ON THE RATIONAL SELECTION OF SHIP SIZE

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ABSTRACT

The selection of vessel size as measured by cargo capacity is one of the most important decisions affecting the overall economics of a proposed ship. This decision is often a difficult one because the predicted availability of cargo has long term trends upwards or downwards. In addition, seasonal fluctuations may be expected. Other complications arise because of differences that may exist on each leg of the voyage in cargo availability, freight rates, and so forth. Under these circumstances, the selection of ship size has in the past been rather arbitrary simply because the complexities of the problem precluded any sort of rational approach. Electronic computers, however, give us the tools we need to solve problems of this nature.

In this paper we show how ship size may be selected in such a way as to provide the most economical design for a given forecast of cargo availability. Sensitivity studies lead to a few tentative conclusions as to the relative importance of factors such as sea speed or length of voyage. The influence of cargo availability patterns receives particular attention. Although the example shown here is for a rather simple case, the ideas behind the analysis can be expanded to handle more complicated situations.

PREFACE

The initial impetus for this paper came from a 1965 course in the use of computers in engineering design. This course, held at The University of Michigan, was financed by the National Science Foundation for the benefit of engineering professors from all over the country. The National Science Foundation also provided funds for the computer time needed to carry out the work reported here.

I am grateful to Mr. Makoto Hoshino for his help in many of the hand calculations as well as work with the computer. Prof. Odo Krappinger has also been helpful in discussing and criticizing this work as it developed. Mr. Warren Seider and Prof. Brice Carnahan gave much patient assistance in developing the initial computer program.

CONTENTS

I. THE PROBLEM OF SIZE

In designing a merchant ship, the selection of size ranks among the most important decisions affecting the overall profitability of the ship as an investment. How you should approach the problems of size depends on circumstances. Bulk carriers, for example, usually find their cargo available in practically unlimited amounts. The most profitable ship size under those conditions is the biggest one allowed by the physical environment: harbor depths, etc. In many commercial services, however, cargo is limited in availability and ships in those trades are denied the economic benefits of great size. This explains why general cargo liners seldom exceed 13,000 tons deadweight whereas tankers have grown to 15 times that capacity. Passenger ships, ferries, petroleum product carriers and many other types of ships are also limited in size by the availability of passengers or cargo. Although we shall confine our discussions here to cargo liners, the ideas we present are applicable to any of these other services.

Figure 1 shows a typical cargo forecast for a ship in the liner trade. In addition to expected long range upward trends, the cargo available per voyage will probably have large seasonal fluctuations and will differ greatly between the two legs of the round trip. Furthermore, the average freight rate per ton of cargo may be appreciably different

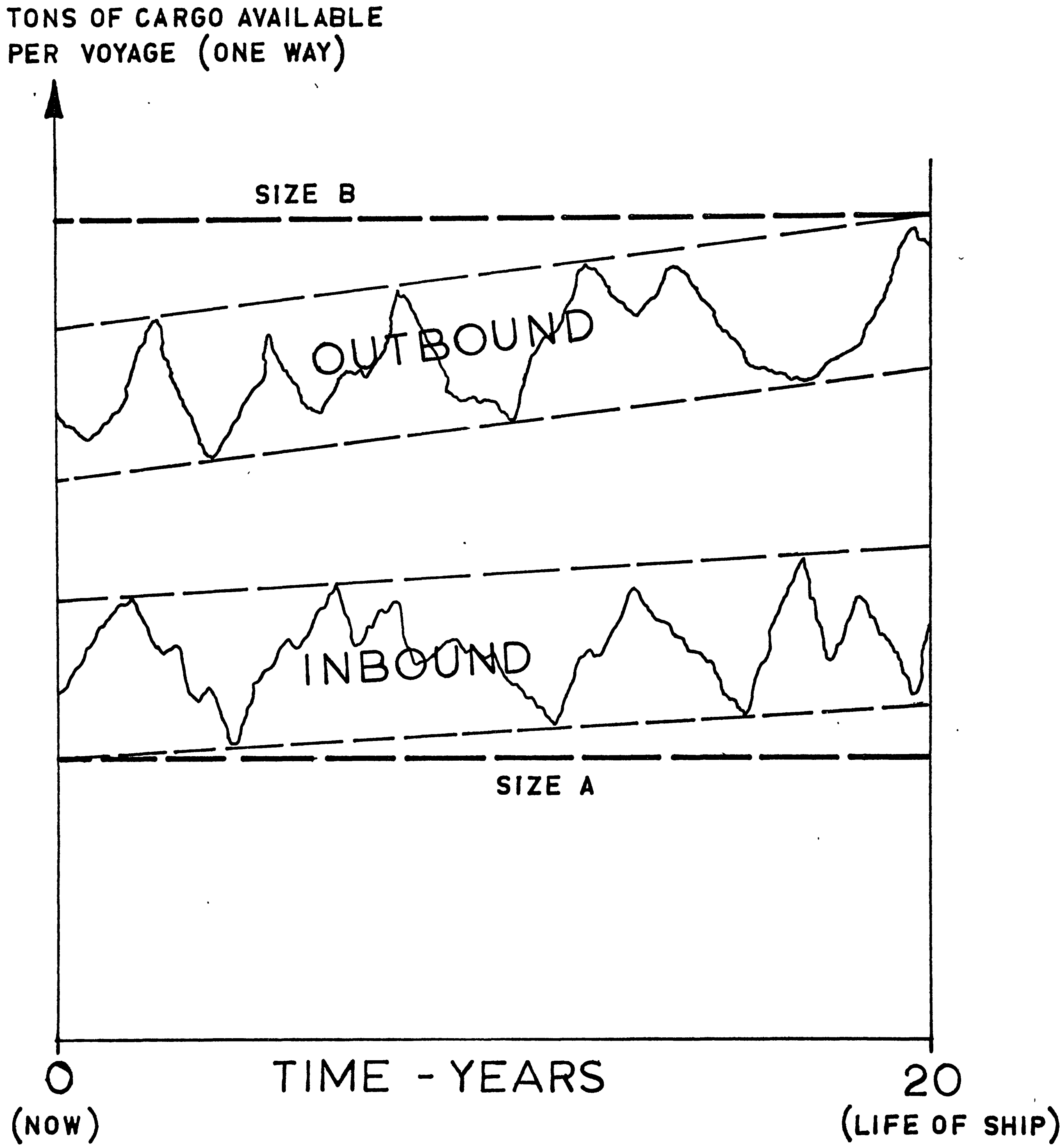


FIGURE 1 - TYPICAL CARGO FORECAST

inbound and outbound. Under these circumstances, what size ship would you select for this particular trade? Clearly, Size A as shown in the figure would be too small and Size B would be too big. The optimal size must fall between those extremes; it can be found only by analyzing the potential economics of several arbitrary designs representing the continuum of all intermediate sizes.

A glance at Figure 1 suggests another complication not yet described: the time-value of money. Near-at-hand cash returns are more desirable than those occurring at more distant dates. Standard interest relationships must thereby be used to discount future amounts of money to a common time basis. We shall discuss this in greater detail in the next section.

II. METHOD OF APPROACH

In the previous section we mentioned some of the complicating factors that influence the optimal size for a cargo liner. There are many other factors we could have added; length of voyage, fuel costs, port turnaround time, bunkering schedule, and so on. As is usually the case with system analyses, there are simply too many factors to allow a complete study of every conceivable combination. We must therefore seek logical shortcut procedures. My approach was to confine my studies to ordinary cargo liners of the type outlined in Table 1. I then developed a general computational procedure, or algorithm, allowing the assumption of any desired value for key factors such as cargo availability year by year. These variable factors are summarized in Table 2. Figure 2 is a simplified flow diagram for the computer program.

TABLE 1

OUTLINE SPECIFICATION FOR THE SHIP

Type: General cargo liner

Machinery: Single screw, geared steam turbine, 600 psi 850 F

Cargo gear: Kingposts and booms

Hull form: Standard sheer and camber; forecastle (20% LBP)

Freeboard: B-1 Series, Reference 2 (scantling draft)

Cost levels for construction or operation: Subsidized U S or unsubsidized foreign

TABLE 2

VARIABLE FACTORS IN THE ALGORITHM

Displacement
Cubic number
Shaft horsepower
Sea distance
Sea speed
Bunker schedule: one way or round trip
Relative freight rates inbound and outbound
Economic life or planning horizon
Port days per round trip
Forecast cargo availability inbound and outbound year-by-year

The validity of the computer program was tested by applying reasonable inputs and checking the results by hand calculation. We then made numerous sensitivity studies to get some feeling for the relative importance of the key operational factors. These sensitivity studies allowed us to draw several useful conclusions, but we made no attempt at compiling a cookbook of answers for every conceivable combination of circumstances. The principal aim of our work, and value of this paper, lie not in the results of the calculations but in the ideas behind them.

III. MEASURES OF MERIT

A problem common to all optimization studies is the selection of a measure of merit. We presumably want to find the most economical ship, but have trouble agreeing on what we mean by "most economical." Ships in the liner trade normally charge for their services according to conference agreements. The revenue per ton, then, would presumably be the same for every alternative design. The advantage of one ship over another would not be in an ability to offer lower rates, but in a greater return on the investment. This line of reasoning led us to assume that the internally generated interest on the investment would be the logical measure of merit. Since the annual returns fluctuated in these studies, we found the interest rate by the trial-and-error procedure of discounting future returns at different rates until we found the rate that made the cumulative present worth of all future returns equal to the investment. This method is most often called the Discounted Cash Flow Rate of Return. The details of the procedure are explained in Ref. 1 (which calls it the Equated Interest Rate of Return).

Unfortunately, the economic criterion explained above turned out to have a serious flaw when applied to our sensitivity studies. We found, not surprisingly, that any major change in the trend of predicted cargo availability (as one example) would produce a marked change in the overall rate of return. This implied a change in the attainable time-value of money which, in turn, altered the relative values of near and future returns. The selection of optimality thus became distorted simply because the derived level of profitability varied to unrealistic extremes. In short, the measuring device was influencing that which we wished to measure.

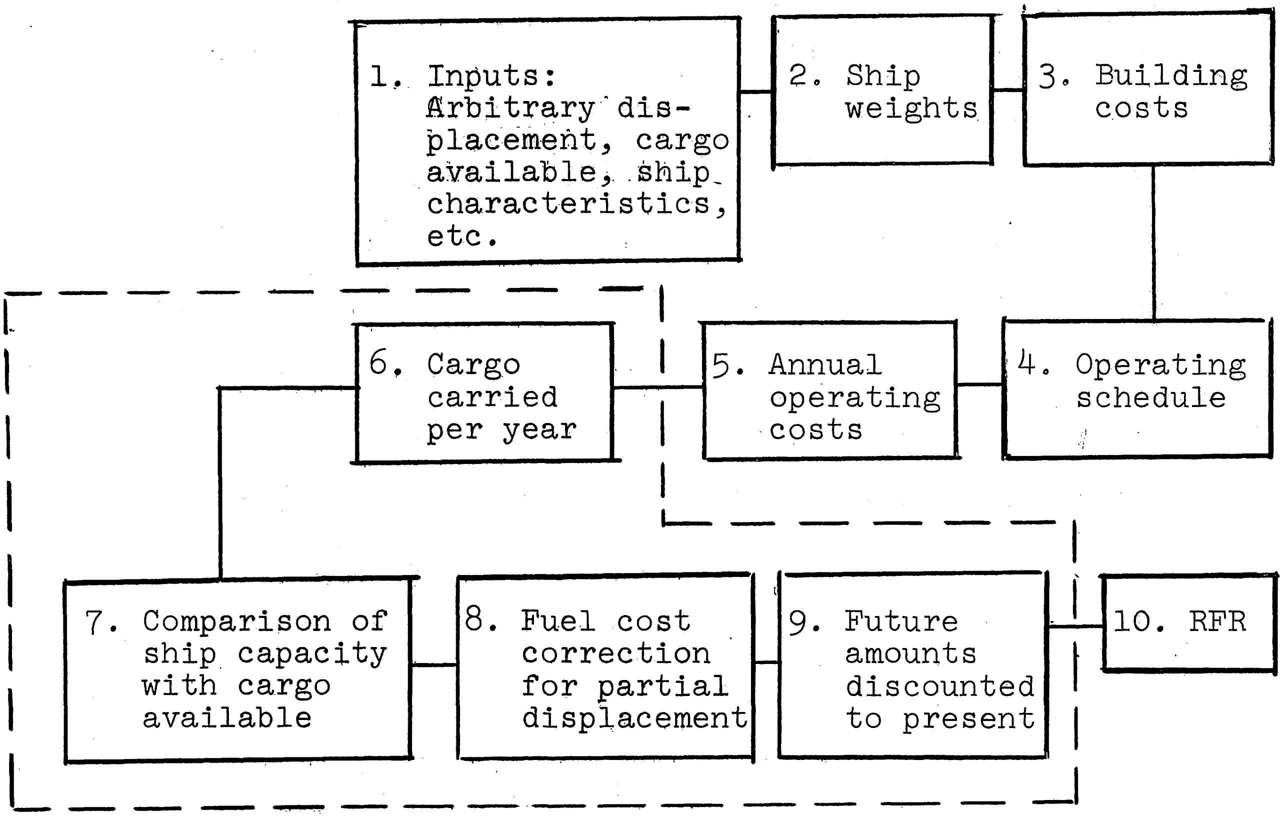
After considering various alternative measures of merit, we settled on the Required Freight Rate (RFR) as being the best of an imperfect lot. RFR, briefly, is the freight rate a shipowner would have to charge if he wants to earn a reasonable after-tax return of about 10 percent on his investment. We define the optimal ship as the one that has the lowest RFR; and, in order to keep our calculations under control, we assume the freight rate will remain constant over the life of the ship. This particular criterion seems better suited to tramps than to cargo liners. We rationalized its use however by arguing that, in the long run, conference freight rates would tend to adjust to conform with the Required Freight Rate.

Corporate profit tax rates and procedures vary between countries. As a general approximation, we used an arbitrary 20 percent interest rate of return before tax for discounting future amounts. One of our sensitivity studies analyzes the impact of this assumption.

IV. OUTLINE OF SOLUTION

Figure 2 shows a simplified flow diagram for our computer program. Appendix 2 spells out the details, while the following notes explain some of the major points involved in the algorithm. Note numbers correspond to the boxes in Figure 2. Before using the program we must select several arbitrary ship sizes. As our measure of ship size we use displacement for convenience in estimating weights, horsepowers and costs. Reference 2 was used for these estimates, with corrections for foreign (non-US) cost levels. The same reference was used for practically all estimates required in the following outline.

1. The primary inputs for the program are summarized in Table 2. Horsepower and cubic number are taken from Reference 2.



Steps within dashed line are calculated separately for each of 20 years

FIGURE 2

SIMPLIFIED FLOW DIAGRAM FOR COMPUTER ALGORITHM

3. Hull costs are based on hull weights, machinery costs on horsepower. Values are based on non-US construction costs.

4. The operating schedule combines sea days and port days to derive the round trips per year. The cargo capacity is derived using appropriate corrections for fuel weight and other non-useful parts of deadweight.

5. The annual costs of operation are based largely on the cubic number and horsepower. Cargo handling costs are specifically excluded.

6 & 7. In any given year, the cargo carried in either direction will be limited either by ship size or by the amount of cargo that is available. These steps compare ship size with available cargo in both directions. Seasonal fluctuations are treated as deterministic amounts, all values within each range being assumed to be equally probable.

8. When the available cargo is less than the ship's capacity, the ship requires less fuel to maintain its schedule. This step corrects the annual fuel consumption estimate for operation at less than design displacement.

9. Up to this point in our algorithm we have estimated, for each year of the ship's life, the annual operating costs and the tons of cargo transported in each direction. In order to correct for the time value of money, we must find the present worth of both dollars and tons. Discounting tons may seem peculiar but is sound in principle. Tons

carried correspond exactly to dollars earned, hence the discount factor may as well be applied to one as to the other.

10. The Required Freight Rate is derived from an equation of this nature:

$$RFR = \frac{\text{investment + present worth of operating costs}}{\text{present worth of cargo transported in tons}}$$

The actual relationship is slightly more complicated because of differing freight rates inbound and outbound.

Finally, the computer results are plotted to find the optimal ship size and minimum RFR for each set of assumptions. We can also find the range of sizes that are within some minimal departure from the optimum. In these studies, we define the reasonable range as being within an arbitrary 2.5 percent of the minimum Required Freight Rate. See Figure 3. In order to get the best possible estimate of the optimal size, auxiliary curves of the differences between successive RFR's are plotted. The optimum point occurs where the auxiliary curve crosses the zero line. The auxiliary curve is not shown in Figure 3.

V. GENERAL CONCLUSIONS

Table 3 and Figure 4 summarize the findings of our studies. We want to discuss these on an individual basis but first we can propose a few general conclusions:

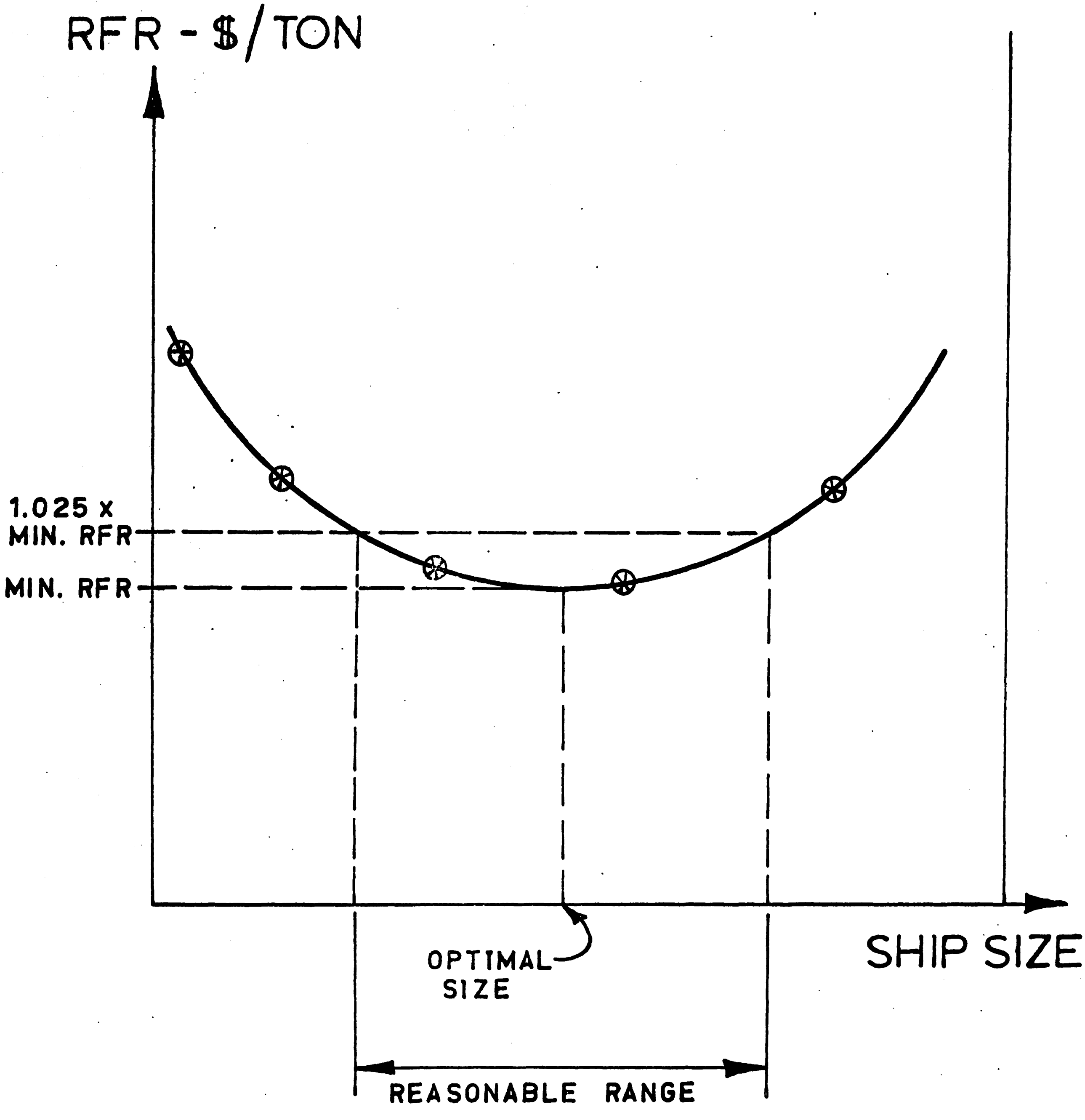
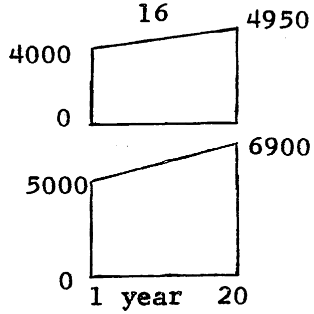
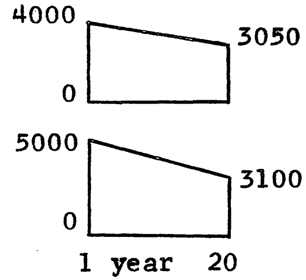


FIGURE 3 -
TYPICAL GRAPHICAL SOLUTION

TABLE 3

SENSITIVITY STUDIES

Parametric Variations and Resulting Change in Optimum
Cargo Capacity and Required Freight Rate

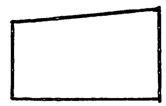
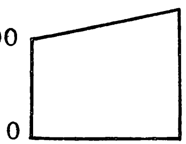
	STUDY							
	1	2A	2B	3A	3B	3C	4A	4B
<u>Parameter</u> (All parameters are the same as in Study 1 except as noted)								
Sea-distance, one way	4000							
Sea speed, knots	18							
Port days per round trip	16							
Cargo available inbound				4000 Constant	4000			
Cargo available outbound				5000 Constant	5000			
KI: Inbound fluctuations	450	0	1800	0				
KO: Outbound fluctuations	600	0	2400					
Distribution of KI & KO	rectangular							
Ratio: freight rates inbound to outbound	0.75							0.25
Interest rate before tax	20%						6%	
<u>Results</u> (Minimum and maximum refer to reasonable range of cargo capacity)								
Min. cargo capacity	4500	4600	5600	4200	5100	3900	4900	4900
Opt. cargo capacity	5300	5300	7200	4900	5900	4600	5800	5700
Max. cargo capacity	6400	6000	-	5900	6600	5500	6850	6460
Min. RFR outbound	\$17.6	\$17.3	\$19.6	\$18.3	\$28.0	\$19.4	\$11.2	\$23.5

(CONTINUED)

TABLE 3 (CONTINUED)

SENSITIVITY STUDIES

Parametric Variations and Resulting Change in Optimum
Cargo Capacity and Required Freight Rate

	STUDY							
	1	4C	6	7	8	9	10	11
Parameter (All parameters are the same as in Study 1 except as noted)								
Sea-distance, one way	4000		12,000					
Sea speed, knots	18			22				
Port days per round trip	16							2
Cargo available inbound					0	Same as 3C	Constant after tenth year	
Cargo available outbound					5000 Constant			
KI: Inbound fluctuations	450							
KO: Outbound fluctuations	600							
Distribution of KI & KO	rectangular							
Ratio: freight rates inbound to outbound	0.75							
Interest rate before tax	20%	1.5						
Results (Minimum and maximum refer to reasonable range of cargo capacity)								
Min. cargo capacity	4500	4350	4550	4500	4100	4400	4450	4500
Opt. cargo capacity	5300	4920	5400	5400	5400	5300	5200	5450
Max. cargo capacity	6400	5970	6400	6500	6200	6400	6300	6420
Min. RFR outbound	$17.6	$12.6	$40.55	$20.0	$29.6	$18.3	$17.65	$11.1

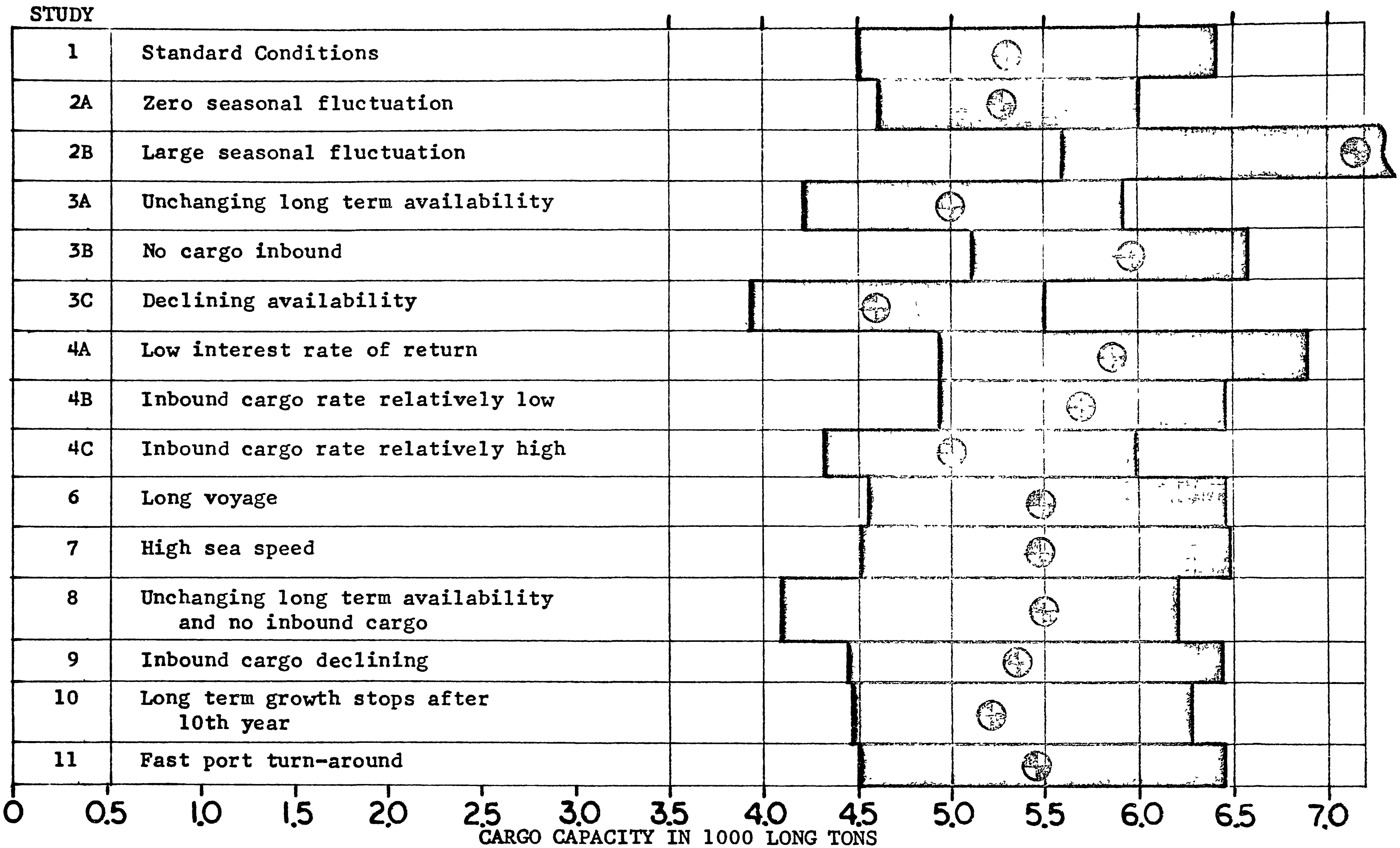


FIGURE 4 - GRAPHICAL SUMMARY

1. Reasonably large departures from the exact optimal size are permissible. As a rule of thumb, if you can keep the ship size within plus or minus 20 percent of the optimal, you will find your overall profitability within 2.5 percent of the maximum. This is in keeping with Ober Direktor Basingstoke's oft-quoted statement from Reference 3, which translates as follows:

> An optimum design is really no better than its neighbors; it just happens to be in the exact center of the best neighborhood. Viewed in the light of other assumptions or measures of merit, the boundaries of the neighborhood shift and with it, the center.

Considering such intangibles as customer satisfaction, ease of cargo handling, and maintenance of sea speed, most owners might prefer a ship that was 15 to 20 percent larger than the optimum.

2. The most unexpected result, to me at least, is the qualitative influence of return cargo on optimal size. Common sense tells us that the ship should be sized to suit the dominant cargo movement. Yet, we find that the availability of return cargoes actually reduces the optimal size. This seeming anomaly is explained under Point 4 in the next section.

3. Glancing at Figure 4 we see that almost all of the studies produced size ranges that overlapped the optimal size of the standard (Study 1). This means that if you should select cargo capacity appropriate to the assumed conditions of the first study, you could be grossly in

error in any one of your assumptions and still be within 2.5 percent of the maximum level of profitability. The important exception to this is the case of extreme seasonal fluctuations in cargo availability, Study 2B.

4. Considering the relative insensitivity of the foregoing results, we are probably justified in feeling confident that modest departures from any of our preliminary assumptions would produce no appreciable change in the outcome. For example, I should be surprised to find any significant change in optimal size resulting from a switch to diesel propulsion or to containerized cargo handling. The same cavalier attitude can be safely taken, I believe, with respect to all of the specifications of Table 1 and the estimating assumptions of Reference 2.

5. The insensitivity of the results also leads to the conclusion that the decision maker might well be satisfied to analyze only a single, most-likely set of conditions. Analyzing the outcomes of a range of cargo forecasts hardly seems worthwhile unless there is a large degree of uncertainty in the extent of seasonal fluctuations.

6. Does all of this insensitivity we have been discussing imply that the whole idea of rational analysis of ship size is a waste of time? I think not. The naval architect who has made such an analysis is certainly in a better position to weigh all factors, both tangible and intangible. His ultimate decision will still involve plenty of intuition, but it will be strengthened by a realistic

feeling for the quantitative influence of most of the important factors. He will bear out the system analyst's credo that it is better to be roughly right than exactly wrong (Reference 4).

VI. SPECIFIC CONCLUSIONS

The following conclusions are based on comparisons between the outcome of the standard assumptions (Study 1) and each of the individual sensitivity studies. I make no claim that Study 1 represents anything more than an arbitrary but reasonable set of assumptions, **incidentally.**

1. Seasonal Fluctuations: Studies 2A and 2B (see Figure 4) show the remarkably potent influence of seasonal fluctuations. In going from 2A to 2B, the increase in optimal size is 1900 tons. This is comparable in size to the increase in fluctuation: from zero to 2400 outbound and from zero to 1800 inbound. (Fluctuations are measured from the mean value.) We can conclude that the lost opportunity cost of cargo left on the pier is much more detrimental than the economic penalty of excess capacity.

As may be inferred from the increase in freight rate, large fluctuations in cargo availability are fundamentally expensive.

Figure 5 summarizes the findings of several auxiliary computer runs, each with a different value for the seasonal fluctuation in availability of cargo.

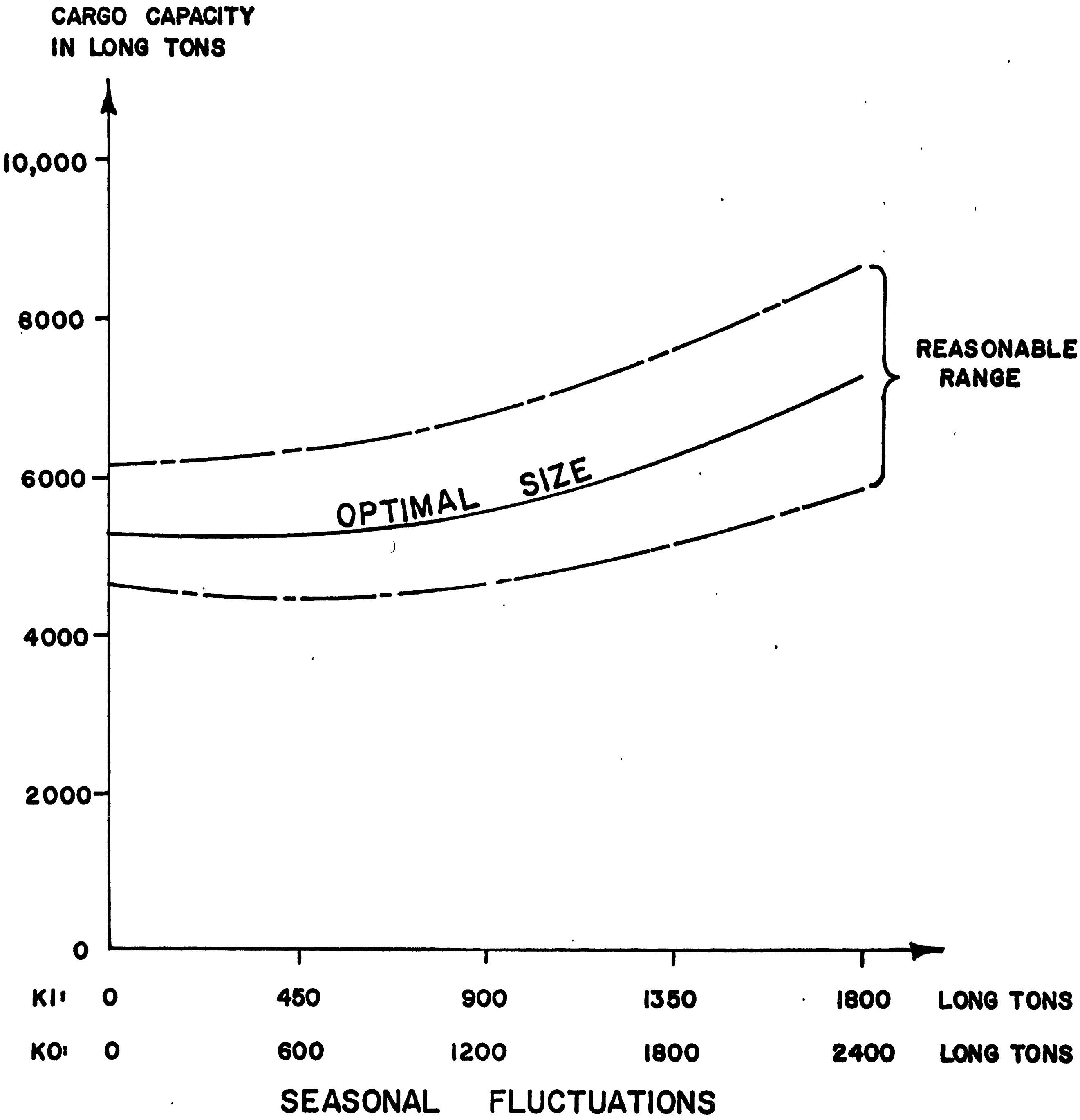


FIGURE 5:

EFFECT OF SEASONAL FLUCTUATIONS IN CARGO AVAILABILITY

(KI & KO MEASURE THE EXTREMES OF FLUCTUATION, INBOUND AND OUTBOUND, ABOVE AND BELOW THE MEAN VALUE.)

2. Long Term Availability Patterns: Studies 1, 3A, and 3C prove the intuitively obvious; increasing future demands call for larger ship sizes, decreasing demands call for smaller sizes. In these studies we confine ourselves to relatively moderate growth rates. Radical increases in cargo availability dictate the added consideration of introducing additional, competing ships into the trade--a complication we want to postpone to some future study.

3. One-Way Trades: Studies 3B and 8 apply to trade routes with no return cargoes. Study 8 represents the case where the long range trend is flat but seasonal fluctuations are expected. The best ship is the one that is just about big enough to accommodate the peak demands.

4. Influence of Return Cargoes: Studies 3A and 8 produce some surprising results. Both studies apply to constant level, long term trends with seasonal fluctuations. Study 8 is for a one-way trade and shows the optimal capacity to be 5400 tons. If small return cargoes are available however--as in Study 3A--the optimal capacity drops to 4900 tons. This contradicts intuitive judgment (mine anyhow) but can nevertheless be shown to be logical with a simple analysis of how the cost and transport factors vary with ship size. Figure 6 shows how RFR is influenced by the presence or absence of return cargoes. Seasonal fluctuations are omitted in order to simplify the setting. We can also assume for simplicity that the net

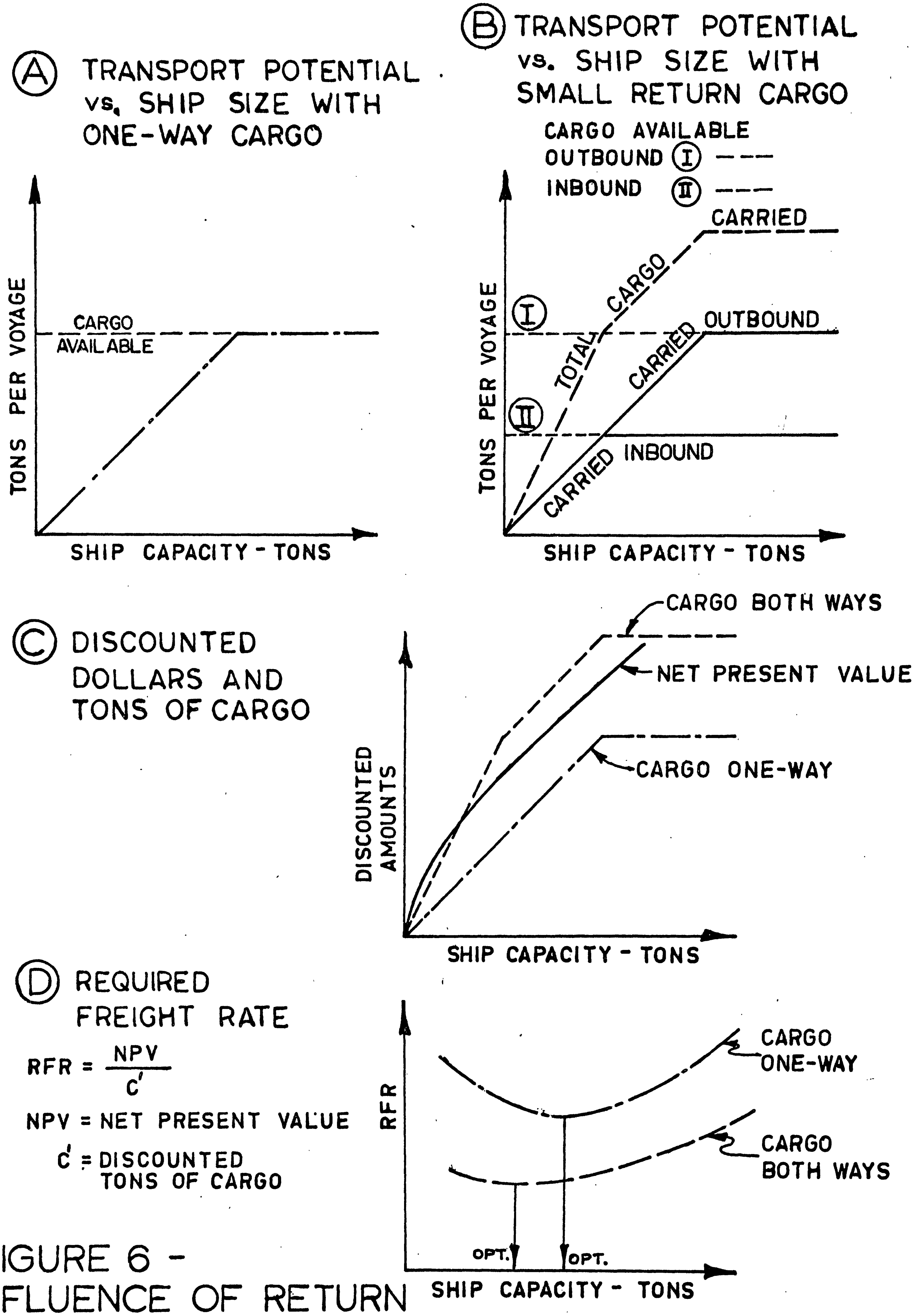


FIGURE 6 -
INFLUENCE OF RETURN CARGO ON OPTIMUM SHIP SIZE

present value will be the same regardless of the presence or absence of return cargo. The characteristic shape of the transport potential curves, however, are markedly different; see Sketch C in Figure 6. As a result, the low point of RFR moves to the left--indicating a smaller optimal capacity.

Studies 1, 3B, 4B, and 9 confirm the findings discussed above.

This characteristic seems worthy of further research. Depending on relative freight rates, there is some unknown quantity of return cargo that will have a maximum effect in reducing the optimal size. This is apparent because, if enough return cargo is carried, the optimal size would be the same as though no cargo at all were available.

A word of caution seems appropriate here. The conclusions we have reached pertaining to the influence of return cargoes are based on the Required Freight Rate criterion. This implies that the availability of return cargo will automatically lower the freight rate for the outbound cargo. If such is not the case, the influence of return cargo will presumably be tempered. This again is worth further study.

5. Level of Profitability: Study 1 uses a stipulated before-tax interest rate of 20 percent. Study 4A uses a before-tax rate of only 6 percent; as a result the optimal size increases by 500 tons. This does not prove that ships should be bigger when profit levels are lower. If

cargo trends had been downward, lowering the interest rate would have indicated a decrease in optimal size. High rates strongly discount the influence of far-future events; low rates do not. Future conditions are thereby relatively more important when levels of profitability are low.

6. Voyage Length: Study 6 increases the one-way sea distance from 4000 to 12,000 nautical miles. The resulting change in optimal size is hardly significant: an increase of 100 tons. The Required Freight Rate of course goes up but by a factor of 2.3, as compared to the distance factor of 3. If cargo handling costs had been included, the factor would have been much smaller than 2.3.

7. Sea Speed: In Study 7 the sea speed is increased from 18 to 22 knots and the entire ship is assumed to be redesigned to suit. The change in optimal size is again little affected, showing an increase of only 100 tons. The 22 percent increase in speed raises the Required Freight Rate by 13 percent.

8. Far-Future Errors in Predicting Cargo Availability;

Study 10 is the same as Study 1 except that, in Study 10, the growth in cargo availability suddenly stops after the tenth year. The resulting drop in optimal size is again only 100 tons. This bears out the relative unimportance of far-future conditions in making decisions today.

9. Port Time: Study 11 reduces the port turnaround time from 16 days to 2 days. This corresponds to the improvement made possible by container transport. The Required

Freight Rate drops from $17.60 to $11.10 per ton; a 37 percent saving. The optimal size goes up only 150 tons, however, and the reasonable range in size is not affected.

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APPENDIX 1

DETAILED ASSUMPTIONS

In addition to those already explained, the following assumptions are used in all of the studies, except as specifically modified in sensitivity analysis.

1. The ship will take on bunkers at each end of the voyage.
2. No passengers or cadets will be acoommodated.
3. The ship will operate 350 days per year.
4. There will be eight port visits per round trip.
5. Cost of bunker oil will average $2.00 per barrel.
6. The ship will be retired after 20 years of service with zero net disposal value.
7. Cargo handling costs are specifically excluded.

Many other assumptions are detailed in the algorithm that follows.

APPENDIX 2

ALGORITHM

What follows is the step-by-step procedure that was used to find the Required Freight Rate for each arbitrary size of ship. Several steps required purely by the mechanics of the Michigan computer are omitted. The variable inputs are listed in Table 2. Equation, table and figure numbers in parentheses are those found in Reference 2. Abbreviations are explained wherever they first appear.

<u>Design Inputs</u>

1. VK: Nominal sea speed in knots (arbitrary)
2. DISPL: Displacement in long tons, salt water. Values are arbitrary. The range of displacements is based on cargo deadweights using the following approximations:

   Deadweight = 1.05 x Cargo Deadweight
   Displacement = 1.7 x Deadweight

3. CB: Block coefficient (Figure 5)
4. CN: Cubic number = $\frac{LBD}{100}$
5. CNX = $\frac{CN}{1000}$
6. SHP: Maximum Continuous Shaft Horsepower (Figure 19)
7. SHPX = $\frac{SHP}{1000}$

Weight Estimate

8. WS: Steel weight (Equation 20 with no corrections for length-depth or extent of superstructure)

9. WO: Outfitting weight (Equation 27 with average coefficient)

10. WHE: Hull engineering weight (Equation 28 with average coefficient)

11. WM: Machinery weight (Equation 29 with average coefficient for machinery amidships. The coefficient applies to maximum SHP)

12. WLS: Light ship weight = Sum of Lines 8 - 11 above

13. DWT: Deadweight = DISPL - WLS

Cost Estimate

(Initial cost estimates are for US construction, corrected later for foreign construction)

14. MS: Steel material cost = \$242x(WS)

15. MO: Outfitting material cost = \$1080x(WO)

16. MHE: Hull engineering material cost = \$2970x(WHE)

17. MM: Machinery material cost (Equation 35)

Note: All material costs above include a 10% margin for miscellaneous costs

18. LS: Steel labor cost including 75% overhead and a 33% margin for miscellaneous labor. Labor rate is \$3.00 per hour (Equation 32 with average coefficient)

19. LO: Outfitting labor and overhead costs (Equation 33 with average coefficient). See Line 18

20. LHE: Hull engineering labor and overhead costs (Equation 34 with average coefficient). See Line 18

21. LM: Machinery labor and overhead costs (Equation 36 with average coefficient and correction for maximum vs normal rating)

22. P: Owner's investment = C×(Sum of all material, labor and overhead costs)

where

C = (correction for profit)(correction for multiple production)(correction for non-US construction) (correction for owner's incidental costs)

C = (1.05)(0.871)(0.50)(1.10) = 0.503

The profit correction is arbitrary. The multiple production correction is for four ships (Table XI). The correction for non-US construction reflects current subsidy levels.

Operating Analysis

23. SDPRT: Sea days per round trip

$$= \frac{2Z}{24VK} = \frac{Z}{12VK}$$

where

Z = one-way distance in nautical miles

24. TDPRT: Total days per round trip

= sea days + port days

25. RTPY: Round trips per year = $\frac{350}{TDPRT}$

26. SDPY: Sea days per year = (SDPRT)(RTPY)

27. PDPY: Port days per year = 350 - SDPY

28. SFPYU: Sea fuel per year, uncorrected for operation at partial displacement (Equation 48 with an added allotment of 13 barrels per day for air conditioning and refrigeration)

29. PFPY: Port fuel per year (Equation 50)

30. CC: Cargo capacity in long tons

$$= 0.985 \text{ DWT} - 400 - \frac{Z}{20,000}\left[0.985 \text{ DWT} - 400 - \frac{\text{DWT}}{0.745(1.0282)^{\text{VK}}} + 925 \left(\frac{\text{VK}}{10}\right)^{1.6} \right]$$

where

Z = fueling radius in nautical miles; one-way distance in this case

DWT = deadweight in long tons

VK = sea speed in knots

This equation was derived from Figure 10A in Reference 2. It is reasonably accurate for speeds between 14 and 24 knots.

Operating Costs

31. NC: Number in crew (Equation 52)

32. CCREW: Annual crew costs. Assuming a non-US crew, an average annual cost of $3000 per man is a reasonable figure

33. CSUBS: Annual subsistence costs = $462x(NC)

34. CMAR: Annual cost of maintenance and repair (Equatopms 54 amd 55, both reduced for foreign costs)

$$= \$6500 \times (\text{CNX})^{0.667} + \$2930 \times (\text{SHPX})^{0.667}$$

35. CSAS: Annual cost of stores and supplies (Equation 56 or 57 depending on number in crew)

36. CPAI: Annual cost of protective and indemnity insurance (Equation 38, using $290 per crew member)

37. CHAMI: Annual cost of hull and machinery insurance (Equation 60 corrected for non-US costs). Includes war risk insurance at 0.1%

$$= \$10,000 + 0.012(\text{P})$$

38. COH: Annual cost of overhead (Equation 61)

39. CP: Annual port costs (Equation 62 and 63)

40. AOCXF: Annual operating costs exclusive of fuel and cargo handling

= Sum of Lines 31 - 39

Transport Analysis

(All steps from Line 41 to Line 53 are calculated separately for each of 20 years)

41. SLR: Speed-length ratio, $\frac{VK}{(L)^{0.5}}$

For the B-1 series of Reference 2 speed, length, and displacement bear the following relationship

$$L = 20.7 \frac{VK}{VK + 2} (DISPL)^{0.333}$$

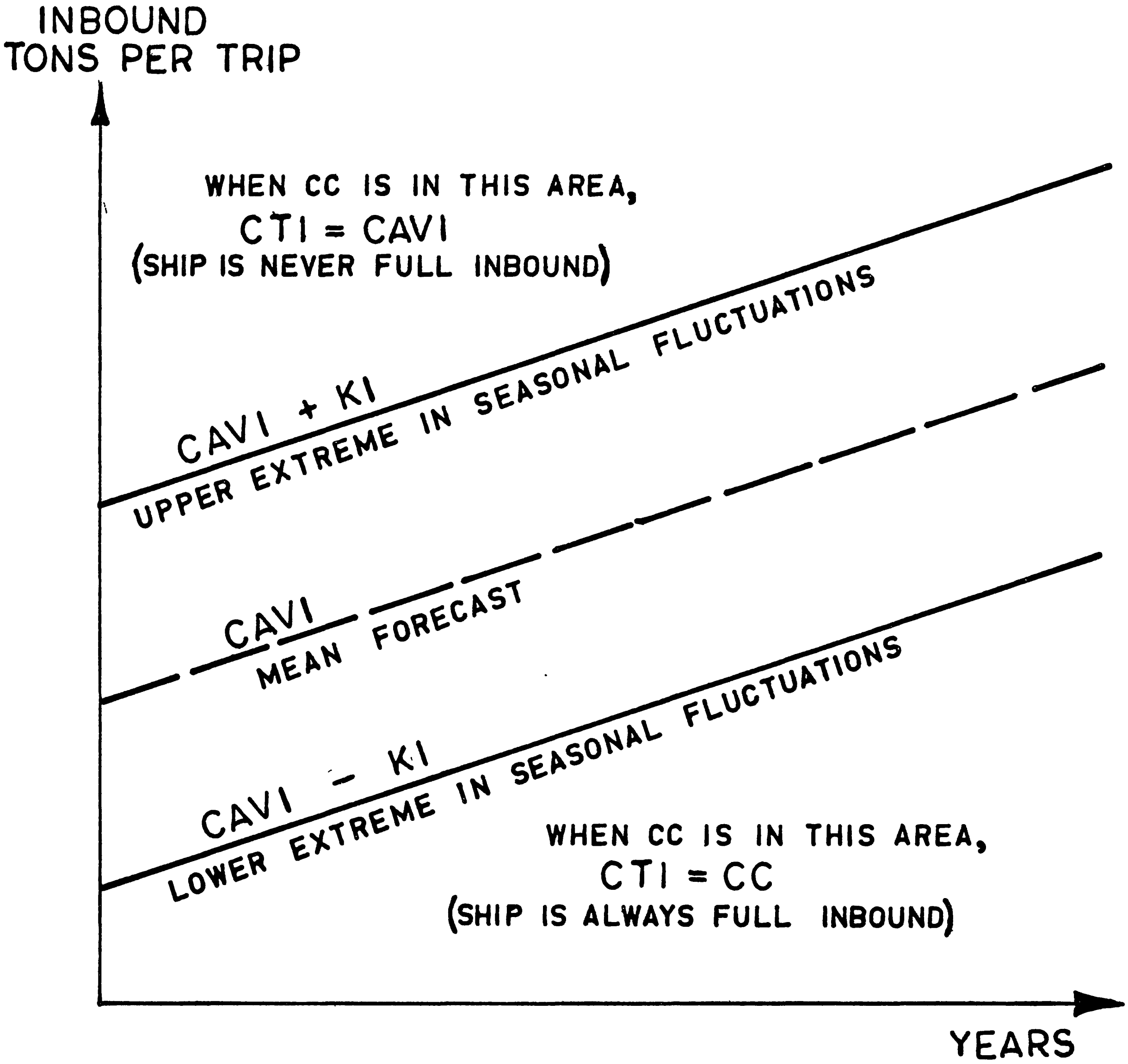
therefore

$$\frac{VK}{(L)^{0.5}} = \frac{VK}{\left[20.7 \frac{VK}{VK + 2} (DISPL)^{0.333}\right]^{0.5}}$$

$$= \frac{VK}{(20.7)^{0.5} \left(\frac{VK}{VK + 2}\right)^{0.5} (DISPL)^{0.167}}$$

$$= \frac{\left[VK(VK + 2)\right]^{0.5}}{4.56(DISPL)^{0.167}}$$

42. CTI: Cargo transported per one-way trip inbound. This value will vary with the ship's cargo capacity and the amount of cargo available. For example, consider the pattern of inbound cargo availability in Figure 7. When the cargo capacity CC is less than the minimum forecast cargo availability, then the ship always sails full inbound. When the cargo capacity exceeds the maximum forecast cargo availability, then the ship never sails full inbound. The difficulty comes in analyzing CTI in the area between the upper and lower extremes. We assume a rectangular probability distribution



CC: CARGO CAPACITY

CTI: CARGO TRANSPORTED INBOUND PER ONE-WAY TRIP

CAVI: CARGO AVAILABLE INBOUND (MEAN FORECAST)

KI: RANGE OF SEASONAL FLUCTUATION ABOVE OR BELOW MEAN FORECAST

FIGURE 7 - INBOUND CARGO AVAILABILITY vs. CARGO TRANSPORTED INBOUND PER ONE-WAY TRIP

of cargo availability between the two extremes (i.e., all values are equally probable).

As CC increases from the lower extreme (CAVI-KI) to the upper extreme (CAVI + KI) the most likely value of CTI will increase linearly from CC to CAVI:

$$CTI = (CAVI - KI) + \tfrac{1}{2}\,(CC - CAVI + KI)$$

$$CTI = CAVI - KI + \tfrac{1}{2}\,CC - \tfrac{1}{2}\,CAVI + \tfrac{1}{2}\,KI$$

$$CTI = \frac{CAVI + CC - KI}{2}$$

43. CTO: Cargo transported per one-way trip outbound; analyzed same way as CTI

44. CTPYI: Cargo tons per year inbound = (CTI)(RTPY)

45. CTPYO: Cargo tons per year outbound

$$= (CTI)(RTPY)$$

Fuel Correction

46. EXDWT: Excess deadweight, taken as the average of the unused cargo capacity inbound and outbound

$$EXDWT = \frac{CC - CTI + CC - CTO}{2} = CC - \frac{CTI + CTO}{2}$$

47. FCOR: Fuel correction in barrels per round trip, for operating at design speed but partial displacement; derived from Table XVI in Reference 2:

$$= \frac{2Z}{1000} \times \left(\frac{EXDWT}{1000}\right) \times 1.12(51)^{SLR}$$

where

Z = one-way distance in nautical miles

SLR = speed-length ratio

48. FPY: Fuel per year for all purposes

$$= SFPYU + PFPY - (FCOR)(RTPY)$$

where

SFPYU = sea fuel per year uncorrected (see line 28)

PFPY = port fuel per year (see Line 29)

RTPY = round trips per year (see Line 25)

49. CF: Cost of fuel per year = (FPY)(CFPB)

where

CFPB = cost of fuel per barrel--$2.00 in this case

50. TAOC: Total annual operating cost exclusive of cargo handling = AOCXF + CF = Line 40 + Line 49

Discounting Future Costs and Cargoes Transported

51. ECTPY: Equivalent cargo transported each year. This is the number of tons of cargo that would have to be carried each year in order to produce the predicted revenue at the outbound freight rate only:

= CTPYO + (CTPYI)(RFRITO)

where

CTPYO = cargo tons per year outbound

CTPYI = cargo tons per year inbound

RFRITO: ratio of freight rates inbound and outbound

52. DECTPY: Discounted equivalent cargo transported each year

= (ECTPY)(SPWF)

Where

SPWF = single payment present worth factor for appropriate before-tax interest rate

53. DTAOC: Discounted total annual operating costs

= (TAOC)(SPWF)

(All steps from Line 41 through Line 53 are calculated separately for each of 20 years)

54. TDECT: Total discounted equivalent cargo transported

$$= \sum_{0}^{20} \text{Line } 52$$

55. TDOC: Total discounted annual operating costs

$$= \sum_{0}^{20} \text{Line } 53$$

Required Freight Rates

56. RFRO: Required Freight Rate, outbound

$$= \frac{P + TDOC}{TDECT}$$

57. RFRI: Required Freight Rate, inbound

$$= (RFRO)(RFRITO)$$

RFRO is taken as the standard for comparison with other alternative displacements. The optimum is found by plotting RFRO against the displacement as in Figure 3.

The average study used about half a minute of computer time (IBM 7090).

APPENDIX 3

SUPPLEMENTARY RESULTS

Optimum deadweights and displacements with upper and lower limits of reasonable ranges

	Deadweight			Displacement		
Study	Min.	Opt.	Max.	Min.	Opt.	Max.
1	5550	6450	7550	9750	11050	12700
2A	5700	6400	7200	10000	11000	12150
2B	6700	7900	—	11450	13900	-
3A	5300	6000	7000	9400	10450	11900
3B	6200	7000	7750	10700	11900	13000
3C	4950	5650	6550	8900	9950	11350
4A	6000	6950	8050	10450	11800	13400
4B	6000	6850	7650	10400	11650	12800
4C	5400	6000	7100	9550	10450	12050
6	6950	7950	8950	11800	13250	14900
7	5850	6800	7950	10850	12250	13950
8	5650	6600	7300	9950	11200	12350
9	5450	6400	7550	9600	11000	12700
10	5500	6300	7450	9750	10900	12550
11	5550	6550	7600	9800	11250	12750