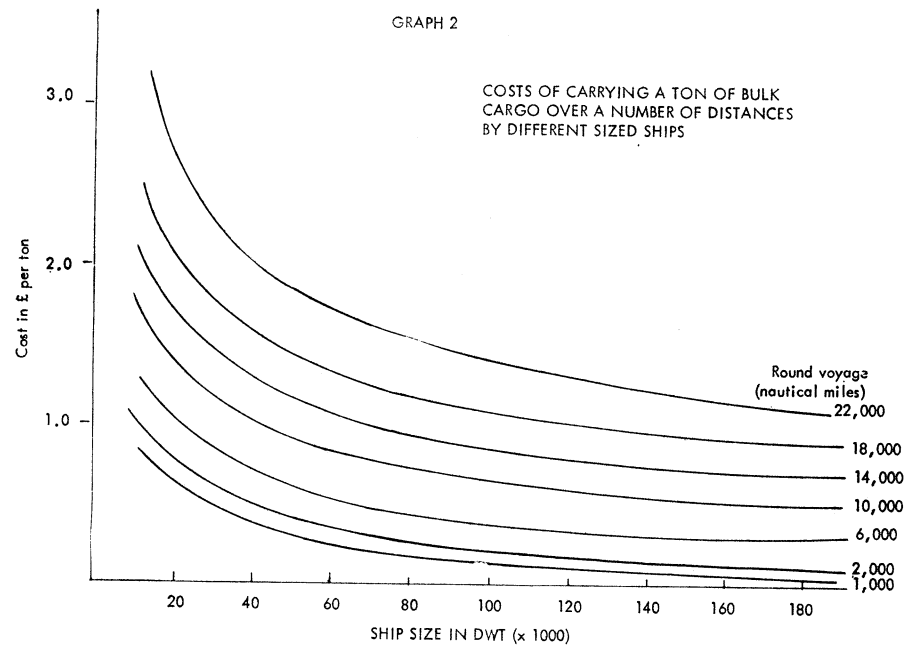
### Ship Costs

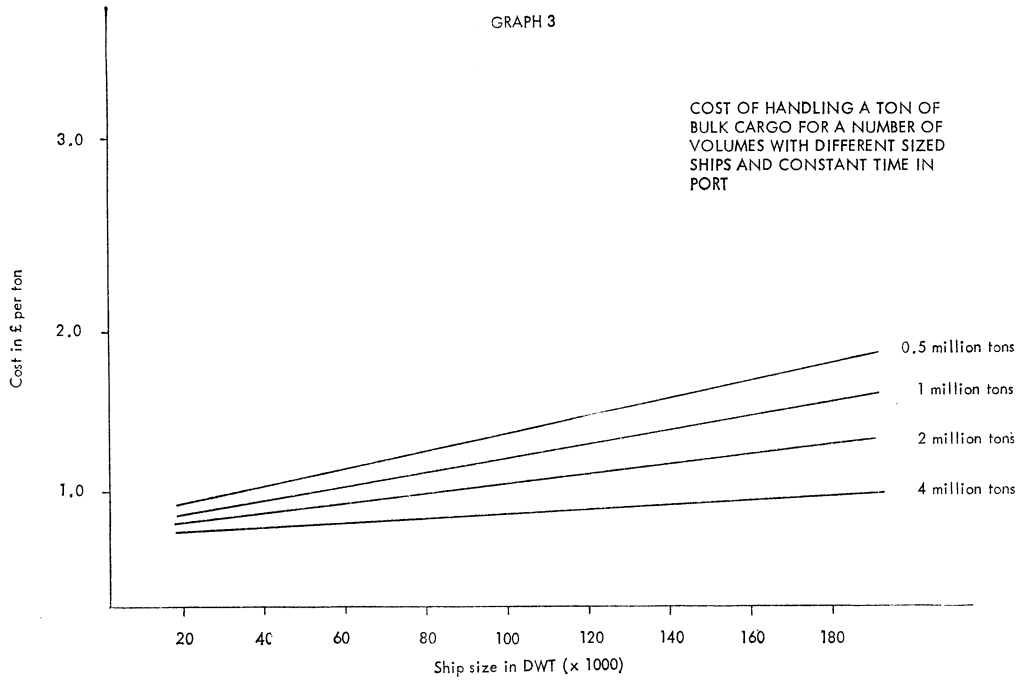
Graph 1 illustrates a typical curve showing costs of transporting a ton of bulk commodity in different sized ships. The most important assumptions defining this curve are:

(i) All ships are depreciated over the same number of years and at a fixed rate per year;
(ii) None of the ships has on-board handling equipment;
(iii) The curve is for a given length of journey, with a full load in one direction and in ballast on the return trip;
(iv) The curve is for a fixed point in time (1967);
(v) A cargo ton equals a deadweight ton;
(vi) The number of days spent in port, at each end of the voyage, is fixed for all sizes of ships.




Graph 2 provides the same information for a number of different voyage lengths (round trips).






**Handling Costs**

Graph 3 gives the theoretical relationship between costs per ton of commodity handled and size of ship. Whereas in ship costs a curve was drawn for a number of voyage distances, for handling costs a set of lines has been constructed for a number of different annual volumes of trade.

If $H$ is the total handling cost per ton,
$R$ is the total capital cost of the handling equipment,
$I$ is the percentage rate of return expected on the capital cost,
$Q_y$ is the total annual tonnage to be handled,
$K_2$ is the running cost per ton,

then
$$H = \frac{RI}{100\,Q_y} + K_2$$

Further, let $Q_s$ be the tonnage handled from a single ship. As $Q_s$ increases it is necessary to keep the total loading or unloading time constant, and the handling speeds have to be increased.

There are four principal ways in which this might be done:

(i) Increasing the speed of existing equipment. Since most handling equipment has a fairly fixed rated speed, this solution is unlikely to be acceptable except over a limited range of ship sizes.

(ii) Using more equipment of the same rated speed. Even if this were practicable, it is likely to be only a short-term measure.

(iii) Increasing the number of working shifts—also likely to be a short-term expedient.

(iv) Having new equipment installed, the rated speed of which has been designed to accommodate ships of the expected size. Although it is possible for the capital cost of this equipment to rise faster or slower than the size of ship it is required to handle in a given time, it has been assumed in this analysis that there will be a direct linear relationship between handling cost and ship size.

The assumption is that the larger ships will normally be handled by new, larger and faster equipment.

Thus, if $K_1$ is the capital cost to be recovered annually for handling a deadweight ton of cargo in a fixed time,

i.e. $$K_1 = \frac{RI}{100\,Q_s}$$

then $$H = \frac{K_1\,Q_s}{Q_y} + K_2$$

Hence handling costs per ton increase linearly with increasing ship size and inversely with increasing total annual tonnage.

**Storage Costs**

Graph 4 illustrates the relationship for storage costs. This can be represented thus:

If $S$ is the total cost of storage per ton (e.g. £/ton),
$Q_y$ is the total annual tonnage to be handled,
$Q_s$ is the tonnage handled from a single ship,
$V$ is the value of the product per ton,
$I$ is the percentage rate of return expected on the capital invested in the product during storage,
$F$ is the cost per square yard of storage space for one year,
$U$ is the number of square yards needed to store one ton,
$K_4$ is running cost (or handling cost not included under the handling costs mentioned previously) in £ per ton,

then $$S = \frac{Q_s\,VI/200 + FU}{Q_y} + K_4$$

$$= \frac{K_3\,Q_s}{Q_y} + K_4$$

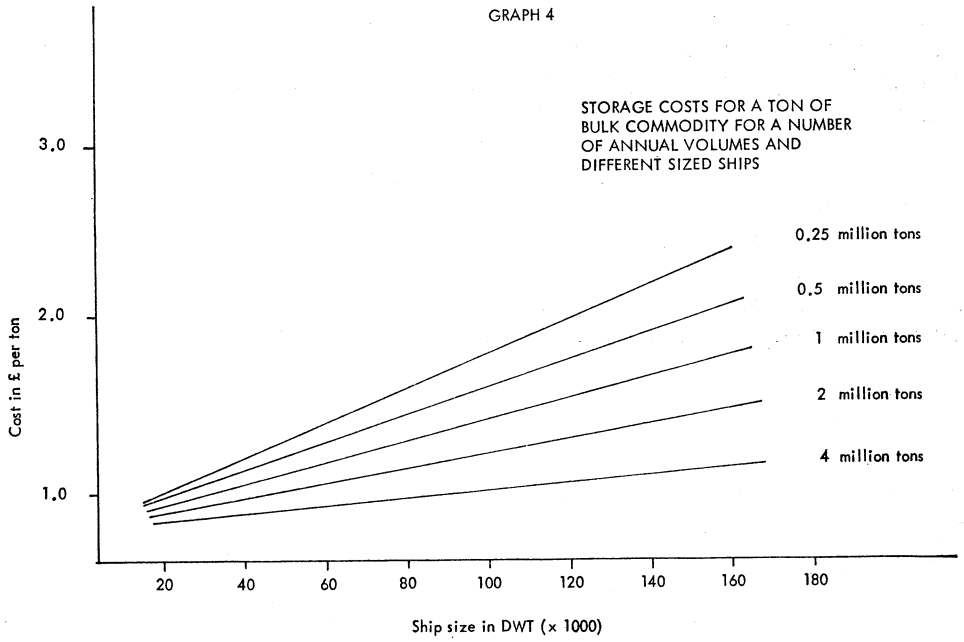
As for handling costs, the storage costs per ton increase linearly with increasing sizes of ships and inversely with increasing total annual tonnage.

**Port Costs**

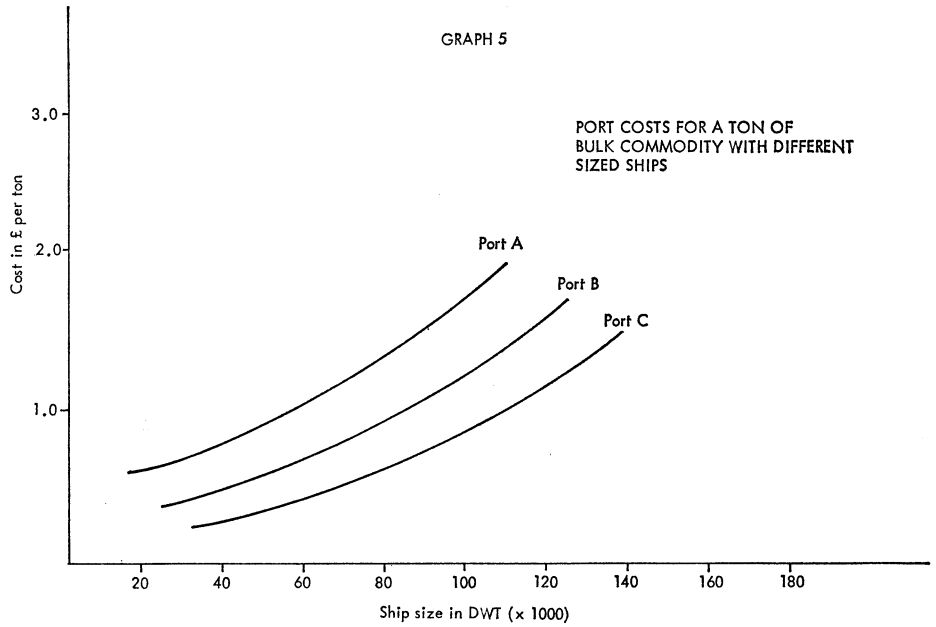
The variation in port costs, for a ton of commodity with different sized ships, is shown in Graph 5.

It is inherently difficult to provide a theoretical relationship between the total port costs per ton of cargo handled and the size of ship. Whereas in the past, at many

GRAPH 4




GRAPH 5



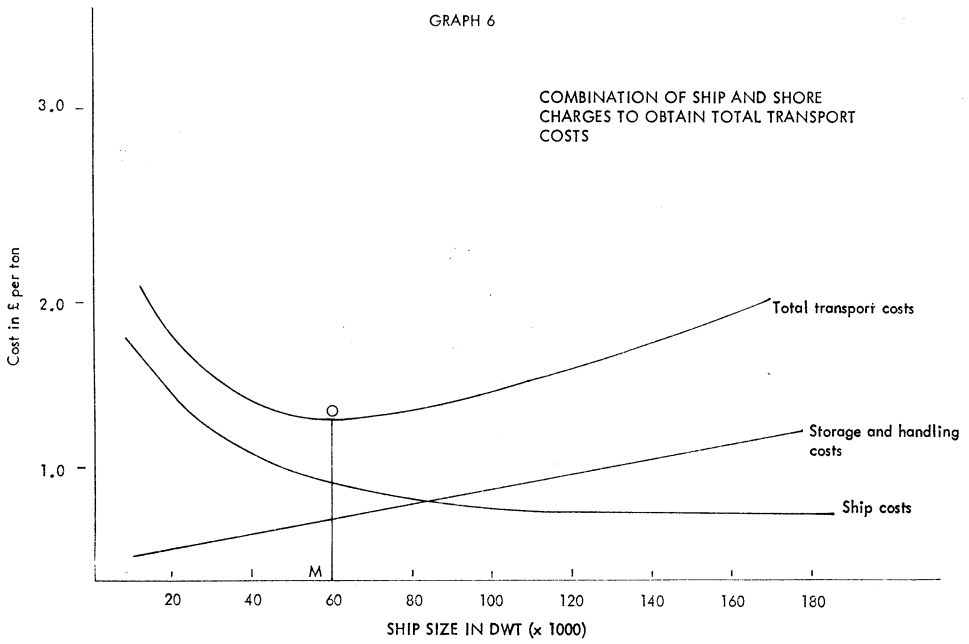
ports, there has been fairly constant cost per ton over a limited size range, significant discontinuities may occur when the ships exceed a certain size and consequently major dredging programmes, and/or lock systems, have to be provided. In some places port charges, as distinct from port costs, are being used as instruments of port policy. This means that total port costs may not be recovered through total port charges, or the distribution of those charges among ships of various sizes may not accurately reflect port costs for those sizes.

Hence it is better to provide a model to predict the best size of ship in the absence of all port charges. Port charges were, in fact, omitted from the general theory, although the optimum size of ship for a given route and volume of trade has been determined by superimposing estimates of the relevant port charges.

## Optimum Costs

In determining the theory for optimum costs a single product has been taken, and port costs are deliberately excluded from this stage of the analysis. The handling and storage costs have been combined and are represented by a single line. In Graph 6 this line has been drawn for a given volume, together with the ship cost curve for a given distance. The optimum size of ship under these conditions will be shown where the curve for total storage, handling and ship cost is at its minimum value. Of course, the storage and handling costs concerned are those that arise at both ends of the voyage. Thus, for a given volume of trade and length of voyage, the ships are economically discouraged from being above a certain size by the cost/ton of handling and storage rising faster than the ship costs/ton are falling.

GRAPH 6



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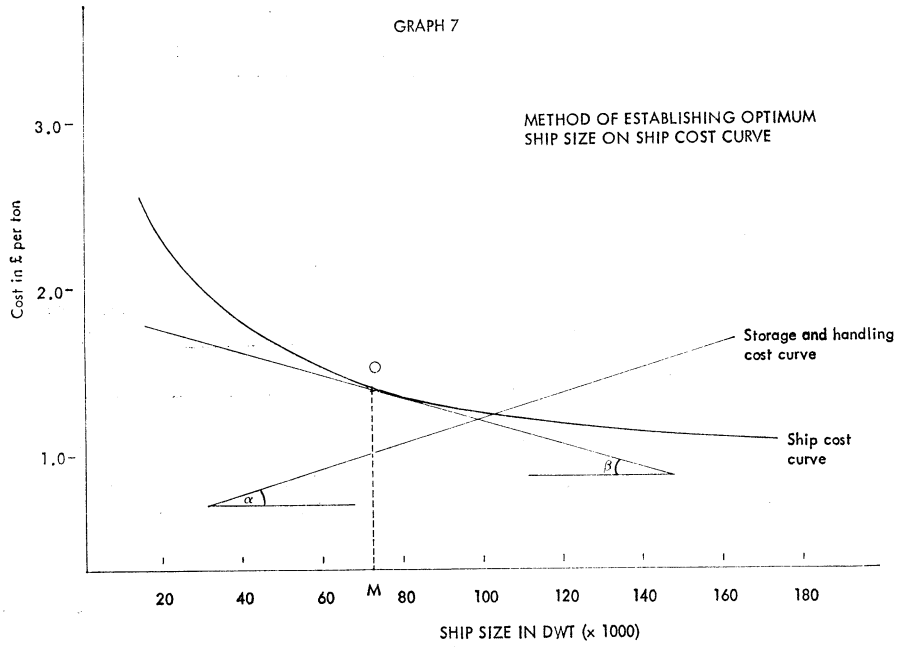
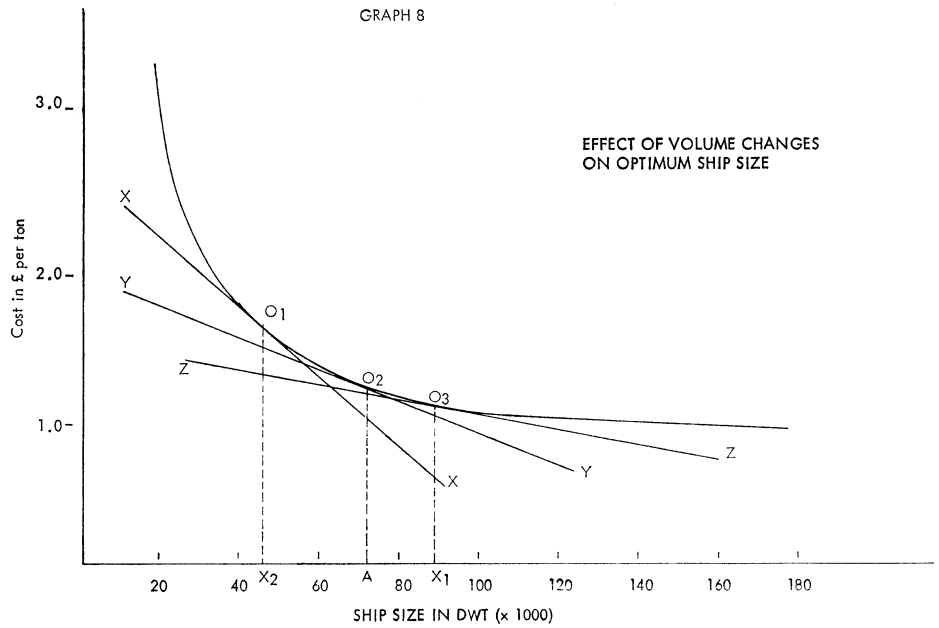
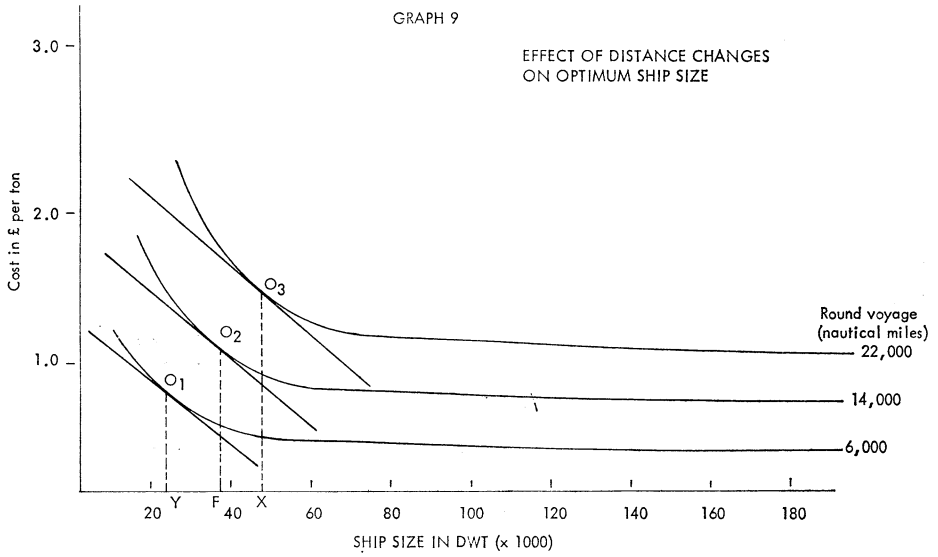



GRAPH 8



GRAPH 9




Furthermore, the height of the storage/handling cost line, as distinct from its slope, does not affect the optimum position. Costs independent of ship size, although they affect the total cost per ton to the consumer, do not influence the optimum size of ship to be used. Because it is the slope and not the height of the lines that matters, the position of the optimum size of ship can be represented on the ship cost curve by drawing the tangents so that the angles $\alpha$ ad $\beta$ in Graph 7 are equal. The point at which this tangent touches the ship cost curve provides the optimum size, regardless of the relative absolute magnitudes of ship, handling and storage costs. Thus there is an optimum for each specific volume of trade and length of voyage.

Reference to Graphs 3 and 4 will show how the tangential line will change its slope as the annual volumes of trade change. Graph 8 illustrates the effect of increasing volume on the optimum ship size. Doubling the volume does not double the optimum size; that is, distance $AX_1$ does not equal twice $AX_2$ even though tangent $ZZ$ represents twice the volume (and is half the slope) of tangent $YY$, which itself represents twice the volume of tangent $XX$.

Alternatively, if the annual volume is now kept constant (which in effect means keeping a constant slope of the handling and storage line, with the ship cost curve drawn for a range of round trip distances), the effect of increasing distance upon optimum ship size can be determined by moving the constant slope tangents until they touch each ship cost curve in turn. This is illustrated in Graph 9, and it can be observed that the optimum does not increase as fast as the increase in round trip distance, i.e. $FX < FY$.

Finally, with both constant annual volume and constant distance, the carriage of freight with a higher value per ton will tend to reduce the optimum size of ship,

TABLE 1

*Commodity Values*

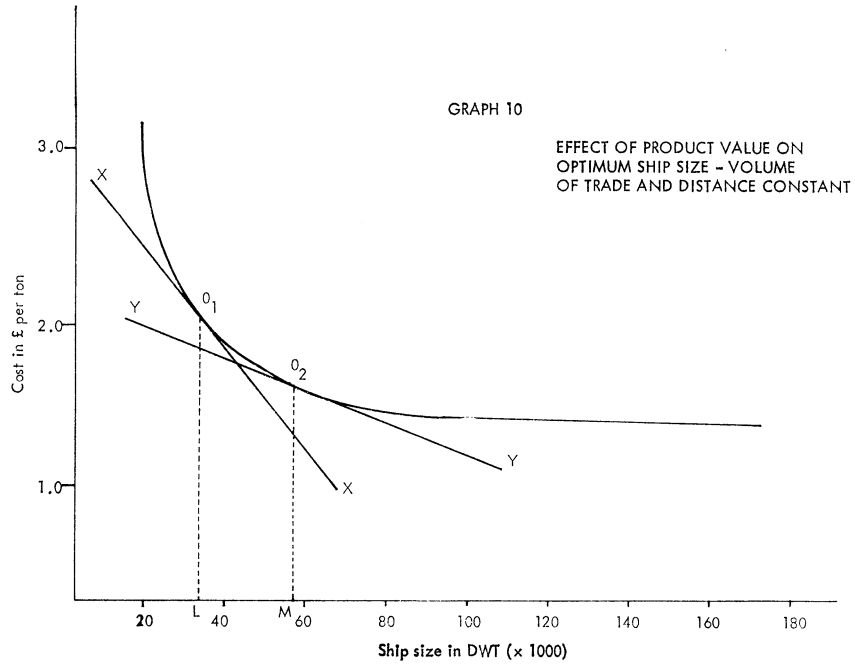
*Costs per ton and per dwt in* 1970 *of commodities normally described as potential bulk products, in approximate ascending order of value per ton (averages based on total annual tonnage of seaborne trade divided into total value)*

| | £/ton | £/dwt |
|---|---|---|
| Steam coal | 4 | 4 |
| Other coal | 5 | 5 |
| Iron ore | 5 | 5 |
| Fuel oil | 6 | 6 |
| Bauxite | 6 | 6 |
| Crude oil | 6 | 6 |
| Raw cement | 7 | 7 |
| Phosphates | 7 | 7 |
| Anthracite | 7 | 7 |
| Salt | 7 | 7 |
| China clay | 8 | 8 |
| Potash | 9 | 9 |
| Sulphur | 11 | 11 |
| Molasses | 12 | 12 |
| Kerosine | 12 | 12 |
| Manganese ore | 12 | 12 |
| Chrome ore | 13 | 13 |
| Motor spirit | 13 | 13 |
| Soda ash | 15 | 15 |
| Maize | 29 | 23 |
| Wheat | 29 | 25 |
| Scrap | 30 | 30 |
| Zinc ore | 35 | 35 |
| Soya beans | 48 | 38 |
| Raw sugar | 52 | 46 |
| Potatoes | 62 | 44 |
| Newsprint | 65 | 48 |
| Wine | 250 | 250 |
| Cotton | 266 | 76 |
| Tea | 420 | 155 |

Source: Stowage factors from *Stowage—The Properties and Stowage of Cargoes*, by R. E. Thomas. Glasgow, Brown Sons & Ferguson 1968.

since the storage costs will rise. The precise relationship is very difficult to establish because part of the value per ton of the product is transport cost; that is, value per ton is not completely independent of ship size. A second problem encountered here is that all products expressed in £/ton weight of cargo have to be reconsidered in terms of £ per deadweight ton; in practice this conversion is made with stowage factors (see Table 1).

The effect of product value on optimum ship size is shown in Graph 10. For example, grain is valued at about £26 per ton of cargo; but the stowage factor is approximately 50. This makes the value per deadweight ton approximately £21.




It is for this value that the curve must be plotted, since it will be remembered that the ship curves assume that 1 ton of cargo can be carried in one deadweight ton of space (40 cu. ft.).

## QUANTIFICATION OF THE THEORY

### Validity of Major Assumptions

It is important to determine the effect of various critical assumptions on the optimum ship sizes determined from the theory.

1. *Constant turnround time for ships*

This assumption is based upon historical observation rather than theoretical analysis. In the very short term it is unlikely to be true, but for the longer term (including a delay time as well as handling time) it would seem to apply to most bulk commodities. An increase in turnround time for larger ships would tend to reduce the optimum ship size for a given volume and distance, and vice versa. Optimum ship size is not very sensitive to changes in this assumption.

2. *Linear storage and handling relationships*

The only likely deviation from the linear relationship between costs per ton and ship size arises from economies of scale. In handling operations this would increase the optimum ship size. The optimum may still be found in the same manner as with the linear relationship. Without knowing the relative magnitudes of the handling and storage costs, it is not possible to say how much a change of this nature will

affect the optimum size. However, it is unlikely that optimum ship size would be very sensitive to this assumption.

3. *Short time lag*

Long-term chartering, and the fact that ships have a lifetime of 20 years or more, can only delay technical innovation and changes in ship sizes. Nevertheless, there is reason to believe that the optimum ship sizes normally change fairly rapidly with changing conditions. The existing fleet has an obvious (and usually well publicised) damping effect when the volume or distance of a particular route or trade has risen very fast and the optimum size exceeds the sizes of all the existing ships capable of carrying the product.

This occurs also, but not nearly so obviously, when there is a sudden concentration of trade on a single route to the detriment of other routes serving the same destination port. The optimum size of ships may then well exceed available supply, although the total volume passing through the destination port may have remained stationary or even declined. This is what appears to have happened in the grain trade from the U.S. Gulf to Rotterdam; converted oil tankers were used for a time to supplement the grain fleet.

In that situation the actual shipping had temporarily lagged behind and below the optimum sizes. It is also possible for it to lag behind and above the optimum sizes: for example, when the trade to a given destination port begins to arrive from many origins instead of on one single route. One of the effects of trans-shipment is to divide the commodity flow between origin ports, so it may well reduce the optimum sizes of ships already arriving at United Kingdom ports.

Thus, anything other than a short time lag may cause actual and optimum values to be different, and the extent of the difference will depend upon the rate of change of circumstances prevailing in the trade at the time. In the past this time lag does not seem to have been significant.

4. *Investment grants*

Investment grants were available to shipbuilders from January 1966 to October 1970. The extent to which the grant, and any similar subsidy, affects optimum ship size depends upon how far the benefits of the grant are passed on to the user in the form of a reduced charge per ton of cargo carried. The ship curves used in the study are based on costs at January 1968, when grants were available, and it has been assumed that the benefit has been passed on; this has the effect of reducing the optimum ship size.

5. *General accuracy*

When optimum ship sizes are estimated from the graphs for given products, lengths of voyages and volumes of trade, it must be noted that their accuracy depends upon the correct construction of the tangents as well as upon the accuracy of the cost curves themselves. This means that for some lengths of voyages and volumes of trade the shape of the relevant curves makes it difficult to record precise optimum sizes. The figures given later in Tables 2 and 3 should, therefore, be taken as a working estimate until the equations of the curves have been better established.

6. *Sensitivity of optimum value*

The extent to which a cost penalty has to be paid when ships of non-optimum size are used is difficult to assess, since actual storage and handling costs are unknown. The penalty will be at its greatest on long-distance low-volume trading routes, and at its least on short distances and high volumes. In practically all circumstances it will be the final consumer who has to meet the additional cost. It is usually preferable to use ships slightly larger than optimum rather than slightly smaller, since a smaller penalty is incurred. In practice, with trading volumes changing continuously, the effect of this is likely to be that as the volumes of trade increase the actual ship sizes will follow the optimum sizes much more closely than when the volumes of trade are falling.

## Calibration of Ship Sizes

A way has been found to calibrate the combined effect of shipping, storage and handling costs for two products, grain and iron ore, by making certain assumptions which are described below. The relationship between ship size and costs is available from an excellent study undertaken at the Department of Trade and Industry [1].

Graph 2 provides a quantified set of curves for ship costs per ton of cargo related to size of ship for a number of different lengths of voyages. They are based on costs at January 1968; I have assumed the 1966 load line rules and a 20 per cent investment grant for ship construction; and, in this analysis, it has been assumed that international competition will ensure that most of the benefits will be passed on to the ship user in the form of lower freight rates. Certain specially built ships, notably those for carrying products with very high stowage factors or at artificial temperatures and pressures, will not conform to these curves. Otherwise these curves will apply to all bulk cargoes.

Since 1968 the capital and operating costs of shipping have increased greatly, and the January 1968 curves cannot be used to estimate current costs. The calibrations below for grain and iron ore are based on carryings in 1968.

*Grain*

For grain the approach has been to establish the optimum size of ship from direct observation over a number of years at a particular port, Rotterdam. The reasons for this choice were as follows:

(i) The grain trade is well established, and substantial quantities arrive from a single source (two U.S. Gulf ports).
(ii) The annual tonnage has remained roughly constant in recent years, allowing any time lag to be overcome.
(iii) The greater part of the grain is handled by a single company.
(iv) So far, there has been no physical limitation on the size of ships used at either end of the voyages.
(v) There is no known subsidy or distortion of the costs of storage or handling.
(vi) Values per ton and stowage factors have not altered dramatically in recent years.
(vii) The shortage of adequate shipping has been partly overcome by the use of tankers and partly by new bulk carrier construction.

TABLE 2

*Optimum ship size in thousands of deadweight tons for different annual volumes of trade and lengths of voyages for grain*

| | *Grain (Value £24 per ton)* | | | | | |
|---|---|---|---|---|---|---|
| *Million tons* | 0·25 | 0·5 | 1 | 2 | 4 | 8 |
| *Nautical miles* | | | | | | |
| 1000 | — | — | — | 25 | 39 | 51 |
| 2000 | — | — | 19 | 30 | 43 | 58 |
| 6000 | — | 20 | 31 | 45 | 65 | 94 |
| 10000 | 16 | 25 | 40 | 61 | 80 | 120 |
| 14000 | 20 | 31 | 47 | 68 | 95 | — |
| 18000 | 25 | 36 | 53 | 77 | 127 | — |
| 22000 | 26 | 42 | 62 | 86 | 140 | — |

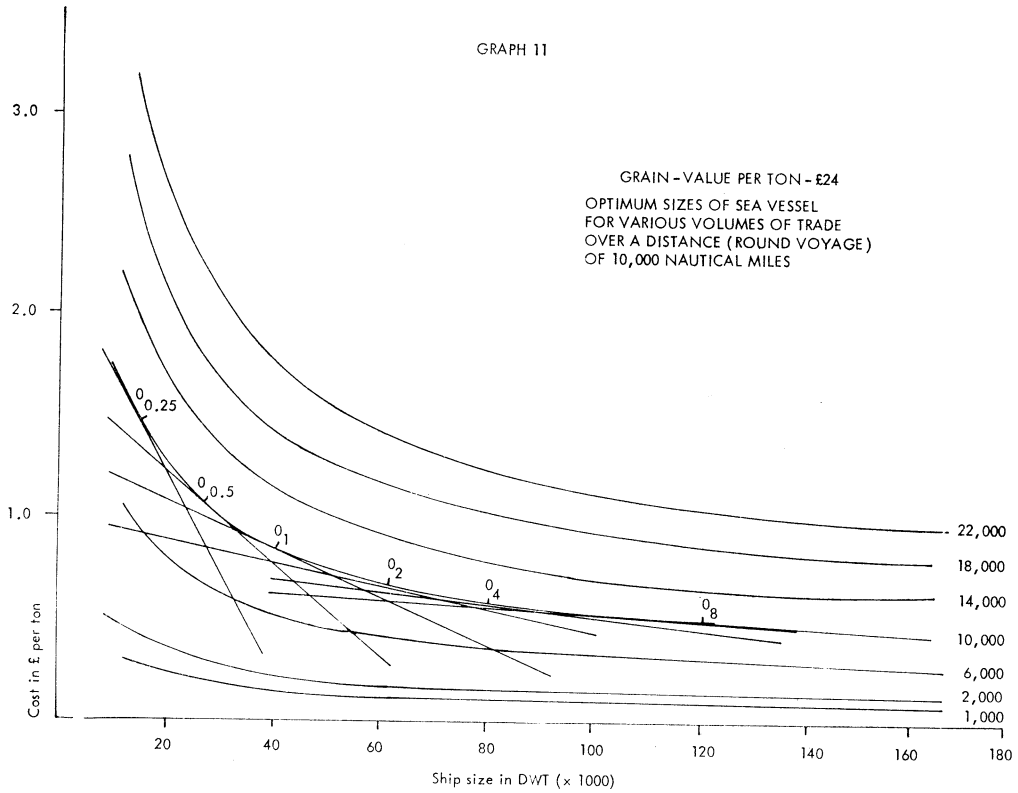
TABLE 3

*Optimum ship size in thousands of deadweight tons for different annual volumes of trade and lengths of voyages for iron ore*

| | *Iron Ore Value/dwt £4* | | | | | |
|---|---|---|---|---|---|---|
| *Million tons* | 0·25 | 0·5 | 1 | 2 | 4 | 8 |
| *Nautical miles* | | | | | | |
| 1000 | * | * | * | 28 | 40 | * |
| 2000 | 10 | 14 | 20 | 38 | 52 | 90 |
| 6000 | 16 | 27 | 37 | 55 | 80 | 135 |
| 10000 | 19 | 34 | 48 | 72 | 96 | 160 |
| 14000 | 27 | 40 | 54 | 80 | 110 | 190 |
| 18000 | 31 | 44 | 58 | 92 | 170 | 210 |
| 22000 | 34 | 52 | 72 | 100 | 200 | * |

(viii) Although there is a seasonality in the shipments of individual types of grains (principally maize and wheat), total shipments of all grains are uniform throughout the year.

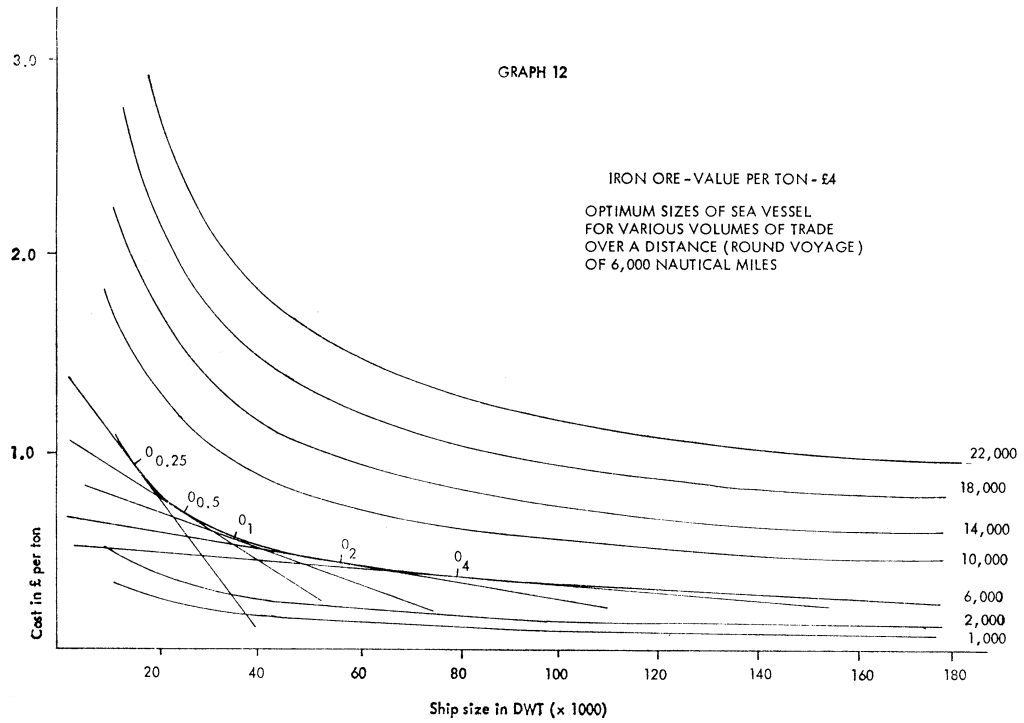
Difficulties will arise because of dispersion about the optima of each route caused by a variety of chance factors—possibilities of return loads, breakdowns of ships, etc. After elimination of these problems the optimum size of grain ship, for a round voyage of 10,000 miles and 1 million tons per annum, has been established as 40,000 deadweight tons. By successive doubling of the slope of the handling and storage lines, it has also been possible to obtain the two-million, one-million and half-million ton lines. Grain (unmilled) has an average stowage factor of 50, so that, although the imported value per ton of cargo is approximately £29 per ton, the value per dead-




weight ton is approximately £24. Table 2 provides optimum values for a number of volumes of trade and lengths of voyages, and Graph 11 illustrates the determination of optimum ship sizes for various volumes of trade.

*Iron Ore*

In the analysis for iron ore use has been made of two independent theoretical studies, one undertaken at Hoogovens Steel Works in the Netherlands and the other at the Steel Company of Wales, both on the optimum sizes of iron ore carriers. These studies were, in fact, directed towards determining the port facilities necessary to accommodate certain volumes of trade and sizes of vessels. From these results it has been possible to establish two points with which to calibrate the curves presented in this report. For a fixed volume of trade (four million tons per annum) and a round trip distance of 3,000 miles, a 65,000-deadweight-ton sea vessel was found to minimise total transport costs. If the round trip distance is increased to 6,000 miles, the corresponding optimum size of ore carrier is 80,000 deadweight tons. This information provides the slope of the tangent in Graph 12 for four million tons. By successive doubling of the slope of this tangent the two million, one million and half-million ton tangents have been obtained, and Table 3 sets out the optimum ship sizes obtained for a variety of different annual volumes and lengths of voyages.




## COMPARISON OF THEORY WITH PRACTICE

When the results suggested by the theory are compared with the sizes of ships that have actually entered United Kingdom ports in recent years, there are a number of reasons for expecting the two sets of data to be different (see Table 4). The most important are:

(i) The theory is concerned with fully loaded ships which arrive and unload all their cargo at a single port. In practice this is not always true, even for bulk carriers.

(ii) The theory assumes the new load line rules. Before 1966 the theoretical results should, therefore, provide a larger optimum than is found in practice, since the new rules have permitted a greater quantity of cargo in a given ship, and this will have reduced the optimum ship size.

(iii) The theory assumes no restraint due to port accessibility.

(iv) The theory assumes that, at a given U.K. port for the two relevant products, the volume of trade from a single source is handled by a single receiver or group of receivers, or shipped by a single shipper or group of shippers, or sent from the source by a single vendor or group of vendors.

The theory of optimum ship size would suggest that a severe physical restriction at a port for ships of large draught may cause a change in the proportions of products received from different sources. For example, Port Talbot may receive a larger proportion of its iron ore from Scandinavia than other U.K. ports, not because of

TABLE 4

*Principal theoretical optimum sizes of ships and the actual number of ships in certain size classes in* 1967

*Iron Ore*

*Theoretical Optima* ('000 *dwt*)

| *Port* | *Origins* | | | | |
|---|---|---|---|---|---|
| | *Liberia* | *Canada* | *Venezuela* | *Brazil* | *Scandinavia* |
| Port Talbot | 12 | 27 | 10 | | 34 |
| Newport | 22 | 33 | 14 | 18 | 15 |
| Cardiff | | 14 | | | |
| Liverpool | 16 | 31 | 25 | 17 | |
| Clyde | 15 | 14 | 27 | | 16 |
| Tyne | 12 | 22 | | | 11 |
| Tees | 17 | 15 | 15 | | 19 |
| Immingham | | 12 | | | 11 |

*Actual Size Classes* ('000 *dwt*)

| *Port* | 0–5 | 5–10 | 10–15 | 15–20 | 20–25 | 25–30 | 30–35 |
|---|---|---|---|---|---|---|---|
| Port Talbot | | All less than 10,000 dwt | | | | | |
| Newport | | 8 | 69 | 41 | 23 | 9 | 4 |
| Cardiff | 6 | 8 | 10 | 39 | | | |
| Liverpool | | Not readily available | | | | | |
| Clyde | 7 | 4 | 8 | 77 | 3 | 10 | 3 |
| Tyne | | 3 | 38 | 3 | 13 | | |
| Tees | | 11 | 60 | 65 | 9 | 7 | |
| Immingham | 9 | — 12 — | | 1 | 1 | | |

any differences in types of ore required in South Wales steel manufacture, but because to receive the ore from any other source would lead to even greater optimum ship sizes and consequent diseconomies. From this may be concluded that:

(i) The removal of draught restrictions from a port may result in a change in the proportions of trade from some or all sources;
(ii) This will lead to different optimum ship sizes;
(iii) An unusual pattern of proportions of trade from various sources may be a better guide to the genuine existence of a port restraint than the direct comparison of current theoretical optimum ship sizes with current port capabilities.

## CONCLUSION

As with all theoretical models, the validity of the theory is dependent on the basic assumptions. Not all the assumptions on which the optimum ship size theory has been based can be verified with the information at present available. However, so far as checks have been possible the theory does not appear to be sensitive to those deviations from the most significant assumptions which have been considered.

The real test of the theory must be in its ability to predict. For two bulk commodities, grain and iron ore, theoretical optimum ship sizes have been calibrated over a range of volumes of trade and lengths of voyages. These results have been used to compare theory with practice for 1967 (see Table 4). Although data from all ports are not readily available in a convenient form for this comparison, nevertheless there does appear to be ample evidence to support the theory. Data from certain continental ports tend to confirm the U.K. findings.

If it is true that trade volume, value and distance determine the best size of cargo vessels to be used, then on most routes the appropriate size of ships changes annually. This would militate against ownership of the vessels by the importers, but would encourage chartering. A large proportion of the chartering undertaken by the oil companies appears to be for this reason.

Whereas in the past the volumes of freight handled at individual ports have been influenced strongly by the natural depths of water available, in the future the trend will be towards the reverse effect. Thus demand will cause tonnage, tonnage will determine ship size and ship size will become a major influence upon depth of water provided. This trend is of vital concern to ports everywhere, but the implication, that ports have to tailor their harbours to suit the shipping if they want to attract (or at least not distract) trade, has been well understood by most ports in North West Europe. These ports not only understand this, they actually behave as if they do. The second implication has not been as widely accepted. The fact that ports do provide deep water facilities does not necessarily mean that they will receive what they conceive to be their share of the business in the sizes of ships received by neighbouring ports. For example, London would not economically receive bulk grain carriers similar in size to those found at Rotterdam, no matter how deep the Thames estuary and Tilbury terminal might be. This is because the volume of trade to London is not large enough to support such a size of ship, even in the complete absence of transshipment. Of course, once transshipment starts via Rotterdam the differences between optimum ship sizes on the relevant routes become even greater.

Finally, the theory of optimum ship size is important for port planners as well as for shipping agents and brokers. This is because each port will have ships calling of sizes depending upon the trading routes it serves. The theory does not concern itself with optimum ship size in the sense of capacity, that is, the cheapest way of carrying a certain quantity of cargo; nor is it directed towards the optimum size in the sense of shape, that is, the best draught, length, etc., for minimum operating costs. These matters are primarily the concern of shipbuilders and operators. The theory is constructed round the trading requirements of specific routes carrying certain products particular distances. Armed with this tool a port should be in a much stronger position to determine its future requirements of channel depths, quay and lock capacities, and quayside storage capacity for bulk cargoes.

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