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A SECOND LOOK AT MEASURES OF MERIT FOR SHIP DESIGN

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ABSTRACT

My purpose in writing this little book is to discuss the relative virtues and shortcomings of the several measures of merit in current use in ship design. In particular, I want to compare the two criteria most popular with U.S. business managers today: net present value and discounted cash flow rate of return, or yield. I also want to make the point that, under some conditions, the required freight rate criterion may be preferable to either of those two. In all this I assume that you are already familiar with the principles of engineering economics. If not, see Reference 1 before proceeding further.

All valid criteria have the characteristic of flat laxity. Therefore, finding an exactly optimal design is not as important as establishing the range of designs that promise close to the maximum level of profitability. Applying the different criteria to a typical speed-optimization study demonstrates that, when properly used, each valid criterion will indicate a design that is within (or at least close to) the reasonable range indicated by the others.

Economic studies usually require us to predict future conditions. An element of uncertainty is thus common. Some basic methods for handling uncertainty are explained, as are methods for choosing between alternatives having differing degrees of uncertainty or risk.

The effects of taxes as well as bank loans are covered in some detail, with illustrative examples from a feasibility study. These demonstrate that taxes have great influence in weighing the economic merit of new technologies but that bank loans do not. In short, from the designer's point of view, economics are important, finances are not.

Recognizing the inventory value of the ship's cargo will justify higher degrees of ship productivity (e.g. design speed). A suggested approach to this is presented here.

PREFACE

When I first set to work on this document my intent was to provide a revised edition of Measures of Merit in Ship Design, lecture notes that I wrote in 1967. As I have used that publication in my course work over the intervening years I have seen many areas for improvement, not only in what is said but how. In particular, the old document's Figure 5 (showing comparative indications of optimality) has, I lament to say, induced mental constipation in generations of students. It, and the research behind it, have now been replaced by a new study -- involving contemporary cost figures -- and are hereby offered up in what I hope will prove to be a more digestible intellectual cuisine.

Other revisions, too numerous to mention, became so extensive that perhaps 85 percent of the original publication has been replaced. Moreover, some fresh topics have been introduced. The net result is that a new, yet related, title seems to be in order. So here it is: A Second Look at Measures of Merit for Ship Design.

Harry Benford

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ABBREVIATIONS

A	Uniform annual returns before tax
A'	Uniform annual returns after tax = $A_B + A_O$
A_B	Uniform annual returns to bank
A_O	Uniform annual returns to owner, after tax
AAB	Average annual benefit
AABI	Average annual benefit index
AAC	Average annual cost
AACR	Annual cost of capital recovery = CR ÷ P
C	Annual transport capacity
CC	Capitalized cost
CR	Capital recovery factor = A ÷ P
CR'	Capital recovery factor after tax = A' ÷ P
DCF	Discounted cash flow method of finding yield (i')
DCF_O	Discounted cash flow method applied to finding owner's yield (i_O) on owner's share of the investment (P_O)
Δ	Difference
ECT	Economic cost of transport
FR	Freight rate
I_B	Annual interest payment to bank or bondholder
i	Annual interest rate at before-tax level, compounded annually
i'	Yield or after-tax interest rate
i_B	Annual interest rate stipulated by bank or bondholder
i_O	Yield calculated from owner's after-tax returns (A_O) and equity capital (P_O)
LCC	Life cycle cost
M	Million
N	Number of years; usually the economic life of the investment
NPV	Net present value of all cash flows discounted to the present
NPV_O	Net present value of owner's equity and returns
NPVI	Net present value index = NPV ÷ P
P	Total initial investment, principal, or present worth of future amounts
P_B	Capital borrowed from bank or bondholder
P_O	Equity capital
PBP	Pay-back period
PV	Present value, or present worth, of both investment and operating costs
PW	Present worth factor or discount factor, single payment
RFR	Required freight rate
SPW	Series present worth factor
t	Tax rate
Ucos	Unit cost of service
Y	Uniform annual costs of operation, exclusive of capital costs

Notes

1. (SPW-5%-25) is a standard mnemonic form for the series present worth factor for five percent interest and for 25 years.
2. Other symbols and abbreviations are explained wherever used.

I. INTRODUCTION

This paper is concerned with the selection of measures of merit for decision-making in ship design. Unfortunately, there is no ideal, universally applicable criterion of desirability. To begin with, business managers frequently disagree as to what the central aim of the enterprise should be; they usually agree that the company should try to be as profitable as it can, but they fail to concur on a definition of "profitable." Second, there can be no universally applicable measure of merit, because differing economic circumstances frequently dictate fundamentally different approaches. Income, for example, may be predicted with confidence. In many situations, however, it cannot; or, indeed, it may be zero as, for instance, in a naval craft or service vessel such as an icebreaker. As another example, a criterion that is suitable for finding the optimum design may fail as a way of deciding yes or no on the entire project. Finally, although any valid measure of merit will be based on economics, there are always important considerations (perhaps related to some owner's vanity) that cannot be expressed in the monetary units of economic analysis. These are the intangible influences, which are strictly subjective and usually the prerogative of top-management. In brief, the major decisions are based on a combination of considerations: quantitative economics tempered with qualitative intangibles.

Overlaying the above-mentioned complications relating to measures of merit is the realization that they are to be used in cost analyses based on questionable predictions of future conditions. The application of statistics and probability theory is an important subject, but one that will be discussed only lightly here. The overriding fact is that engineering economy involves debatable data analyzed by debatable means. A recognition of this keeps the practitioner in a humble frame of mind that leads to reasonable dealings with others. It should not, however, lead him into slothful ways. Economic analysis deserves, in so far as practical, sound principles and rigorous practices.

Any valid, widely accepted measure of merit for a proposed investment will fall into one of three categories depending on whether the analyst wants to assign (vs derive) an interest rate and assign (vs derive) a level of income. Table 1 illustrates this.

for several good reasons. It produces numbers with dollar signs attached, which attribute is reportedly highly favored by some managers, especially those without engineering backgrounds. To them, dimensionless numbers (such as yield) seem somehow unsubstantial, hence lacking in real meaning. More to the point, however, is the fact that in many cases NPV is a more accurate gage of human satisfaction than is yield. As for RFR, its only element of human satisfaction resides with the shipowner's customer, and pleasing him (or her) is not quite as important -- in the shipowner's eyes -- as pleasing himself.

Weaknesses in NPV and how to overcome. Net present value does have two weaknesses, although these can be overcome by substituting its derivatives. One weakness is its inherent tendency (being dimensional) to favor massive investments. Would you favor a $10 million investment with a $5 NPV or a $2 investment with a $4 NPV? Moreover, although the

TABLE 1: Three Major Categories of Measures of Merit

Required Assumptions		Primary Measure of Merit	Surrogates or Derivatives
Revenue	Interest Rate		
yes	yes	NPV	NPVI, AAB, AABI
yes	No	Yield	CR, CR', PBP
No	Yes	AAC	RFR, ECT, LCC, CC

In this table, the abbreviations stand for:

NPV: Net present value
NPVI: Net present value index
AAB: Average annual benefit
AABI: Average annual benefit index
CR: Capital recovery factor before tax
CR': Capital recovery factor after tax
PCB: Pay-back period
AAC: Average annual cost
RFR: Required freight rate
ECT: Economic cost of transport
LCC: Life cycle cost
CC: Capitalized cost

These measures are defined in the next chapter.

II. MEASURES DEFINED

NPV and Its Derivatives

Net present value is one of the most widely accepted measures of merit. Although it requires assumptions as to both revenue and interest rate, it is popular

organization's central aim may be to maximize its overall NPV, it cannot attain that aim in its total portfolio by selecting between competing investment opportunities strictly on a basis of their individual net present values. Assuming its available capital is limited, the firm should rank competing alternatives on a basis of net present value per dollar of investment. I choose to call this ratio the net present value index (NPVI), although others call it (or slight variations) profitability index, discounted profit to investment ratio, or capital efficiency. See Reference 2. If your organization's real bottleneck is not spare cash but, let us say, project engineers, then NPVI should be defined as net present value per project engineer.

Unequal lives. A second weakness of NPV is that it tends to favor long-lived *visa vis* short-lived investments. This deficiency can be overcome by multiplying each NPV by a capital recovery factor appropriate to the project's economic life. This produces what I call the average annual benefit (AAB), which we can assume will be always the same for the original unit and all its replacements. Life expectancy, then, is no longer a factor because each alternative forms the start of a perpetual series. If you will recall, we use an exactly parallel procedure in converting present worth (or life cycle cost) to average annual cost -- and for the same purpose.

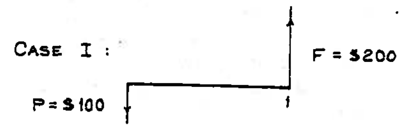
Eliminating both biases. If we now go one step beyond AAB and divide it by the initial investment, we arrive at what we might call the average annual benefit index (AABI), or average annual benefit per dollar invested. This offspring of NPV overcomes both its parent's shortcomings in that it neutralizes the family proclivities toward larger, longer-lived investments.

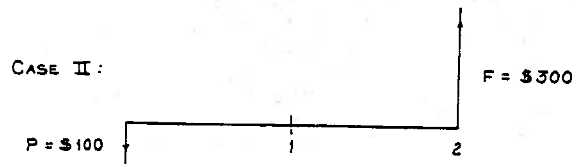
Interest rate for NPV. Finally, a word about interest rates. In using NPV we must agree upon some minimum acceptable interest rate for discounting future amounts. Selecting a rate is usually management's prerogative and always involves some element of subjective judgment. As a minimum, the cut-off rate should equal the firm's cost of capital plus one or two percent just for the trouble and risk involved. If risks are thought to be more than minimal, the rates should be increased accordingly. When corrected for inflation, cut-off rates in this country typically run around eight or nine percent on low-risk investments. We'll have more to say on this in a later section.

Yield and Its Surrogates

Another widely accepted measure of merit is called here yield. You will also find it referred to as discounted cash flow rate of return (DCF), internally generated interest, rate of return, internal rate of return, profitability index, percentage return, investor's method, equivalent return on investment -- and others. See Reference 2.

Where yield may mislead. Yield avoids the shortcomings of NPV in that it does not give unfair advantage to larger investments or those with longer lives. There are, however, cases where it can be misleading. Here is an extreme example. Suppose that your personal time-value of money is such that you would have trouble choosing between $100 now and the secure promise of $120 one year from now. That would establish your visceral interest rate at 20 percent. Next, suppose some reliable person should offer you two mutually exclusive investment opportunities. In one case an investment of $100 will repay $200 in a year's time. In the other, an investment of $100 will repay $300 in two years' time.





If you understand and agree with the psychological wisdom of using compound interest relationships for discounting future cash flows, you could use NPV to measure and compare the relative desirability of the two proposals. More basically, if your gut-dictated interest rate were indeed 20 percent, your subjective judgment would lead you to choose the second. But, let us try NPV to check that conclusion.

Case I:

$$NPV = (PW\text{-}20\%\text{-}1)\frac{1}{1.2}\ \$200 - \$100 = \$66.67$$

Case II:

$$NPV = (PW\text{-}20\%\text{-}2)\frac{1}{1.44}\ \$300 - \$100 = \$108.33$$

As predicted, Case II looks better in terms of NPV. Suppose, however, we use yield (i) as our guide. Then we should have:

Case I: $\frac{F}{P} = \frac{\$200}{\$100} = 2$

$N = 1$

So $(1+i) = 2$

and $i = 100$ percent

Case II: $\frac{F}{P} = \frac{\$300}{\$1400} = 3$

$N = 2$

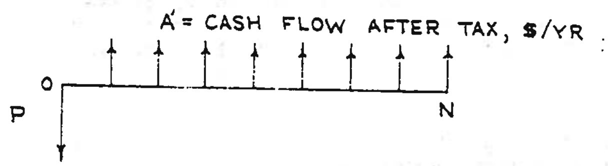
So $(1+i)^{} = 3$

$1+i = 3^{0.5}$

and i = 73.2 percent

An all-out defender of yield would argue that Case I was the better offer. Yet, from a human-satisfaction point of view, that would be misleading. (Let's keep reminding ourselves that the final goal of the engineer's vocation is human satisfaction.)

Applying yield to normal cases. Having relied on that exaggerated example, let us get back to a more normal perspective and admit that ship economic studies are not at all like that. In the normal case we are trying to select between alternative design proposals, each of which involves an initial investment and continuing annual returns over a long period -- typically twenty years. If our predicted cash flow pattern is at all complex, we can derive the yield by using trial-and-error to find that interest rate that brings NPV to zero. In over ninety percent of actual design studies, however, we can safely simplify our work by adopting (for each alternative) a cash flow pattern of this basic configuration:



A family of assumptions. This cash flow pattern implies the following assumptions:

1) The tax depreciation period equals the economic life.

2) Taxes are based on straight-line depreciation.

3) There are no bank loans or bonded debts.

4) The investment is made in a single lump sum on the day the ship is delivered.

5) No working capital is required.

6) The ship's net disposal value will be zero.

7) No tax-deferral privileges are used.

8) No investment tax credit is used.

9) Revenues and operating costs will remain uniform throughout the economic life of the ship (in constant-values dollars).

10) There are no major components (e.g. containers) with economic lives that differ from that of the ship.

These are admittedly bold assumptions. Yet, in the majority of ship economic studies they are reasonably safe because the errors induced tend to be much the same for all alternatives. Remember, in engineering economics, it is the differences between alternatives that command our attention. You will find in dealing with many shipowners a strong desire to introduce every conceivable real-life complication in infinite varieties and combinations thereof. For the sake of your computer budget and your own sanity, however, you must try to confine such baroque efforts to the final few alternatives. Your initial winnowing should as much as possible be based on simplified models.

Surrogates for yield. If you are willing to accept the standard, simple cash flow implied above, finding yield is easy. First solve for CR', which equals $A' \div P$, then use Figure 1 to derive the yield.

As may be obvious from Figure 1, the design that promises highest yield will be the one with the highest value of CR' -- assuming equal lives. Thus, CR' becomes a valid surrogate for yield and saves one step in computation. Going further, unless there is something peculiar in the tax structure, the design

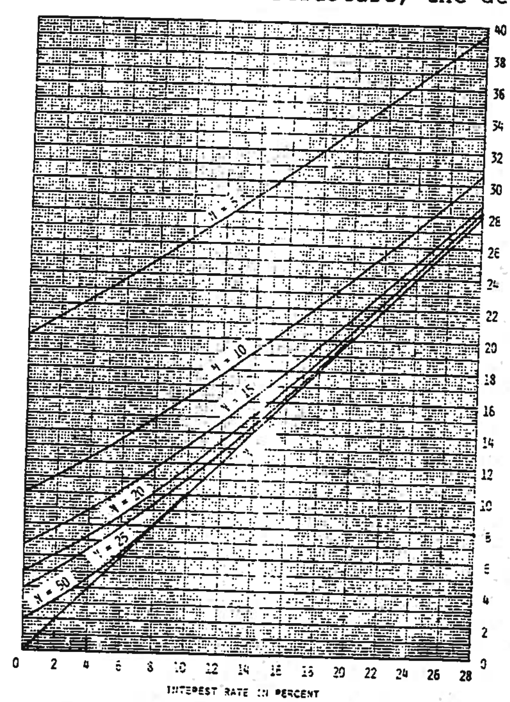


Figure 1. Capital Recovery Factor Versus Interest Rate.

that promises maximum capital recovery factor before tax will be the same as that that promises maximum capital recovery factor after tax. Remember our old standard relationship:

$$CR' = CR(1-t) + \frac{t}{N} \qquad (1)$$

Since t and N are normally assumed to be the same for all alternatives, we can readily see that CR and CR' will point in the same direction.

A word about taxes. The preceding paragraph may lead you to conclude that corporate income taxes have no effect on technical decisions. That is misleading, and we shall show cases before we are through where the tax does indeed have a pronounced effect.

The nexus between yield and NPV. If all alternatives have equal lives, and if all of our abovementioned simplifying assumptions are accepted, then yield and NPVI will point to the same decisions. Here is why: by definition

$$NPVI = \frac{NPV}{P} \qquad (2)$$

but $NPV = (SPW\text{-}i'\text{-}N)A' - P$

so $$NPVI = \frac{(SPW\text{-}i'\text{-}N)A' - P}{P}$$

$$NPVI = \frac{(SPW\text{-}i'\text{-}N)A'}{P} - 1$$

but $\frac{A'}{P} = CR'$

therefore $NPVI = (SPW\text{-}i'\text{-}N)CR' - 1$. (3)

Since the series present worth factor should be the same for all alternatives (i' and N being equal), it is clear that the alternative promising maximum CR' will automatically promise maximum NPVI. This helps explains a pecularity of the NPVI criterion, which is that it shows the same optimum regardless of the discount rate used -- which is certainly not true of NPV.

Equation (3) may upon a little reflection seem rather anomalous. Since SPW and CR are normally thought of as reciprocals, you might conclude that NPVI should always come out equal to zero. That is not the case, however, because as here defined CR' is derived (A'÷P) while SPW is based on an assigned interest rate, and the two will seldom be reciprocals.

Pay-back period. Another related measure of merit is the pay-back period (PBP), which answers the entrepreneur's question: how long before I get my money back? Assuming uniform returns, the pay-back period is easily found:

$$PBP = \frac{P}{A'} \qquad (4)$$

This is the reciprocal of CR' and so incorporates all that criterion's strengths and weaknesses. Its main problem is that it has often been misused and has acquired a somewhat unsavory reputation. Let us agree that it cannot do anything for us that CR' or CR or yield cannot do, and so need not concern us further.

AAC and Its Derivatives

The average annual cost (AAC) concept is another widely used measure of merit. It is valid in situations where the level of revenue is likely to be the same for all alternatives, including the special case where there are no revenues at all. An examples of uniform revenues would be a fleet of ships committed to some fixed annual transport demand. Cases of no revenue would include military craft and government-operated service vessels. Another case would be component parts of any sort of ship; these can be selected on a basis of minimizing AAC so long as the choice will in no way affect the ship's gross earning potential.

Life cycle cost. A related criterion is the life cycle cost (LCC), which is the present value (or present worth) of a unit's initial and operating costs. If all alternatives have equal lives, AAC and LCC will invariably agree as to the best. Where lives differ, however, LCC will be misleading and should not be used. You can make an exception to this by comparing, for example, a series of five units each with a four-year life, with a competing series of two units each with a ten-year life. That is an unnecessary complication, however; you could more easily correct for differing lives by multiplying each LCC by a capital recovery factor appropriate to its economic life. That would produce the average annual cost, however, so why not use that as your criterion instead of LCC?

Capitalized cost. A closely related criterion is called capitalized cost. It is defined as the present worth of providing a perpetual service. In it, we assume that as each unit wears out it will be replaced by its clone -- in perpetuity. All costs, both initial and operating, are assumed to remain identical from unit to unit. Perhaps the easiest way to handle the problem is to find the average annual cost for the first unit, pretend that that goes on forever, and then find the present worth of that unending stream by multiplying by the series present worth factor appropriate to

$N = \infty$:

$$(SPW\text{-}i\text{-}\infty) = \frac{(1+i)^{\infty}-1}{i(1+i)^{\infty}} = \frac{1}{i} \qquad (5)$$

In short:

$$CC = \frac{AAC}{i} \qquad (6)$$

Capitalized cost is seldom used these days, and is, at best, an awkward substitute for AAC.

How NPV and LCC differ. At this point we must pause to clarify two important differences between net present value and life cycle cost. The first difference pertains to applicability. NPV is used for money-earning investments; LCC is used where net cash flows are essentially all negative. (The mathematics, however, are identical.) The other difference pertains to the selection of interest rates. In NPV, future cash flows are discounted at the minimum acceptable interest rate. In LCC (as well as AAC and all its other derivatives) future cash flows are discounted at the target rate -- which will normally be somewhat higher than the minimum acceptable rate. Remember that the businessman who uses NPV to select investments will choose those projects that promise the highest positive value of that criterion. If all goes right the true rate of return should be higher than that minimum.

What if benefits differ? A basic shortcoming common to AAC, LCC, and CC is that they measure only costs and ignore benefits. Suppose proposal A has a higher AAC than does proposal B, but also offers better service. Then a large measure of subjective judgment must be introduced to make the comparison at all valid. This is a nearly insurmountable difficulty that arises in applying engineering economics to military vessels or service craft of almost any kind. About the only solution I can suggest would be to ask the potential users to tell you how many type B vessels they would consider equal in desirability to, say, ten of type A. Average their figures and use the ratio to increase the numerical value of vessel B's AAC.

Required freight rate. In the case of ships providing a measurably useful service, this shortcoming of AAC (or LCC, or CC) can be overcome. Simply find its value per unit of useful work done. This brings us to the popular concept of required freight rate (RFR), which is particularly applicable to merchant ships:

$$RFR = \frac{AAC}{C} \qquad (7)$$

where C = annual transport capacity (usually in tons or tonnes)

The concept is closely akin to what economists call a shadow rate, and is the intellectual descendent of Adam Smith's "natural rate." As Adam Smith theorized, in a free market higher rates will attract new competition, which will drive rates down to the natural level. Lower rates, on the other hand, will encourage some of the competition to turn elsewhere, and their departure will reduce competition and so allow prices to rise to the natural level. The "natural rate," then, is one that is just profitable enough to overcome the investor's aversion to the risks inherent in the enterprise. The theory behind RFR is that the best ship for any given trade will be that one that can offer the required service at the lowest cost to the customer while returning to the owner a reasonable return on his investment.

RFR is best suited to bulk carriers (dry or liquid) engaged in transporting a single product one way and returning in ballast. The value for C is then easily established. Ships engaged in multi-cargo, multi-leg trades are less easily analyzed in this way. The concept can, however, be nicely applied to ferries (using dollars per vehicle), passenger ships (dollars per passenger), dredges (dollars per cubic yard moved), etc.

Interest rates for RFR. Once again, in finding RFR the selection of an interest rate is required. This should be a target rate appropriate to the risks inherent in the given trade. This target rate may be adjusted up or down a little if you believe your ship will be built and operated in an economic environment that is more or less favorable than that of your principal competitors. Moreover, since these rates are normally given on an after-tax basis, the RFR must be adjusted to pay any applicable corporate income taxes. The standard approach is explained in Reference 1. Briefly, the initial investment is converted to an annual cost of capital recovery by multiplying it by a tax-adjusted capital recovery factor:

$$CR = \frac{CR' - \frac{t}{N}}{1-t} \qquad (8)$$

where

CR' = capital recovery factor based on owner's target yield and economic life of the ship (N)

t = tax rate

Our equation for required freight rate then becomes:

$$RFR = \frac{(CR)P+Y}{C} \qquad (9)$$

where

Y = uniform annual operating costs.

Non-uniform costs. If the annual operating costs are predictable but non-uniform, they can be converted to an equivalent uniform annual stream by summing their individual present values and then multiplying by a capital recovery factor. In finding present worth, use a before-tax interest rate, i.e. one based on the CR value found above. The capital recovery factor then applied to that present worth should of course be the same. Perhaps a more readily understandable approach would be to use the after-tax interest rate but apply it to the tax-corrected operating cost, which is found using a correction factor equal to (1-t). The result should, of course, be the same.

Analyzing differences. Suppose you have to choose between two alternatives both of which have equal annual incomes -- perhaps zero or perhaps unknown, but still the same. The one with higher first cost is expected to have lower operating costs. Suppose further that each has uniform annual costs and both lives are the same. We can then, if we wish, examine the difference in investment (ΔP) from selecting the more expensive unit and its saving in annual operating costs (ΔY). We can derive the corresponding yield or NPV, or any of the other criteria that assume a known income. That is because any saving in operating cost will produce an equivalent increase in cash flow. But be careful. If taxes are involved, the saving in operating cost will again be tempered by the tax, which will in turn be tempered by a difference in the depreciation tax shield. The net gain, then, becomes:

$$\Delta A' = \Delta Y' = \Delta Y(1-t) + t\frac{\Delta P}{N} \qquad (10)$$

The same concept can be extended to multiple-choice situations, such as optimization studies. To do this, rank the alternatives in order of ascending first costs. Then use NPV or yield (or other) to analyze the incremental cost and incremental cash flow in going from the first to the second alternative. If that meets your standard of profitability, go on and compare the third to the second. Continue this procedure until the incremental cash flow is no longer great enough to justify the incremental investment. That is, for example, until the NPV of the difference becomes negative or the yield becomes less than the cut-off rate.

The analysis-of-increments method as outlined above is sufficient for selecting designs where there is a relatively smooth series of steps in advancing from one alternative to another. Where the progression is untidy, however, you may not want to quit as soon as you reach the less-than-acceptable measure of profitability. Perhaps benefit is to be gained by going even further. That being the case, examine the differences between the new alternative and the last acceptable one (not the one or ones that failed to meet the standard).

III. DIFFERENCES IN RESULTS

The Three Clans

We have described more than a dozen valid measures of merit. We have shown that there exists families of these measures within which any one can often substitute for any other without changing the indicated optimal design. That is, each will point in exactly the same direction. Table 2 defines some of these families.

We can conclude from Table 2 that, given our standard assumptions, most valid measures of merit will be in agreement. That is, a ship designed on one basis will be exactly the same as one designed on another. Any measure can serve as a surrogate for another. There are important exceptions, however, the major ones being NPV and RFR. Under normal conditions, NPV, RFR, and yield (the latter representing the extensive clan defined in Table 2) will all proclaim different values of design variables to be the best of all possible. Why? Because NPV and yield each impute a different time-value to money (i.e., different interest rates), while RFR imputes a freight rate different from that assumed in finding NPV or yield. The three cannot agree except by rare coincidence. Differences in interest rates produce differences in relative values of initial investment and future cash flows. Different freight rates produce differences in optimal degree of productivity. Let me expand on this.

Procrustes' Bed

Suppose for a given design study we used RFR based on a ten percent yield in order to find the ideal speed. If we then used the minimum value of RFR (which corresponds to that speed) as an assumed freight rate and used the same ten percent interest to discount future cash flows, we should find that the maximum attainable NPV would be zero and would occur at that same power and speed. NPV and RFR, in short, would fall into line. Similarly, if we used that same freight rate (i.e. minimum attainable RFR) and solved for yield, we should find that its maximum value would equal exactly ten percent and it would occur at the same power and speed indicated by NPV and RFR.

TABLE 2: Groupings of Measures of Merit

Assumptions	Equivalent Measures of Merit: All incomes same (possibly zero)	Equivalent Measures of Merit: Incomes differ between alternatives
standard*, except lives differ	AAC and CC	Yield and AABI
standard*, with all lives same	Above plus LCC	Above plus CR, CR', NPVI and PBP

*see page 4 for standard assumptions.

An illustration. To illustrate the points made above, we have taken the economic data for a typical bulk cararier and derived optimum values of BHP and designed sea speed. See appendix for details. We have done this using first RFR, then yield, then NPV. True to the conditions of the Procrustean bed delineated above, in finding yield and NPV we used as our freight rate the minimum attainable value of RFR ($8.95/ton); and, in finding NPV we also used the same interest rate (namely ten percent) as that assumed in finding RFR. Figure 2 plots the results of the three analyses, and shows that all three criteria point to the same speed and power as being the most economic.

A note about these figures: Throughout the rest of the text you will find several drawings similar in nature to Figure 2. They are drawn with the intent of showing that different measures of merit and different assumptions of various sorts will affect the indicated optimal point in a design (represented here as power and speed). These have been drawn by combining two or more curves from individually derived plots. In combining curves we have made no effort to coordinate the vertical scales. They are accurately drawn with respect to horizontal location, but the vertical location is strictly arbitrary. In those cases where vertical spread is significant, we show the pertinent numerical values. Each contour is identified by a circled number. That corresponds to the individual test from which the curve was derived. Table 9 (in appendix) shows details about the basic assumptions and the results.

Escape from Procrustes

In real life, of course, the amazing coincidences involved in Figure 2 will seldom obtain. The fellow who uses NPV will normally start with a predicted freight rate and select that speed that promises the highest, positive value of NPV. Although he may use a ten percent discount rate, the expected actual rate of return will be higher, as evidenced by the positive value of NPV. Because he has discounted future cash flows at a rate lower than actually attainable (i.e., the derived value of yield) he has not discounted the future benefits of higher speed as much as he should -- in the eyes of the advocate of yield -- and has consequently given those benefits undue advantage. This, then, means that under normal conditions NPV will favor a faster (or otherwise more productive ship.

Effect of interest rate on NPV. In illustration of the above, suppose we assume the same $8.95/ton freight rate used above, but reduce the discount rate for NPV from the attainable ten percent to eight percent. Figure 3 shows that this lower interest rate causes NPV to favor a somewhat higher power and speed.

Effect of freight rate. If actual freight rates are considerably different from those indicated by RFR, the three basic criteria will all point to different design values as being best.

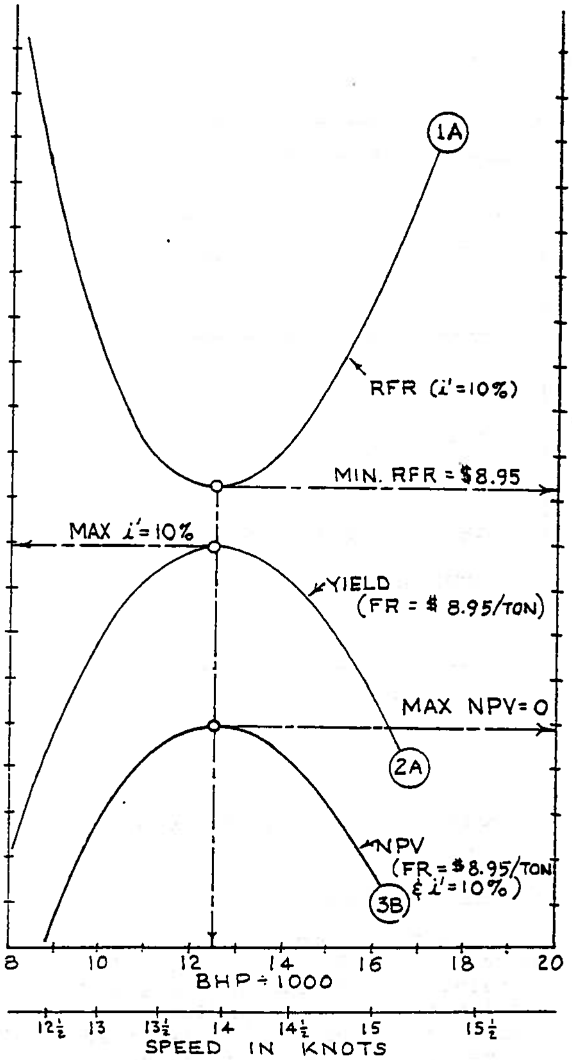


Figure 2. Shows how measures of merit can be forced to indicate same optimum design.

Figure 4 shows results based on a freight rate of $10.74/ton, which is 20 percent above the best RFR for ten percent yield. The curve for RFR is the same as before because the same interest rate is used and the criterion is blind to actual freight rates, so that change has no effect. The curves for yield and NPV now point to higher optimal values of power and speed. The departure of NPV is particularly pronounced for two reasons. First is the tendency to favor larger projects; second is the use of an eight percent discount rate in place of the ten percent interest rate used in RFR.

Freight rates and productivity. RFR and yield will point to the same speed only if the freight rate assumed in finding yield happens to coincide with the lowest attainable value of RFR. Common sense suggests that high freight rates justify high speed (or other factors of productivity). Thus, if the expected freight rate exceeds the minimum RFR, yield will

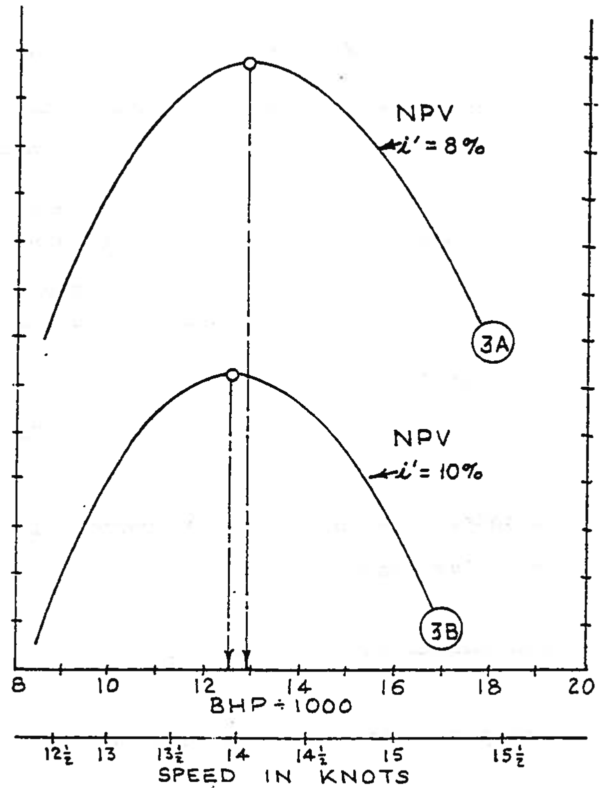


Figure 3. Shows that lower discount rate leads to higher design values indicated by NPV.

point to a faster (more productive) ship; if expected rates are lower, yield will point to a slower (less productive) ship.

Or, from another perspective, we can say that RFR assumes an interest rate that usually differs from that actually attainable (as measured by yield). Figures 5 and 6 show that higher attainable freight rates justify higher powers and speeds (i.e. more productive ships). They also show that RFR is blind to this trend and will therefore fail to agree with yield except where the actual freight rate happens to coincide with the best value of RFR.

Time Out for Some Waffling

It can be argued that the preceding discussion of yield vs RFR is academic. If you are in a position to predict freight rates with confidence you should not fool with RFR because that requires an asumption of something that can be accurately estimated: namely interest rate. It can also be argued, however, that any derived value of yield must be looked upon as suspect if it is far different from the value you would judge right for use in RFR. Higher values would imply that your competition was

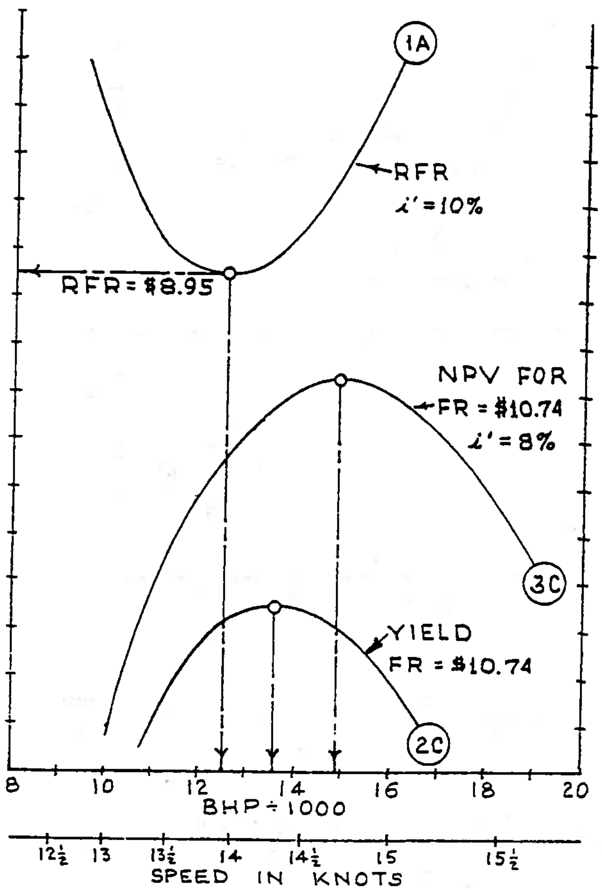


Figure 4. Shows how a different freight rate distorts indications of optimum design.

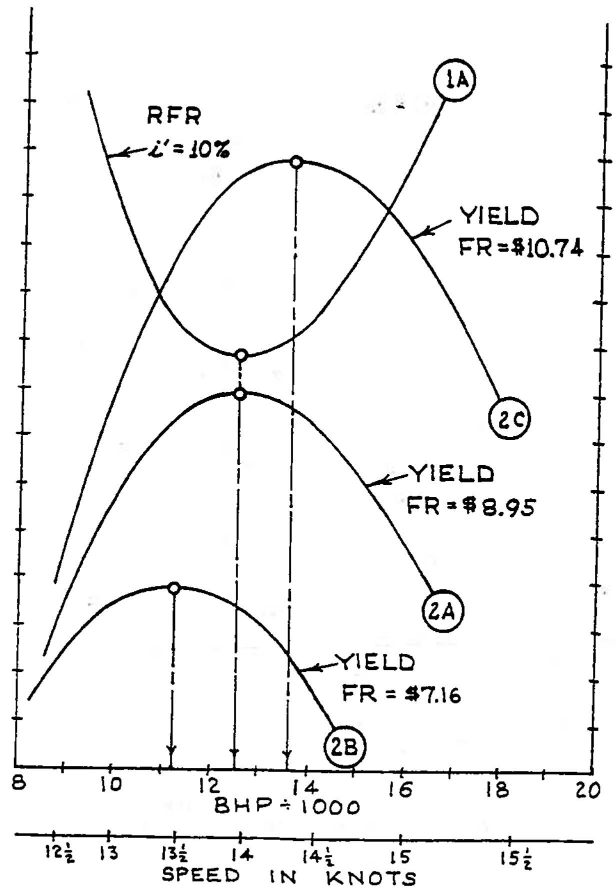


Figure 5. Shows how freight rate (FR) changes optimal design based on yield. Also shows that RFR and yield agree only when actual freight rate equals minimum attainable RFR.

poorly managed or operating under higher costs; lower values would mean that even the best design would be an undesirable investment.

NPVI Revisited

In our earlier discussion of the net present value index (NPVI) we mentioned that the indicated point of optimality seems to be unaffected by the interest rate chosen. Figure 7 illustrates this, and also shows that NPVI and yield are in agreement.

Analyzing Differences Revisited

On page 7 we explained how some economists seek optimum decisions by examining in sequence the differences between alternatives. Let us now see how much effect that will have in our selection of best power and speed for our sample ship.

We must first recognize that our optimization studies have assumed that engine sizes can be procured in a continuum of values. In reality,

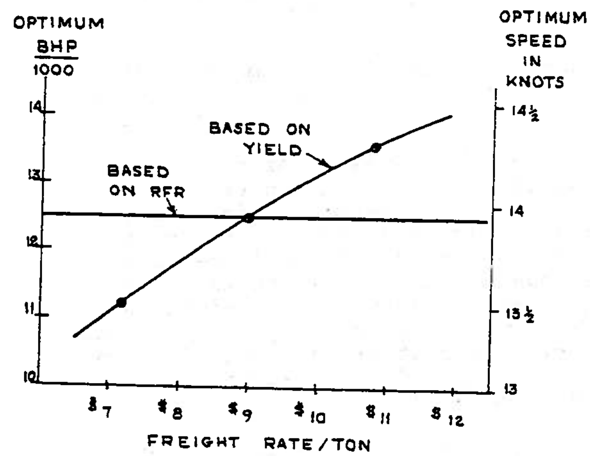


Figure 6. Cross curves derived from Figure 5 showing point of agreement between yield and RFR.

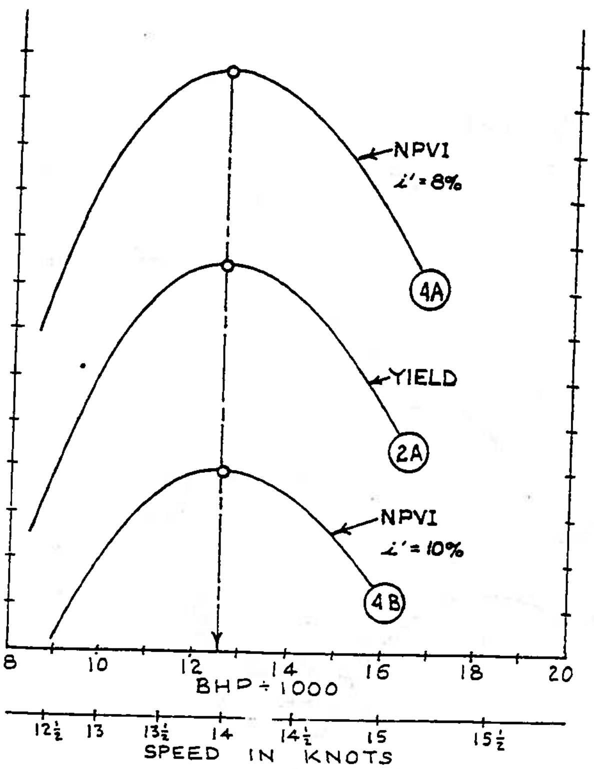


Figure 7. Shows that optimal design indicated by NPVI is the same regardless of discount rate. Also shows that NPVI and yield agree.

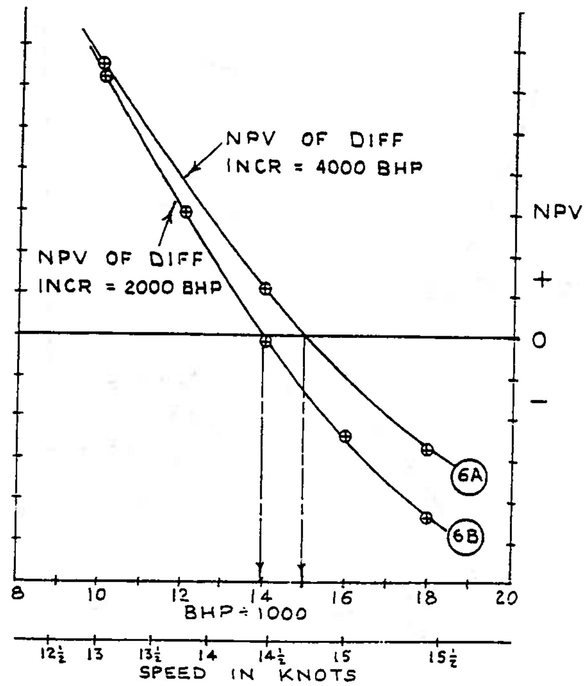


Figure 8. Shows results of finding NPV of incremental costs and returns for two sizes of increment.

although steam turbine plants can be selected in close to a continuum, diesel plants can be found only in rather widely spaced, discrete powers. As we shall see, the size of the steps will have an effect on the design selected by this method.

Let us assume for the moment that available powers are indeed a continuous variable. Let us further assume that the owner has stipulated a cut-off rate of eight percent interest. As normally understood, then, we should examine incremental investments and incremental returns in sequence until we reach the point where the NPV of the increments comes down to zero, or where the yield of the increments comes down to eight percent (or, more conveniently, the capital recovery factor after tax comes down to 0.1018, corresponding to eight percent interest and 20-year life).

Experience has shown that indications of optimality based on the incremental technique are affected by the size of the design increments used. We therefore applied the method twice, once using BHP increments of 2000, and then again of 4000. Figure 8 shows NPV (using eight percent interest) under both sets of assumptions. As may be noted, the two contours come down to zero NPV at different values of BHP.

Had we been more realistic and examined only discrete values of commercially available BHP, we should have stopped somewhat short of the extreme values indicated in Figure 8, thus tempering the degree of overdesign inherent in the incremental technique. The tendency would still be there, however.

As shown in Figure 8, the tendency toward overdesign will vary with the size of the increments used in the analysis. Indeed, as the increments approach negligible proportions, the indicated points of optimality approach the value found in the normal way. Figure 9 shows the cross curve of optimum BHP versus the increment selected. The value shown for increments of zero corresponds to the optimum value of NPV shown in Figure 3 using the same eight percent interest. Parallel studies applying similar techniques with yield (in place of NPV) produce identical results in every respect.

The results of these studies lead us to conclude that techniques based on examination of differences can easily lead to overdesign. This is because those techniques treat the cut-off rate as a target rather than as a minimum acceptable level of profitability.

IV. RELATED TOPICS

Benign Influence of Flat Laxity

If you will glance at Figure 24, in the appendix, you will note that the curve of RFR is remarkably flat on either

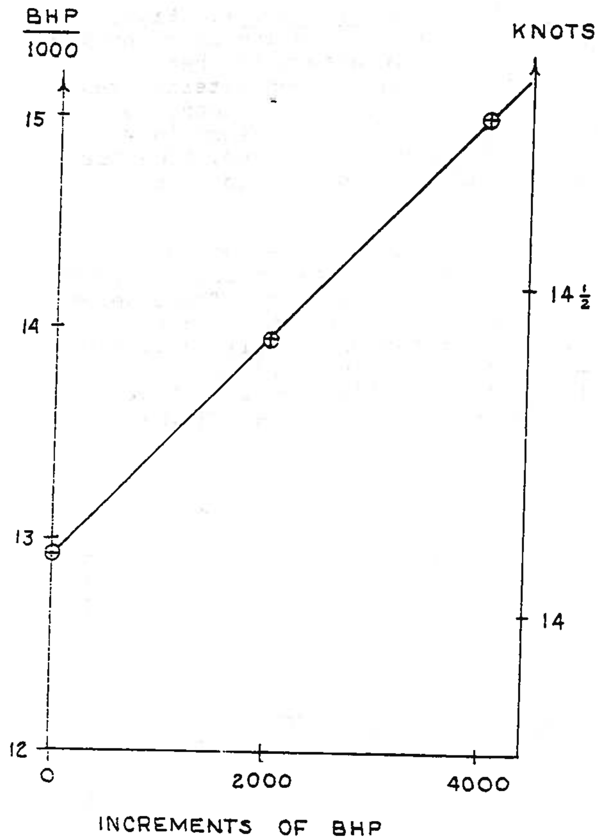


Figure 9. Shows how size of design increment affects outcome of NPV of incremental costs and returns.

side of its optimum point. This is highly characteristic of ship economy relationships and results from the nature of the trade-offs that inevitably occur. As we try different values of any design parameter (e.g. power) we find that some favorable factors are sloping up, some down. The optimum point occurs where their ratio (or difference) attains its extreme value, which inherently is approached or departed from only gradually. We call this characteristic flat laxity. In typical evaluations the flatness is so pronounced that you have trouble pinpointing the best value of your design parameter. Indeed, in order to do so you should analyze the differences between successive values of that parameter and find (graphically) where the difference becomes zero. This is the same thing in principle as differentiating the equation of a curve in order to find its maximum or minimum. Table 7 and Figure 24, in the appendix, show how this is done for one typical case.

Having said all that about finding exact points of optimality, it is now important to say that the characteristic of flat laxity makes that search generally unimportant. What is important is to define the overall shape of the curve so as to show the decision maker the acceptable range of values of each design variable. So armed, he is able to complement the numbers with his intuitive judgment regarding the intangible considerations.

This characteristic of flat laxity also means that a design decision based on one measure of merit may not be too seriously wrong if weighed in the scales of another. In illustration of this, Table 9, in the appendix, shows for each of several measures of merit both the exact point of optimality and the range within which departures from optimal value of speed or power will keep the numerical value of the measure within one percent of the optimum. The one percent ranges are shown as bars. The conclusion is farily obvious: It is not easy to design a really bad ship.

Selecting an Interest Rate

Let us refer back to our discussion of target interest rates, which are closely tied in with reasonable levels of profitability. What constitutes "reasonable" is hard to say. Under U.S. economic conditions, a ship operating company that wants to attract equity capital through the sale of stocks -- or borrow from a bank at minimum commercial rates -- probably ought to aim for a minimum yield on total capital of from ten to fifteen percent in constant-value terms. Captive fleets, with secure sources of income, might favor the lower figure; common carriers might favor the higher. (See References 3 or 4 for further details with respect to levels of profitability considered appropriate by corporate managers.) The federal government also recognizes the time-value of money. Cost-effectiveness studies using interest rates of from six to ten percent are now commonly used in designing governmental ships. Some observers recommend rates as high as twenty percent.

It is important to bear in mind that we normally deal in constant-value dollars in engineering economy studies. In the simplest terms this means that we pretend, in effect, that inflation or deflation do not exist. As long as the shipowner is free to adjust his freight rates to reflect his changing costs that is a reasonably safe simplification.

Unit Cost of Service

Some injudicious analysts try to ignore both the income tax and the owner's need for reasonable profits. They produce studies based on minimizing the owner's cost of providing the service. This variation has several designations. Among these are "fully distributed cost" and "cost of service." We shall use the latter term here, and abbreviate it UCOS. In principle it may be applied to either the AAC or RFR criteria. The mathematics are exactly the same but the logic (and usually the conclusions) are fundamentally different and usually wrong. Correct studies are based on cost of service to the customer and recognize the tax. The others are based on cost of service to the owner and ignore the tax. Correct studies put proper emphasis on the time-value of money; the others do not. (In point of fact, while the correct approach results in before-tax interest rates of perhaps twenty percent, the minimum-cost-to-owner method usually uses rates of only five or six percent.)

Figure 10 is a graphical presentation of the factors entering into the calculations of unit cost of service and RFR. It shows the strikingly different emphases put on capital costs. In considering cost of service, the capital costs are about equal to the operating costs. In considering RFR, however, capital costs are shown to be over twice as great as the operating costs. Incidentally, this underscores the importance of reducing U.S. shipbuilding costs.

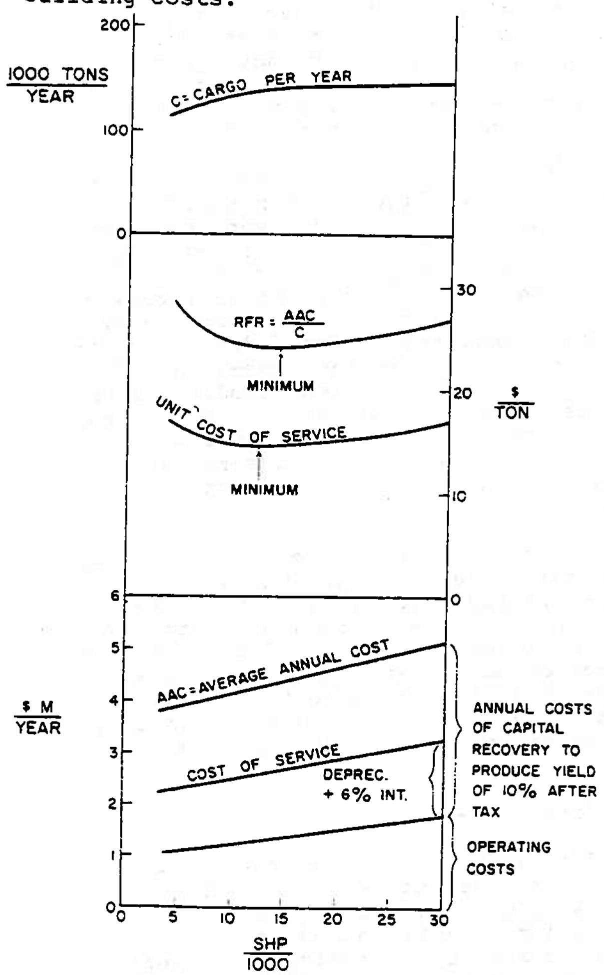


Figure 10. Factors enginering into unit cost of service and required freight rate.

More quantitative differences. Figure 11 compares optimum designs indicated by RFR and UCOS. A basic assumption here is that income varies between alternatives. Given that assumption, UCOS leads to under-design. As we shall show later, however, if incomes are fixed, UCOS (or similar criteria) can lead to over-design.

Figure 12 shows the effect of interest rates on optimal values of speed and power indicated by RFR. These demonstrate, as might be expected, that demands for higher profitability dictate demands for higher productivity. The same qualitative effect would follow a change in corporate taxrate. Higher

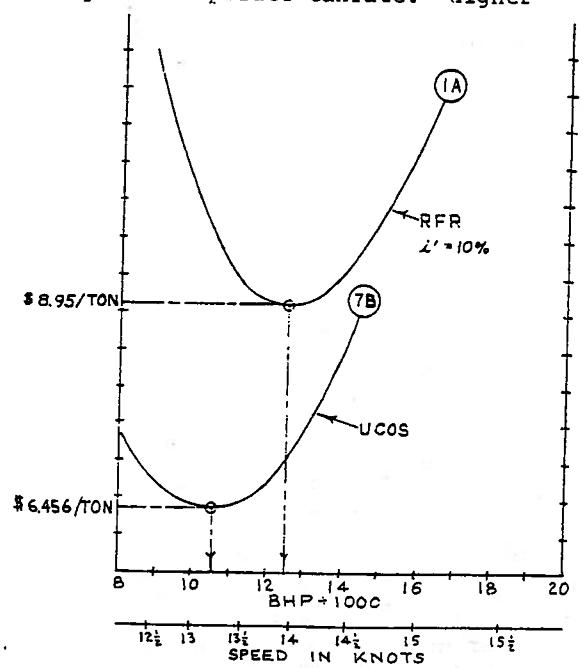


Figure 11. Shows how unit cost of service may lead to underdesign.

taxes lead to higher annual costs of capital recovery, hence higher values of RFR, just the same as higher interest rates.

Taxes

In our earlier section on yield and its surrogates, we showed that under certain circumstances we can ignore corporate income taxes without affecting our design decision. That, however, is the exception to the rule that taxes generally have a pronounced effect on design. The businessman, if he is to survive, must pass the tax burden along to his customer. In short, the corporate income tax is not a way to soak the rich, but is in reality a hidden sales tax. This is most apparent when finding RFR, remembering that the annual cost of capital recovery must be high enough to repay capital at a reasonable

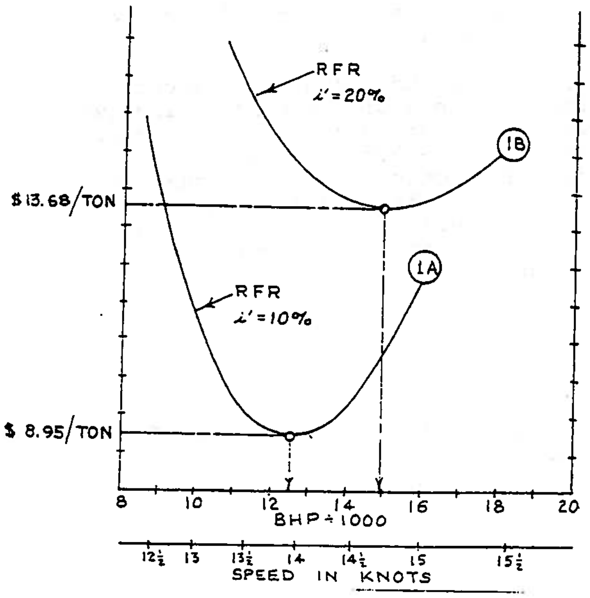


Figure 12. Shows how assigned interest rate influences optimal design as indicated by RFR.

level of profitability after tax. The tax, then, has the effect of increasing the time-value of money and will therefore affect design decisions just like a change in specified interest rate. Conversely, ignoring the tax is equivalent to applying an abnormally low interest rate.

Taxes and NPV. Let us look at that last statement in detail. Suppose we are optimizing speed and power on a basis of NPV and use before-tax rather than after-tax cash flows. The benefits of higher speeds will be greatly exaggerated and the maximum value of NPV will occur at an aberrantly high speed. This trend is implied in Figure 3. Although those contours are for different interest rates rather than tax effects, they serve to show that lowering the time-value of money leads in the direction of over-design.

Taxes and yield. Suppose our measure of merit is yield or one of its surrogates. Here, as we have already shown, there are common conditions where the tax may be safely ignored. (You may recall that we showed why the maximum value of CR and CR' would occur at the same design point.)

Taxes and AAC. If our measure is average annual cost and we ignore the tax, we are in effect forgetting that differences in cost between alternatives are tempered by the tax. The tendency, then, is to lead to over-design. This will be illustrated shortly.

Taxes and RFR. Finally, moving back to RFR, ignoring the tax has the effect of reducing the annual cost of capital recovery, hence lowering the resulting value of RFR. Lower freight rates lead to lower demands for productivity, hence lower optimal speeds. See Figure 12.

Summary of tax effects. Table 3 summarizes what we have concluded about the effect of taxes, or rather what mistakes we may make if we ignore taxes.

TABLE 3: Tax Effects

Measure of Merit	Effect of Ignoring Taxes
NPV	Over-design
Yield	No change (assuming our standard simple cash flow pattern)
AAC	Over-design
RFR	Under-design

A Case Study

Here is a feasibility study that illustrates the impact of the tax in situations where AAC is an appropriate criterion -- that is, where the income is fixed and the contenders vie on the basis of minimizing capital and operating costs in combination. Here are the essential facts:

	Defender	Challenger
P: Investment	\$26M	\$34M
Y: Annual operating costs	\$3.3M	\$2.5M

Both alternatives are so designed that equal incomes would be produced, these being ships of equal speed in the liner trade (where cargo is limited in availability). A life of 25 years is assumed in each case. Since incomes are unknown but equal, the logical measure of merit is the average annual cost (AAC). This is made up of two components: the annual cost of capital recovery (ACCR) and the annual cost of operation (Y):

$$AAC = AACR + Y$$

$$AAC = (CR\text{-}i\text{-}25)P + Y \qquad (8)$$

As is usually the case, the challenger offers lower costs in the future in exchange for a greater initial cost (low Y, high P). Proponents of the challenger are therefore anxious to stress future savings and downgrade added first costs. This they do by applying a low interest rate, usually five or six percent. They justify this level as being the approximate bank borrowing rate (corrected for inflation) and, by implication, assuming that none of the income will be taxed. They use, in short, the cost of service (or fully-distributed cost) approach which was shown to lead to underdesign in variable income studies. Their comparison would be as follows:

$$AAC = (CR\text{-}6\%\text{-}25)0.0782P + Y$$

from interest tables

	Defender	Challenger
ACCR = 0.0782P	\$2.03M	\$2.66M
Y	3.30M	2.50M
AAC	\$5.33M	\$5.16M

The challenger has the lower average annual cost and therefore seems to be superior to the defender. If we shift our basis from owner's costs (as above) to required costs to the customer, however, we reach the opposite conclusion. Assume that the entrepreneur wants to earn a ten percent yield on total investment and that he pays a 50 percent tax based on straight-line depreciation with zero scrap value. The annual cost of capital recovery must then be based on a CR derived as follows:

i' = stipulated yield = 10%

$(CR'\text{-}10\%\text{-}25) = 0.1102$ (from interest tables)

$$CR = \frac{CR' - \frac{t}{N}}{1 - t} = \frac{0.1102 - \frac{.50}{25}}{1 - .50}$$

$$CR = 0.1084$$

	Defender	Challenger
ACCR = 0.1804P	\$4.69M	\$6.13M
Y	3.30M	2.50M
AAC	\$7.99M	\$8.63M

Thus, the defender is actually superior and the cost-of-service criterion pointed in the direction of overdesign. (The cost-of-service study shown just previously is taken out of the <u>Congressional Record.</u> It was used with success to convince Congress of the "wisdom" of appropriating funds for the challenger concept.)

Another, and often more convenient, approach to feasibility studies involves analyzing the differences between challenger and defender. For example: If we accept the higher cost of the challenger (\$34M -\$26M = \$8M), we will increase before-tax returns by (\$3.3M -\$2.5M = \$0.8M); how good is this investment? We have, in effect:

$$CR = \frac{A}{P} = \frac{\$0.8M}{\$8M} = 0.10$$

$$CR' = CR\ (1-t) + \frac{t}{N}$$

$$CR' = 0.10(0.50) + \frac{0.50}{25} = 0.07$$

i' = 4.9% (Figure 1)

Most entrepreneurs would agree that this is an unacceptably low yield and would therefore reject the challenger.

Some analysts would prefer to solve the preceding problem using after-tax returns instead of before-tax returns. The principle is the same, only the mechanics differ:

$$A' = A(1-t) + t\,\frac{P}{N}$$

$$A' = \$0.8M(0.5) + 0.5\,\frac{\$8M}{25} = \$0.56M$$

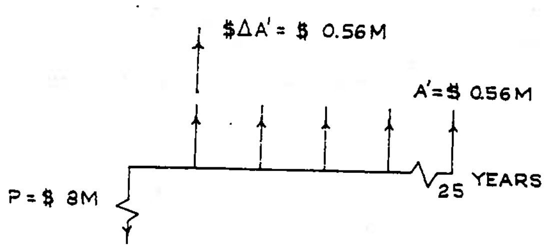
$$CR' = \frac{A'}{P} = \frac{\$0.56M}{\$8M} = 0.07 \text{ (as before)}$$

i' = 4.9% (as before)

When a tax credit is in effect, it allows a corporation to reduce its tax by a given proportion of the invested cost during the first year in which the investment shows a profit. The tax credit does not affect the depreciation schedule or subsequent taxes in any way. If we apply the credit to the subject study, we will again have annual after-tax returns of $0.56M -- except during the first year, when the returns will be increased by the tax credit, which we shall assume to be seven percent:

ΔA' in first year = 0.07$8M = $0.56M.
(That ΔA' equals A' is coincidental.)

Our cash-flow diagram will now be as follows:



We no longer have the simple cash flow pattern implicit in solving for i' through the expedient of the capital recovery factor. We must use the more basic DCF approach, applying trial and error to find the interest rate that will make the present worth of the returns equal to the investment:

P = (SPW-i'-25)$0.56M + (PW-i'-1)$0.56M

Let us first try i' = 5 percent:

$8M = (SPW-5%-25)14.07 $0.56M +
(PW-5%-1)0.9524 $0.56M

$8M = $7.89M + $0.53M

$8M $8.42M

Error = ($0/42M)

Let us next try i' = 6 percent:

$8M = (SPW-6%-25)12.8 $0.56M +
(PW-6%-1)0.9434 $0.56M

$8M = $7.15M + $0.53M

$8M ≠ $7.68M

Error = ($0.32M)

By interpolation, the yield is now found to be 5.6 percent, whereas it was 4.9 percent without benefit of the tax credit.

If we use one of the accelerated depreciation plans, we will also find a slightly better yield than that produced with straight-line depreciation. Using sum-of-years-digits, for example, we find a yield of 5.8 percent in place of the 4.9 percent resulting from straight-line depreciation.

In summary of the above paragraphs, we can conclude that tax-reducing devices (such as the tax credit or accelerated write-off) decrease somewhat the difference between levels of profitability before and after tax. The advantages of future savings are thereby somewhat enhanced. In the sample feasibility study, however, the challenger would still be considered a poor choice. As an incidental note, reducing the tax rate from 50 percent to 39 percent would have about the same overall effect as either the seven percent investment tax credit or accelerated write-off. Methods for analyzing cases where the tx life is shorter than the economic life are covered in Reference 5.

V. INVENTORY VALUE

All of the criteria we have examined so far ignore one point, namely that of the inventory value of the goods in transit. This represents an investment that is not producing returns and should therefore be treated as a lost-opportunity cost.

Where both ship and cargo are owned by the same entity (as in captive fleets) the advantage of reduced sea time is clear. The same principles should apply, however, even where ownership is split. This is because the owner of the cargo should be willing to pay higher freight rates for faster service. If completely free market conditions exist, the combined owners (cargo and ship) would tend to make the same decision as would be made by an individual who owned both.

Taxes and Inventory

If we recognize cargo inventory as a hidden cost, we must also recognize the necessity of passing it along to the customer. That will increase revenues and also the tax base. The increase in freight rate, then, must equal the inventory cost multiplied by the reciprocal of (1-t), where t is the tax rate.

Expression for Inventory Cost

Let us consider the cost of inventory, I_o, for one ship load. The cost to the owner will be

$$I_o = ivDW_c \frac{d}{365} \qquad (11)$$

where

i = annual interest rate appropriate to the owner's time-value of money

v = value of cargo per ton (or other unit) as loaded aboard

DW_c = cargo deadweight

d = days in transit .

The inventory cost to the customer (I) will equal the above expression divided by (1-t):

$$I = \frac{ivDW_c d}{(1-t)365} \qquad (12)$$

The inventory cost per voyage can be converted to an annual cost (I_A) by multiplying by the cargo legs per year. Assuming the one-way trade route typical of bulk trades, we have:

$$I_A = I(RT) = \frac{ivDW_c d}{(1-t)365}(RT) \qquad (13)$$

where

RT = round trips per year

but

$(RT)DW_c = C$ where

where

C = annual transport capacity

so

$$I_A = \frac{ivdC}{(1-t)365} \qquad (14)$$

This can be converted to a unit inventory cost per ton of cargo delivered, C_I, by dividing the annual inventory cost, I_A, by the quantity carried per year, C. Therefore the inventory cost per ton of cargo becomes:

$$C_I = \frac{I_A}{C} = \frac{ivd}{(1-t)365} \qquad (15)$$

Economic Cost of Transport

Equation (15) pertains to the economics of the cargo alone. We can easily derive the combined economics of ship and cargo by adding the required freight rate, RFR, to produce what I choose to call the economic cost of transport, ECT:

$$ECT = \frac{(CR)P + Y}{C} + \frac{ivd}{(1-t)365} \qquad (16)$$

Figure 13 shows a curve for ECT for a cargo valued at $500 per ton. The curve for RFR (equivalent to ECT for worthless cargo) is the same as that shown in Figure 2. The impact on indication of optimal speed and power is worth noting.

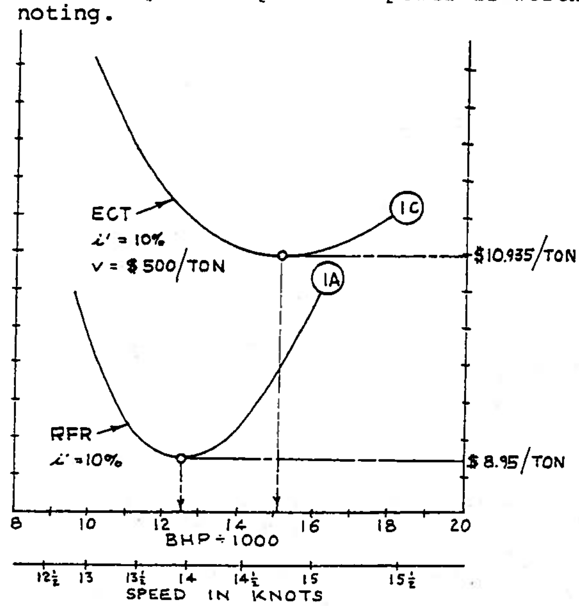


Figure 13: Shows tendency for inventory cost to justify higher speeds.

The ECT curve in Figure 13 assumes cargo valued at $500 per ton; the RFR curve assumes cargo of no value. The impact on design of intermediate values can be found by straight-line interpolation.

Effect on NPV

The inventory cost can be treated the same as working capital, that is a fully recoverable, non-decreciable addition to the initial investment. The ship's NPV would thereby be reduced by the value of one ship load of cargo (i.e., vDW_c). This would, however, be tempered by the fraction of time there is cargo in transit:

$$\Delta NPV = -vDW_c \frac{dRT}{365} \qquad (17)$$

where

ΔNPV = change in net present value

Effect on Yield

Inventory costs will reduce yield because they will in effect increase the investment (as shown in Equation 17) without changing the returns.

Wider Horizons

We might carry the logic of the foregoing discussion to a recognition of inventory costs of stockpiles at either end of the voyage, and to other shoreside costs including packaging. See References 6 and 7. Although such inland incursions are outside the scope of the present work, the principles explained here can easily be applied. We need only expand the scope of how we delineate the system to be optimized, and construct the complex analysis from its simple components. Reference 8 contains a sample study in illustration of this concept.

VI. LEVERAGE: THE INFLUENCE OF BORROWED CAPITAL

Economics vs. Finances

Many entrepreneurs like to supplement their equity capital with funds borrowed from banks or raised through the sale of bonds. Either source requires the payment of capital plus interest at a fixed rate, regardless of the success or failure of the venture. They also involve legal clauses permitting the lender to take possession of the physical equipment if the entrepreneur fails to honor his commitments. Obviously, as the reliance on borrowed capital increases, the risk to the owners (stockholders) also increases. This is tempered, however, by an important advantage: increased yield on equity capital becomes possible by virtue of the greater total amount of available funds. Another tempering factor is that the enterprise need pay no tax on that part of the gross income that it turns over to the bank or bondholder for interest. This, in effect, cuts the cost of borrowing about in two. To save words, from here on when we refer to bank loans, the term should interpreted as also including the possibility of bonded indebtedness.

<u>Loans and taxes</u>. Reference 5 explains how to analyze returns before and after tax when the pay-back period to the bank differs from the economic life of the ship. For this discussion, however, we shall assume that the debt is repaid in equal annual installments over the life of the ship. We shall also assume the use of straight-line depreciation and zero disposal value. Our expressions for conditions before and after tax now become:

$$A' = A(1-t) + t\frac{P}{N} + tI_B \qquad (18)$$

and

$$CR' = CR(1-t) + \frac{t}{N} + t\frac{I_B}{P} \qquad (19)$$

where I_B = annual interest paid to the bank. I_B will diminish from year to year, but for design purposes we can safely assume that it will be constant and equal to the annual return to the bank minus a uniform annual payback of the initial loan:

$$I_B = A_B - \frac{P_B}{N} \qquad (20)$$

where A_B = annual return to the bank

and P_B = initial amount of the bank loan

The annual return to the bank is found by means of the appropriate capital recovery factor:

$$A_B = (CR\text{-}i_B\text{-}N)P_B \qquad (21)$$

where i_B = bank interest rate.
Substituting Equation (21) into Equation (20):

$$I_B = (CR\text{-}i_B\text{-}N) - \frac{1}{N}\,P_B \qquad (22)$$

<u>Case study</u>. We can illustrate the beneficial effects of interest payments by looking again at the feasibility study examined in the preceding section on taxes. Assume that the bank is willing to put up 60 percent of the money for either alternative at six percent interest. Also assume that the owner again wants to earn a 10 percent yield (i') on the total investment, regardless of which alternative is selected. (This assumption will be discussed in detail later.) Comparing our alternatives on an average annual cost basis, we find ourselves with the same i', hence the same CR' as before; but CR will be somewhat reduced because of the tax shield. Rearranging Equation (19):

$$CR = \frac{CR' - \frac{t}{N} - t\frac{I_B}{P}}{1 - t} \qquad (23)$$

where

$$(CR'\text{-}10\%\text{-}25) = 0.1102$$

and

$$I_B = (CR \rightarrow 6\% - 25) - \frac{1}{25} P_B \quad (24)$$

$$I_B = (0.0782 - 0.04)P_B = 0.0382\ P_B$$

or

$$I_B = 0.0382 \times 0.6P = 0.229P$$

so

$$CR = \frac{0.1102 - \frac{0.50}{25} - 0.50 \times 0.0229 \frac{P}{P}}{1 - 0.50}$$

$$CR = \frac{0.1102 - 0.02 - 0.0115}{0.5} = 0.1574$$

(Without the tax shield for I_B, CR = 0.1804, as previously shown.) We can now calculate the average annual cost for each alternative:

	Defender	Challenger
P: Investment	$26M	$34M
ACCR = 0.1574P	4.10M	5.36M
Y: Annual operating costs	3.30M	2.50M
AAC	$7.40M	$7.86M

The defender still enjoys the lower average annual cost.

If we use the alternative procedure of analyzing the differences in cost between defender and challenger we have:

$$\Delta P = \$34M - \$26M = \$8M$$

$$\Delta A = \$3.3M - \$2.5M = \$0.8M$$

$$\Delta A' = A(1-t) + t \frac{\Delta P}{N} + t(\Delta I_B)$$

$$\Delta A' = \$0.8M\ (0.5) + 0.5 \frac{\$8M}{25} + 0.5 \times 0.0229\ \$8M$$

$$\Delta A' = \$0.40M + \$0.16M + \$0.09M = \$0.65M$$

The after-tax capital recovery factor implicit in accepting the challenger in place of the defender then becomes:

$$CR' = \frac{\Delta A'}{\Delta P} = \frac{\$0.65M}{\$8M} = 0.0812$$

Referring to Figure 1, we find i' = 6.3% (up from 4.9% without the tax credit for bank interest).

<u>Conclusion</u>. We can conclude from the two foregoing analyses that leverage has a modest tendency toward reducing the time-value of money at the before-tax level. In cases where income is fixed, lower interest rates (appropriate to the decreased time-value of money) will automatically attach greater importance to future savings. Thus, added investments leading to lower operating costs will be more easily justified, at least to some degree. This should be apparent from the numerical examples shown in the preceding section.

The More General Case

We have just considered the special case of fixed income. What about the more common case, where incomes are different for each alternative? In the next several paragraphs we shall look into this; but we must consider separately two fundamentally different assumptions about the arrangement of the loan. In the first of these we examine the situation where the bank is willing to lend a given fraction of the total investment (i.e., a fixed debt/equity ratio). In the second, we examine the situation where the owner has only a limited amount of equity capital and the bank is willing to lend whatever else is needed.

Fixed Debt/Equity Ratio

Let us first assume that the bank is willing to put up a fixed proportion of the total investment (regardless of the amount), leaving it to the owner to provide the rest from his equity capital. In illustration we shall assume that the bank agrees to putup 80 percent of the total capital at six percent interest, payable in equal annual amounts over the 20-year life of the ship. The details of the ship and trade are the same as those discussed in earlier sections and shown in Table 4, in the appendix. Let us see how the bank loan will affect the choice of optimum power and speed as defined by RFR, then NPV, and then yield.

<u>Using RFR</u>. Figure 14 compares RFRs based on the standard all-equity investment (upper curve) and the investment with an assumed 80 percent bank loan (lower curve). The stipulated yield on the <u>total</u> investment is held at ten percent in each case. As may be noted, the bank loan produces a modest reduction (about seven percent) in RFR, but changes the optimal design by only a trivial amount.

The reason is as already stated: The tax advantage of the loan is such as to reduce slightly the difference between the time values of money before and after tax.

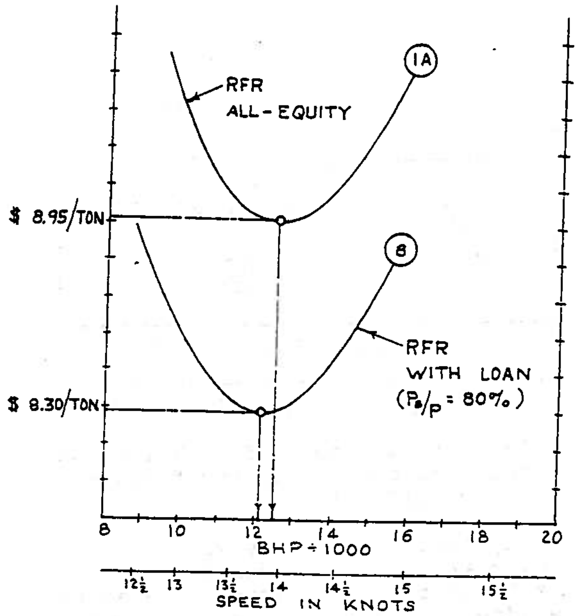


Figure 14. Shows effect of bank loan on RFR assuming a fixed debt/equity ratio.

Using NPV. Figure 15 compares NPVs with and without bank loans. In both cases total after-tax cash flows are discounted at eight percent. Again, the effect of the bank loan is to reduce the tax, which produces a dramatic increase in NPV but only a slight increase in optimal power and speed.

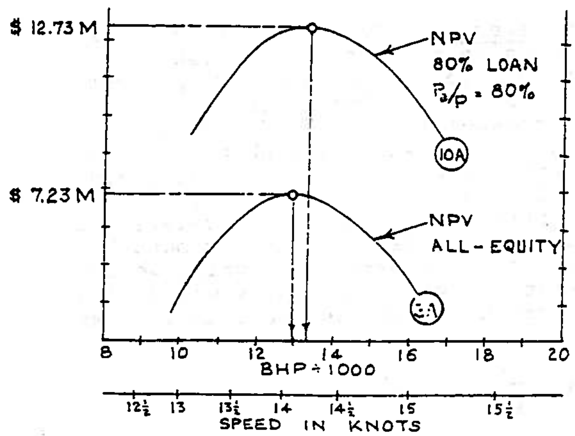


Figure 15. Shows effect of bank loan on NPV assuming a fixed debt/equity ratio.

Using yield. Figure 16 compares overall yields with and without the bank loan. Here the reduction in tax produces a modest increase in the measure of profitability but no change in the indication of optimal power and speed.

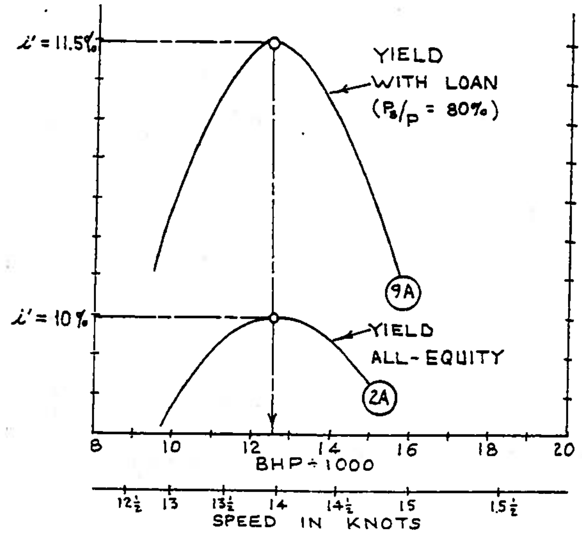


Figure 16. Shows effect of bank loan on yield assuming fixed debt/equity ratio.

Conclusion. An overall conclusion has to be that fixed debt/equity ratio loans have but negligible effects on the choice of optimal design.

Fixed Equity, Varying Loan

We have just considered the basic assumption of fixed debt/equity ratio. Let us next consider the case where the owner supplies a fixed amount from equity (in this case $10 million) and the bank will lend whatever else is needed, again at the same six percent interest.

Using RFR. Figure 17 compares RFR values with and without bank loans as described above. Once again, the effect on design is negligible. The modest reduction in optimum speed is explained by the decreased impact of the tax on RFR.

Using NPV. Figure 18 compares NPV value with and without bank loans, again assuming owner's equity fixed at $10 million. The modest increases in optimal power and speed arise from the greater after-tax cash flow produced by the tax benefits associated with interest payments to the bank.

Using yield. Figure 19 compares values of yield with and without bank loans, again assuming owner's equity fixed at $10 million. As in the immediately preceding paragraph the modest increase in optimal power and speed is explained by the improved cash flow resulting from the tax benefit of the loan.

Conclusion. The immediately preceding paragraphs would lead us to conclude that the assumption of a bank loan with fixed equity has a somewhat greater impact on design than does the assumption of fixed debt/equity ratio. The effect is still not particularly pronounced, however. We are thus led to conclude further that

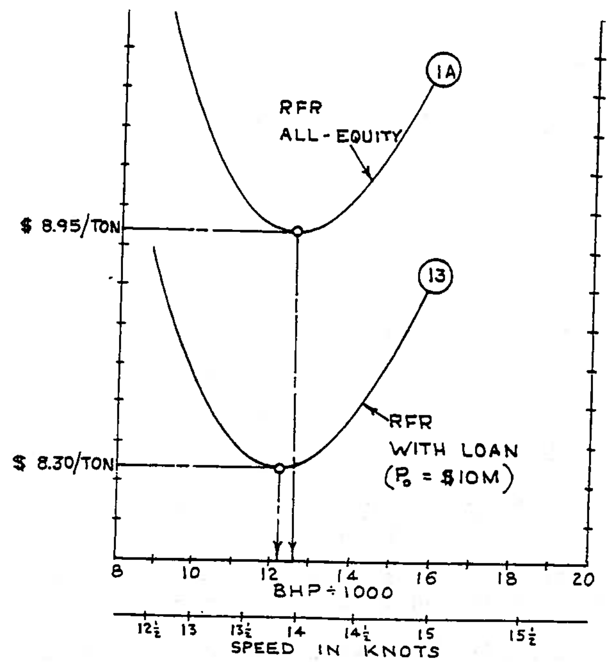


Figure 17. Shows effect of bank loan on RFR assuming owner's equity fixed at $10 million.

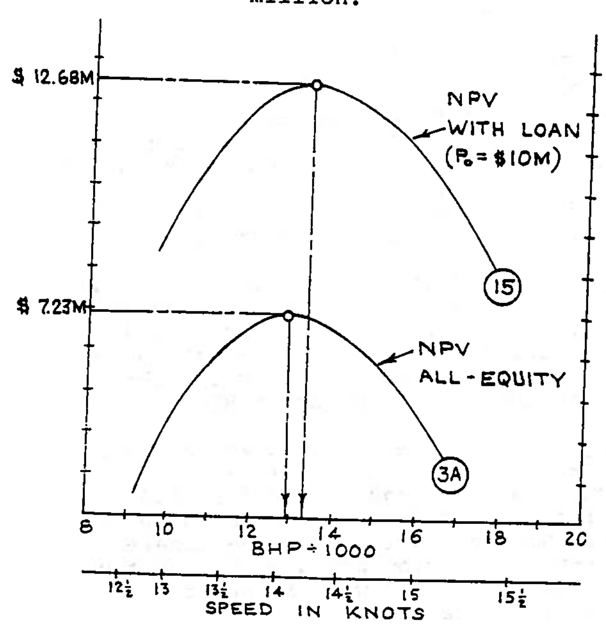


Figure 18. Shows effect of bank loan on NPV assuming owner's equity fixed at $10 million.

economic factors rather than financial factors should drive the design.

Equity as a Basis for Measuring Profitability

When leverage is involved, there is a natural tendency to look only at the owner's yield (i_o) on his own capital (P_o) rather than at the total yield (i') on total capital (P). There may be merit in this; but there is also danger of being misled if we do not recognize that

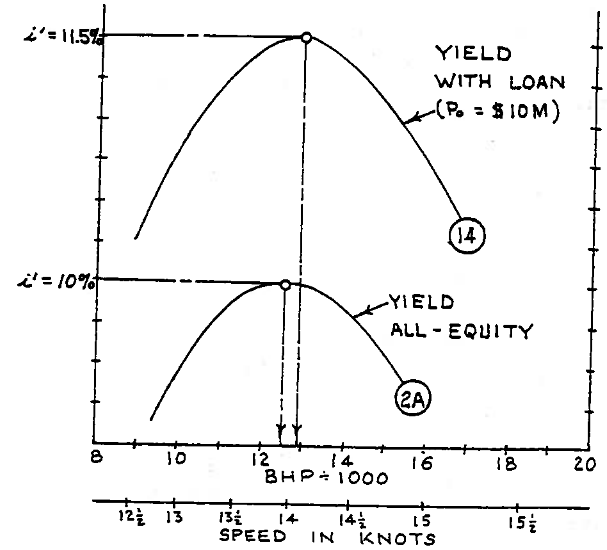


Figure 19. Shows effect of bank loan on yield assuming owner's equity fixed at $10 million.

increasing leverage carries with it increasing risk to the stockholders. The net result is that the apparent benefits of the added capital are, to a considerable degree, cancelled by the added risks. The extent of this counter-weighting will depend on the business environment. A small company with few reserves might find that a modest error in its estimate of income would prevent it from honoring its bank payments, and the entire business could thereby be foreclosed. A large organization, on the other hand, might easily cover such a loss.

Aim of leverage. In any event, businessmen recognize the element of risk entailed in leverage and the more prudent of them simply aim for the same total yield irrespective of the degree of leverage. For example, a shipowner who was satisfied with a 10.5 percent yield on an all-equity investment would probably settle for nothing less (relative to the total investment) if he borrowed half the capital at 6 percent -- which would mean that the yield on equity would come to 15 percent. This is found as follows:

$$\frac{P_o}{P} i_o + \frac{P_B}{P} i_B = i'$$

$$0.5\ i_o + 0.5 \times 6\% = 10.5\%$$

$$i_o = \frac{10.5\% - 3\%}{0.5} = 15\%$$

The logic behind this is reflected in the ICC decision (Reference 9), which says that, for regulated airlines, a 10.5 percent yield on total investment would be fair and reasonable, allowing 5 percent for bank loans and 16 percent for yield on equity. In short, use leverage to raise i_o, not lower i'. If the shipowner does not subscribe to this philosophy, you can depend on it, the banker will; which means that the loan will either be unavailable or will be made only at a discouragingly high interest rate.

<u>Disadvantages of stressing only owner's view.</u> In view of what is explained above, for design purposes you are well advised to resist the tendency (and some owners' urgings, perhaps) to separate owner's returns from total after-tax returns. If your criterion is RFR, I recommend starting with the same overall yield regardless of leverage. After you have used that approach to select the optimum ship, you may then go on to show the owner your prediction of his yield on equity -- but only as a matter of information. On the other hand, if the owner is sure he wants you to use the availability of borrowed funds to lower overall profitability (i.e. overall yield), then you must recognize that such a decision will tend to degrade the time-value of money. The annual cost of capital recovery will be reduced, leading to a lower RFR, leading to a lessened demand for productivity. A ship designed on that basis will tend toward under-design. The indicated optimum speed, for example, would be somewhat lower than that arrived at on the basis of a higher overall yield.

<u>Effect with fixed debt/equity ratio.</u> Suppose you are asked to design a ship on a basis of maximizing either the yield or NPV of the owner's investment, P_o, and owner's returns, A_o. What effect this will have on the design will depend on whether the debt/equity ratio will be the same for all designs, or the owner's equity is fixed and the bank will lend whatever else is needed. Let us first consider the assumption of fixed debt/equity ratio. Figure 20 shows two curves of yield plotted against power and speed for our sample ship assuming an 80 percent bank loan at six percent interest. The upper curve is for owner's yield.

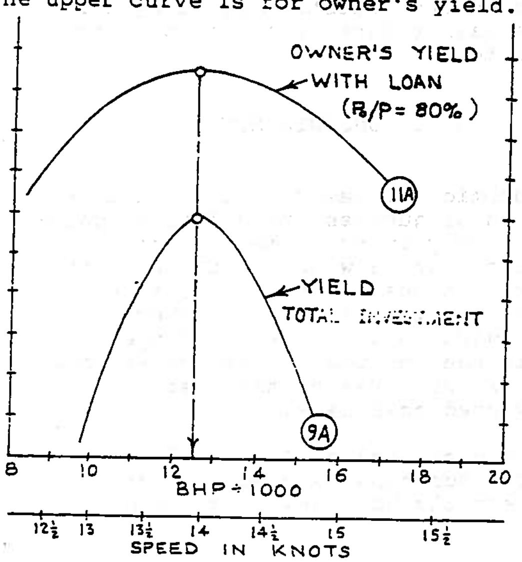


Figure 20. Shows that owner's yield and total yield occur at same design condition when debt/equity ratio is held constant.

The lower curve is for total yield (bank plus owner). Note that they point to identical design powers and speeds as being optimum.

Figure 21 shows two curves of NPV for the same set of assumptions. Again, you may see that the best design based on total economics is almost exactly the same as that based on owner's economics.

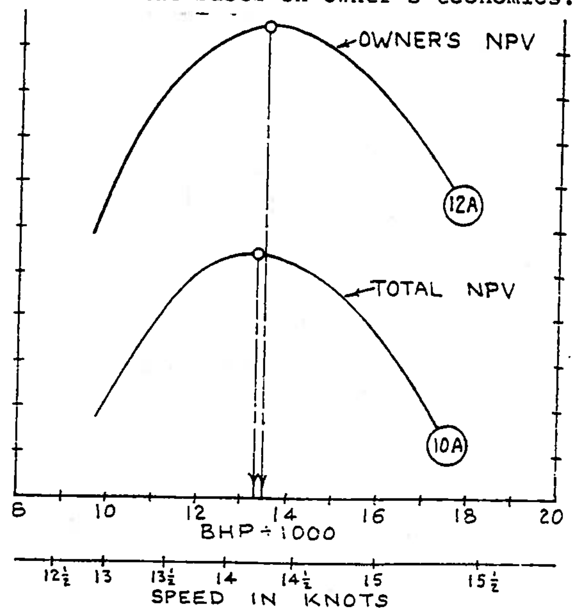


Figure 21. Shows that owner's NPV and total NPV occur at almost the same design condition when debt/equity ratio is held constant.

<u>Conclusion.</u> The two foregoing studies lead us to conclude that owner's view and (owner+banker's) view will virtually coincide when the debt/equity ratio is the same for all alternatives and the measure of merit is either yield or NPV. There is, in short, little if any reason to go to the extra trouble of separating out the owner's share of the economic pie.

<u>Effect with fixed equity, variable loan.</u> Suppose next that the owner can raise only $10 million and the bank is willing to provide the rest, again at six percent interest -- a dubious assumption, for reasons already explained. Figure 22 compares owner's yields (i_o) and total yields (i') for two levels of revenue per ton, corresponding to RFR and RFR plus twenty percent. At the lower freight rate the difference in best BHP is a modest seven percent. At the higher freight rate, however, the difference increases to 16 percent -- a significant gap.

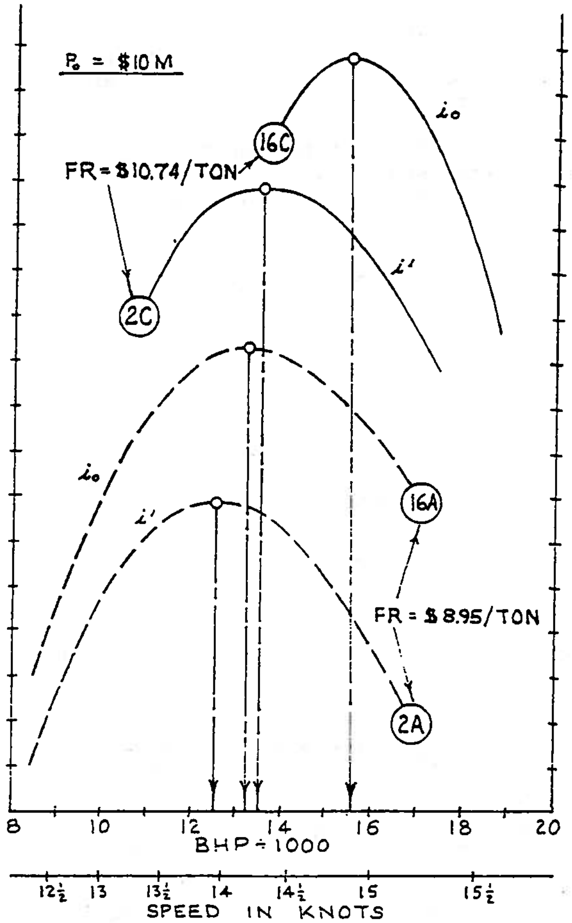


Figure 22. Shows that optimizing on a basis of fixed equity tends toward over-design. The trend is particularly strong at higher freight rates.

Figure 23 is also based on an assumed $10 million owner's investment, the rest to be loaned by the bank at six percent interest. Two criteria are shown: i_o and NPV_o. Notice that they both point to the same BHP as being ideal. This makes sense. If the owner's investment is the same for all alternatives, then NPV_o and $NPVI_o$ become directly proportional, and -- as already demonstrated, $NPVI_o$ and i_o will always point to the same optimum, given all our standard assumptions. Thus, the conclusions drawn from Figure 22 (for i_o) could as well be applied to similar curves for NPV_o.

Conclusion. The last few paragraphs lead us to conclude that basing design decisions on owner's equity is reasonable under conditions of fixed debt/equity ratio. When the owner's equity is fixed, however, using it as a basis for decision making entails risks that are not quantified in the resulting measure of merit.

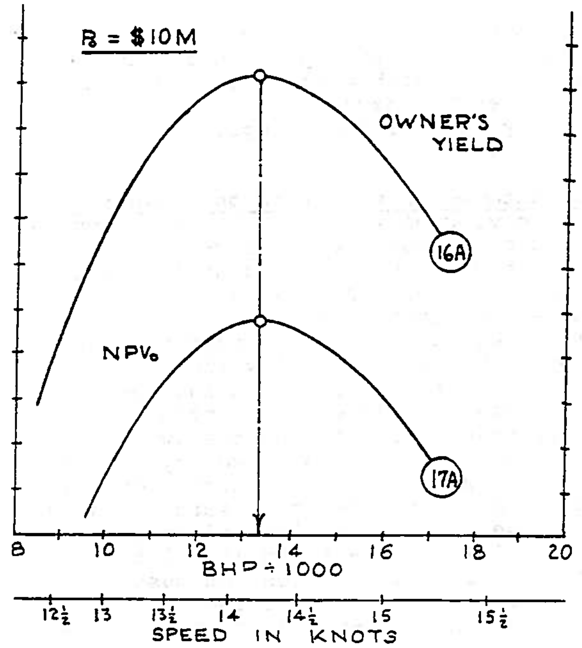


Figure 23. Shows that owner's yield (i_o) and owner's NPV (NPV_o) point to the same optimum design.

Where risks vary. The last combination (fixed equity, and fixed interest rate), if carried to extremes, can be altogether unreliable. The reason is that we have failed to account for the increasing risk to both owner and banker that may result from higher debt/equity ratios. This brings up the subject of decision-making where the alternatives are subject to different degrees of risk. We handle this in our everyday life on an intuitive basis, demanding higher rates of return from the riskier ventures. Reference 3 outlines some useful rules of thumb used by business managers. For more sophisticated approaches, see References 10 and 11.

The related question of recognizing the uncertain future is taken up in the next chapter.

VII. UNCERTAINTY

Economic studies are built on a foundation of guesses about future conditions. Nearly every element of the analysis may prove wrong in actual fact. This does not mean that we should throw up our hands in resignation. There are rational ways to minimize the dangers inherent in the unknown future and we shall mention two or three of the most commonly-used ones here.

By way of preface I may add that successful business managers cannot explain exactly how they go about making decisions. There is clearly room for intuition in this, but the logical methods explained below have a place as well.

Expectation

In the expectation approach, you simply consider the economic results expected for each alternative under each of several possible future conditions, and take as your measure of merit the weighted average of each. Here is an example. Suppose you are asked to select between two kinds of propulsion plants. One will be more profitable than the other only if fuel prices continue to rise. Your estimates of the relative probability of future fuel prices and corresponding yields are shown in Table 3.

TABLE 3. Predicted Yields

	Future Fuel Prices		
	Remain Fixed	Rise Slowly	Rise Rapidly
Probability	0.25	0.60	0.15
Ship A	19%	15%	13%
Ship B	24%	14%	12%

The expectation for A is found as follows:

$$E_A = 0.25 \times 0.19 + 0.60 \times 0.15 + 0.15 \times 0.13 = 0.157$$

Similarly, the expectation for B is:

$$E_B = 0.25 \times 0.24 + 0.60 \times 0.14 + 0.15 \times 0.12 = 0.162$$

Based on expectation, we should favor Ship B.

Maxi-Min

The pessimist reasons that whatever decision he makes will anger the gods and the worst will always happen. He therefore favors the decision the worst possible outcome for which is the least unfavorable. That is, he looks for the maximum of the minimum results -- which in this case goes with Ship A. (The optimist, on the other hand, would choose Ship B because it offers the best of the best -- the maxi-max criterion.)

There are several other logical approaches to handling uncertainty, which you can look up in standard texts on management. The ones outlined above will serve as a start and are good enough for the majority of cases.

If your economic study considers large numbers of alternatives, you would normally start out using only single most likely values for each (i.e. the so-called deterministic approach). The more elaborate procedures outlined above would be saved for evaluating only the final few contenders. This is simply a matter of keeping the computational procedures within bounds.

VIII. CONCLUSIONS

We have defined several valid economic measures of merit that have important application in ship design. We have explained why the various measures may or may not point to the same design value as being ideal. We have illustrated these differences with typical design studies. One family of studies looked at the feasibility of an advanced type of power plant. Another sought to find optimum values of power and speed. Both represent the traditional tradeoffs inherent in engineering design: higher first cost balanced by the future advantages of a more productive or more efficient item of capital equipment. Although confined to a limited number of specific cases, the conclusions reached in these studies are qualitatively valid for a broad range of practical applications. Some general conclusions are as follows.

There is no universal measure of merit applicable to every design problem under every kind of circumstance.

Where incomes can be predicted, some managers will prefer yield (DCF) and others will prefer NPV. Some will want to consider both criteria. In general, yield is preferred by entrepreneurs (a dying breed, alas). On the other hand, conservative corporate executives may tend toward NPV, reflecting a natural bureaucratic preference for enlarging one's scope of operation in place of maximizing returns to the stockholder. Even where the central aim of a corporation may be to maximize its net present value, when its funds are limited it should select individual investments on a basis of their net present value per dollar invested. We call this ratio the net present value index (NPVI), which is shown to be exactly equivalent to yield when incomes and expenses are taken to be uniform during the life of the investment.

When incomes are the same (including zero) for all alternatives, average annual cost appears to be generally valid. If lives are also the same for all alternatives, the present value (life cycle cost) criterion is acceptable, too. These criteria require a stipulated interest rate, which is best taken as the owner's desired level of profitability; it is usually not the same as the minimum level, or cutoff rate used in NPV. The stipulated rate should vary with the risks involved.

Where incomes will vary with productivity, the required freight rate (RFR) is often a useful criterion. It equals the average annual cost per unit of cargo moved in any given voyage.

Where income can be predicted and lives are the same, decisions can often be made on a basis of returns before tax; the best design before tax is also usually the best design after tax. Where incomes cannot be predicted, however, the calculation of AAC or RFR should be based on the owner's stipulated yield corrected for tax.

The corporate income tax, in the long run, requires an increase in freight rates. High freight rates justify more productive ships (e.g., higher speeds). On the other hand, taxes reduce the benefits arising from the greater income (or lowered operating cost) of more productive or more efficient ships. Thus, recognition of the tax will have seemingly opposite effects on design depending on the framework of assumptions and selection of measure of merit. The major point to keep in mind is that taxes must not be forgotten.

Debt capital allows an investor to extend the scope of his activities, hence increase his profits. It also increases his risks, however, so that one should not use the availability of low-interest debt as an excuse to lower the standard of profitability on the total investment. The significant influence of bank loans is that the government treats the interest paid to the bank as tax-free expense to the shipowner. This reduces the impact of the tax, placing slightly less weight on the time-value of money.

Making decisions on a basis of the owner's rate of return on his equity is not recommended. Where the bank will lend a given fraction of the total investment, optimizing on equity will lead to much the same decision as optimizing on total investment (and so involves needless complication). Where the owner's equity is fixed and the bank will lend however much else is needed, optimizing on equity may lead to excessive investments with consequent added risk to the owner. Yield is an incomplete indicator of merit when risks vary between alternatives.

In summary of the two preceding paragraphs, make design decisions on a basis of economics, not finances.

A cargo ship should be looked upon as but one part of a complete door-to-door transport system. Naval architects must try to understand the entire system and to recognize that optimizing just the ship or water leg of the system may be a mistake. As illustration we have shown how a recognition of the inventory value of goods in transit may justify an appreciable increase in design speed.

The bulk of ship economic studies can be based on many simplifying assumptions. After the initial winnowing, the final contenders may be subjected to more careful analysis. In the final stages, for example, the complexities of actual tax arrangements can be introduced. Probability theory can also be applied and the outcomes predicted and compared under different possible future scenarios.

Perhaps the most important thing that can be said here is that determining an exact point of optimality is much less important than finding the reasonable range: the variation in design permitted by a negligible relaxation from the best attainable value of the measure of merit. Avoid computer optimization programs that find only the optimum point. Finding the reasonable range will give the decision-maker a wide menu of designs, thus allowing him maximum freedom in introducing intangible considerations into his thinking. It will also obviate dichotomy between the true believers of the competing measures of merit. Flat laxity can lead to ecumenical harmony among even the most doctrinaire economists.

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APPENDIX

Sample Ship

The several optimization studies used throughout the text are based on the Panamax-size bulk carrier developed in Reference 12. In each case the same hull configuration was assumed, but installed power and speed were treated as continuous variables to be optimized by each of the several measures of merit, as explained in the text of this publication. The reference study optimized both speed and block coefficient. To simplify the work of the present study, we held block coefficient constant, introducing an error of minor proportions.

Table 4 shows the basic characteristics of the subject ship and the assumed service.

Economic Assumptions

Table 5 shows the basic economic assumptions held constant through the comparative evaluations cited in the text.

TABLE 4. Ship and Voyage Particulars

Type	Dry bulk carrier
Length between perps.	810 ft(247m)
Beam	105.8 ft (32.2m)
Depth	60.7 ft (18.5m)
Operating draft	43 ft (13.1m)
Block coefficient	0.84
Displacement	88,440 long tons (89,700 tonnes)
Machinery:	single screw, geared diesel plant burning 3500 sec. Redwood fuel.
Voyage:	6000-mile round trip, carrying cargo in only one direction.

TABLE 5. Economic Assumptions

Cost levels:	January 1980 U.S. construction and operation (both unsubsidized)
Fuel price:	$150 per ton
Economic life:	20 years
Tax depreciation period:	20 years
Disposal value:	zero
Depreciation plan:	straight-line
Annual revenues and expenses:	uniform
Tax rate:	40 percent
Tax deferral:	not used
Tax credit:	not used

(Other specific assumptions are explained in the text.)

Economic Characteristics vs BHP

Table 6 shows our estimates of costs and transport capability for our sample ship with various levels of installed horsepower.

TABLE 6. Economic Characteristics at Various Levels of Installed Power

$\frac{\text{BHP}}{1000}$ (max. cont. rating)	6	8	10	12	14	16	18	20	22
Sea speed (knots)	11.08	12.12	13.02	13.78	14.43	14.97	15.42	15.82	16.18
Investment ($ millions)	44.20	45.07	45.88	46.68	47.46	48.19	48.92	49.62	50.31
Cargo Carried per year (Millions of tons)	1.180	1.274	1.353	1.418	1.472	1.516	1.552	1.582	1.609
Annual operating costs ($ millions)	3.982	4.354	4.737	5.107	5.487	5.866	6.235	6.608	6.980

Sample Analyses

Based on the economic data shown in the previous table, we show in Tables 7 and 8 how quantitative values of three of the measures of merit are derived. Figure 24 shows how the differences between successive values of RFR are plotted in order to determine that value of BHP where the slope of the RFR curve will be zero (i.e., at its minimum value). The figure also shows the curve of RFR and the range of BHP values in which all values of RFR are within one percent of the minimum. This figure is based on Test 1A.

TABLE 7. Typical Economic Evaluations

(see Table 8 for explanation of key steps)

1) BHP/1000 (max. cont. rating)	6	8	10	12	14	16	18	20	22
2) Sea speed (knots)	11.08	12.12	13.02	13.78	14.43	14.97	15.42	15.82	16.18
3) Investment ($ millions)	44.20	45.07	45.88	46.68	47.46	48.19	48.92	49.62	50.31
4) Cargo carrier per year (millions of tons)	1.180	1.274	1.353	1.418	1.472	1.516	1.552	1.582	1.609
5) Annual operating costs ($ millions)	3.982	4.354	4.737	5.107	5.487	5.866	6.235	6.608	6.980
6) RFR ($/ton)	9.461	9.166	9.011	8.951	8.967	9.035	9.139	9.274	9.419
7) ΔRFR	.295	.155	.060	-.016	-.068	-.104			
8) Freight rate ($/ton)	8.950 →								
9) Annual revenue ($ millions)	10.561	11.402	12.109	12.691	13.174	13.568	13.890	14.159	14.400
10) Cash flow before tax ($ millions)	6.579	7.048	7.372	7.584	7.687	7.702	7.655	7.551	7.421
11) Cash flow after tax ($ millions)	4.831	5.130	5.341	5.484	5.561	5.585	5.571	5.523	5.459
12) CR'	.1093	.1138	.1164	.1175	.1172	.1159	.1139	.1113	.1085
13) (SPW - 8% -20)	9.818 →								
14) NPV ($ millions)	3.231	5.296	6.588	7.162	7.138	6.644	5.776	4.605	3.286

TABLE 8. Explanation for Key Steps in Table 7.

(6) $$RFR = \frac{(CR)P + Y}{C}$$

CR is based on a 10 percent yield after tax:

(CR'-10%-20) = 0.1175 (see interest tables)

$$CR = \frac{CR' - \frac{t}{N}}{1-t} = \frac{0.1175 - \frac{0.40}{20}}{1 - 0.40} = 0.1625$$

$$\text{so} \quad RFR = \frac{(0.1625)P + Y}{C}$$

$$= \frac{(0.1625)\ ③ + ⑤}{④}$$

(7) ΔRFR: difference between successive values of RFR (used to find BHP of minimum RFR)

(8) In this case the revenue per ton is taken as $8.95, the required freight rate.

(9) Annual revenue = $8.95×④ .

(10) Cash flow before tax = ⑨ - ⑤

(11) Cash flow after tax = $A' = A(1-t) + t\frac{P}{N}$

$$= ⑩\ (1-0.40) + 0.40\frac{③}{20}$$

(12) $CR' = \frac{A'}{P} = \frac{⑪}{③}$

Note: This is used as a surrogate for yield.

(13) (SPW-8%-20) = 9.818 (from interest tables)

(14) NPV = (SPW-8%-20)A' - P

= 9.818 × ⑪ - ③

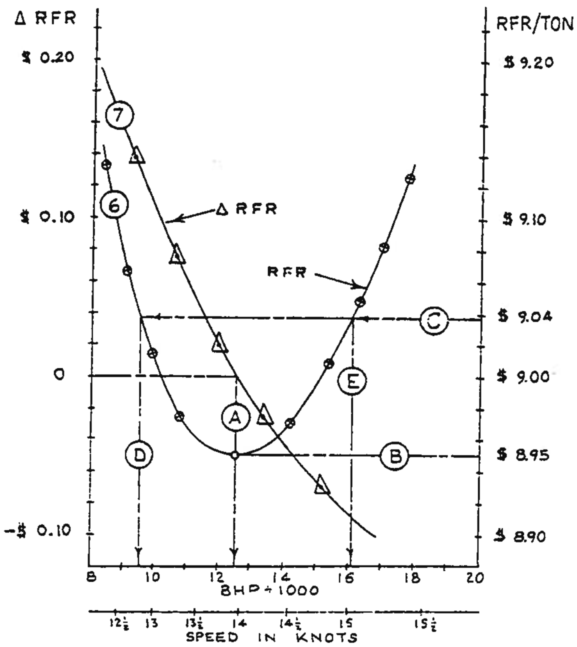


Figure 24. Shows how ΔRFR curve is used to pinpoint best value of BHP. Also shows how the one percent range is found. Curve (7) is drawn first. It plots differences between successive values of RFR as shown by Line 7 in Table 7. It is located along the x-axis midway between successive values of BHP. Wherever this crosses the horizontal reference line (for ΔRFR = zero) we shall find the point of minimum RFR, hence the optimum power -- in this case 12,500 BHP. See Line (A). Curve (6) is plotted next. It is based on values shown in Line 6 of Table 7. Its minimum point is made to occur somewhere on Line (A). Line (B) is drawn horizontally through the minimum point on Curve (6) and shows the minimum attainable RFR to be \$8.95/ton. Curve (C) is used to find the range within which BHP and speed can be varied without raising RFR by more than one percent. It is drawn horizontally at an RFR of 1.01 × \$8.95 = \$9.04/ton. Lines (D) and (E), drawn vertically through the intersections of Lines (C) and (6), show that BHP may vary between 9500 and 16,100 without departing by more than one percent from the minimum attainable RFR.

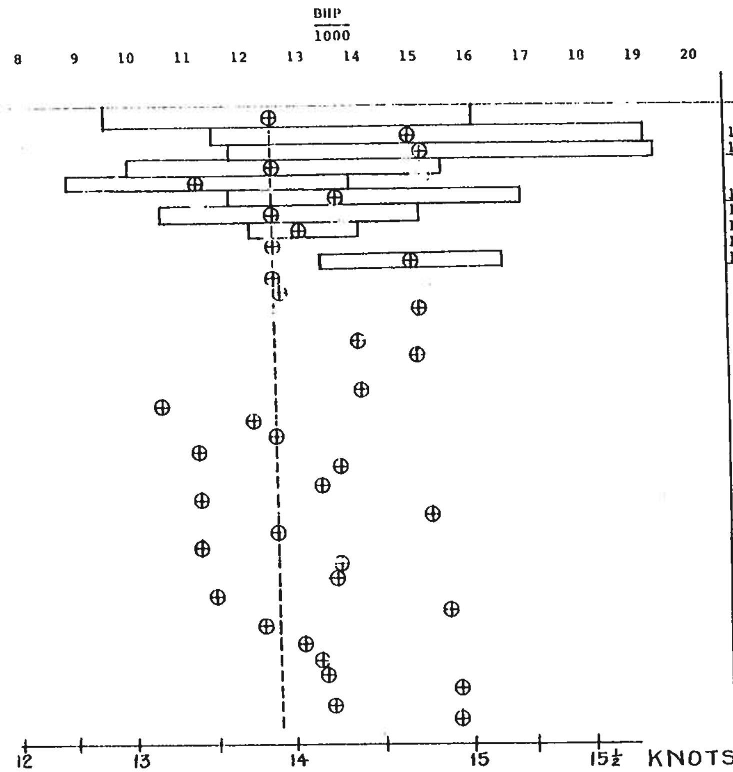
Compendium of Results

Table 9 summarizes the results of the many optimization studies discussed in the text. The columns identify the several measures of merit and the variations in basic assumptions. Derived values of optimal power and speed are shown both numerically and graphically. In some instances the extent of the one percent range is shown (by horizontal bars). The vertical dashed line represents the "standard" value of BHP (12,500) which corresponds to the minimum RFR based on a ten percent yield.

If you will examine the results of Tests 3A, 3B, and 3C you will note that with respect to NPV the extent of the one percent range is strongly related to the maximum value of the NPV. This is most strikingly shown in Test 3B. Here the freight rate and interest rate are so chosen as to dictate a maximum NPV of zero. As a result, the one percent range disappears altogether.

TABLE 9. Summary of Results

TEST	MofM	i'	FREIGHT RATE	MISC. NOTES	BEST VALUE MofM	OPTIMUM BHP/1000	OPTIMUM V_K
1A	RFR	10%	-		$8.95/ton	12.50	13.94
1B	"	20%	-		$13.68/ton	14.93	14.72
1C	ECT	10%	-	v = $500/ton	$10.935/ton	15.12	14.77
2A	YIELD	-	(RFR): $8.95/ton		10%	12.50	13.94
2B	"	-	(.8RFR): $7.16/ton		5.8%	11.20	13.49
2C	"	-	(1.2RFR):$10.74/ton		13.9%	13.58	14.29
2D	CR		(RFR): $8.95/ton		16.26%	12.50	13.94
3A	NPV	9%	" "		$7.23M	12.90	14.07
3B	"	10%	" "		0	12.50	13.94
3C	"	8%	(1.2RFR):$10.74/ton		$22.73M	14.90	14.71
4A	NPVI	8%	(RFR): $8.95/ton		15.45%	12.50	13.94
4B	"	10%	" "		0	12.53	13.95
5A }	YIELD OF	8%	" "	Incr: 4000BHP	8%	15.05	14.75
5B }	DIFF.		" "	Incr: 2000BHP	8%	13.95	14.41
6A }	NPV OF	8%	" "	Incr: 4000BHP	0	15.00	14.74
6B }	DIFF.		" "	Incr: 2000BHP	0	13.95	14.41
7B	UCOS	6%	-	No tax	$6.456	10.52	13.23
8	RFR	10%	-	P_n=0.8P	$8.30/ton	12.10	13.80
9A }	YIELD	-	(RFR): $8.95/ton	↓	11.5%	12.50	13.94
9B }		-	(.8RFR): $7.16/ton		7.5%	11.20	13.49
9C }		-	(1.2RFR):$10.74/ton		15.3%	13.62	14.31
10A }	NPV	8%	(RFR): $8.95/ton		$12.73M	13.28	14.20
10B }			(.8RFR): $7.16/ton		$2.26M	11.08	13.44
10C }			(1.2RFR):$10.74/ton		$29.32M	15.20	14.80
11A }	i_o		(RFR): $8.95/ton		29.8%	12.50	13.94
11B }			(.8RFR): $7.16/ton		12.1%	11.20	13.49
11C }			(1.2RFR):$10.74/ton		46%	13.60	14.30
12A }	NPV_o	8%	(RFR): $8.95/ton		$18.15M	13.55	14.28
12B }			(.8RFR): $7.16/ton		$3.07M	11.43	13.57
12C }			(1.2RFR):$10.74/ton		$33.80M	15.53	14.90
13	RFR	10%	-	P_o = $10M	$8.30/ton	12.20	13.84
14	YIELD	-	(RFR): $8.95/ton	↓	11.5%	12.81	14.04
15	NPV	8%	" "		$12.68M	13.32	14.21
16A }	i_o	-	" "		22.7%	13.37	14.22
16C }		-	(1.2RFR):$10.74/ton		44.5%	15.78	14.97
17A }	NPV_o	8%	(RFR): $8.95/ton		$12.7M	13.38	14.23
17C }			(1.2RFR):$10.74/ton		$31.93M	15.78	14.97



MIN.	MAX.	TEST
9.50	16.10	1A
11.42	19.22	1B
11.61	19.32	1C
9.90	15.48	2A
8.75	13.75	2B
11.75	16.90	2C
10.63	15.04	2D
12.02	13.90	3A
12.50	12.50	3B
13.28	16.68	3C