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MEASURES OF MERIT FOR SHIP DESIGN

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THE UNIVERSITY OF MICHIGAN
COLLEGE OF ENGINEERING

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ABSTRACT

My purpose in writing this paper is to explain the role of engineering economy in ship design and to discuss the relative virtues and shortcomings of the several measures of merit in current use. In particular, I want to compare the two criteria most popular with United States 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.

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 the reasonable range indicated by the others.

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.

CONTENTS

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
AAC	Average annual cost
ACCR	Annual cost of capital recovery = CR x P
C	Annual transport capacity
CR	Capital recovery factor = $A \div P$
CR'	Capital recovery factor after tax = $A' \div P$
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
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)
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 $\div$ P
P	Total initial investment, principal, or present worth of future amounts
P_B	Capital borrowed from bank or bondholder
P_O	Equity capital
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
Y	Uniform annual costs of operation, exclusive of capital costs

Notes

1. (SPW-5%-25) is the standard mnemonic form for the series present worth factor for five percent interest and for 25 years. Reference 1.

2. Other symbols and abbreviations are explained wherever used.

MEASURES OF MERIT

This paper is concerned with the selection and application of measures of merit for decision-making in ship design. This is one of the key factors in systems analysis, which is an approach to decision-making based on:

1. A clear delineation of the objective in functional terms;
2. A clear delineation of the constraints and other conditions of operation;
3. A measure of merit;
4. A compilation of all conceivable, practical strategies for accomplishing the objective in the face of the constraints; and
5. An analysis of the quantitative value of the measure of merit attainable by each of the strategies.

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, can often be predicted with confidence. In many situations, however, it cannot; or, indeed, it may be zero for a service vessel such as an icebreaker. 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

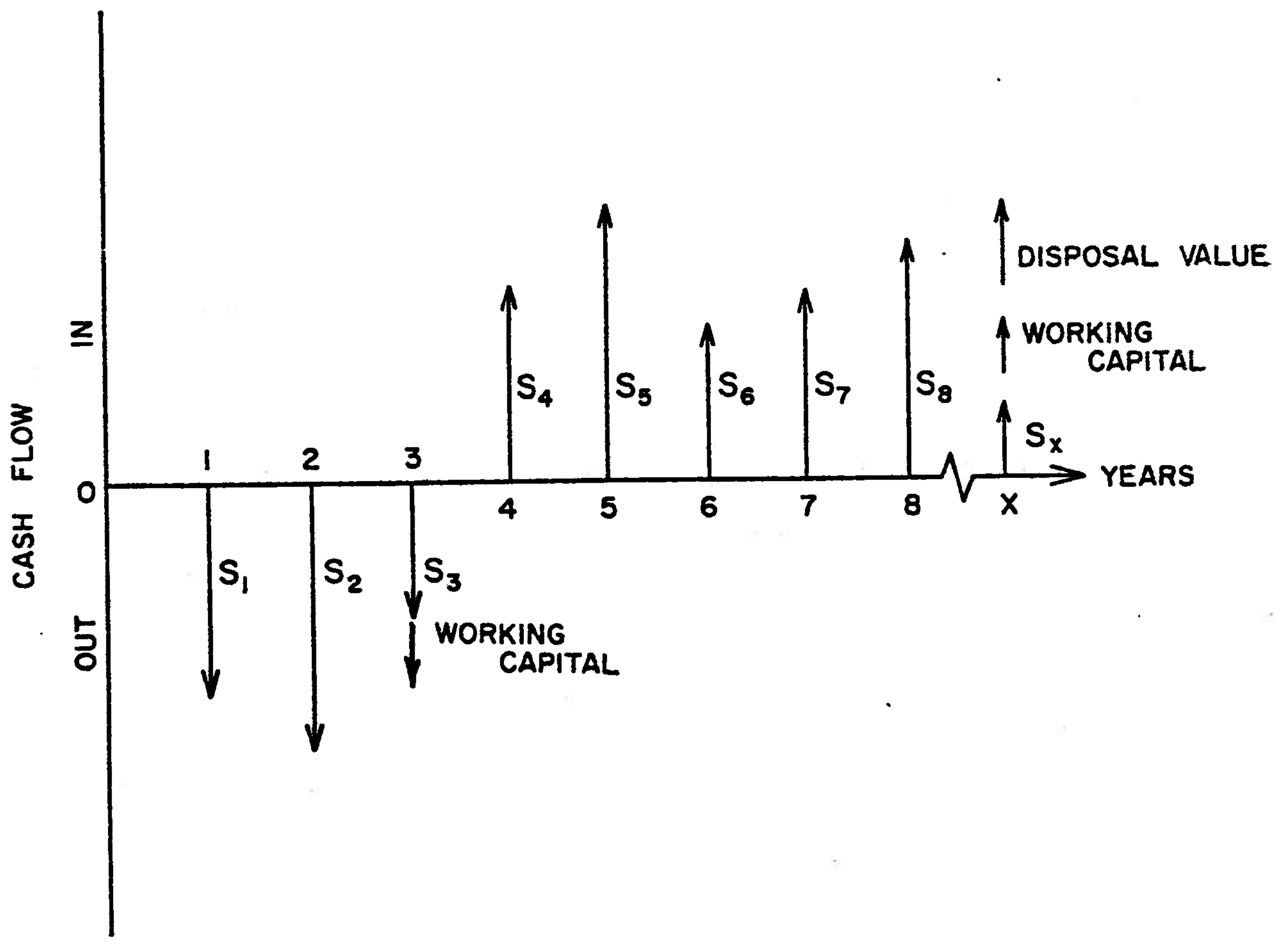
Overlaying the above-mentioned complications relating to measures of merit is the realization that they are to be used in cost analyses based on questionable predictions of future conditions. The application of statistics and probability theory is an important subject, but one that will not be discussed here other than to make the point that systems analysis 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 sound principles and rigorous practices.

Measures of Merit When Incomes Are Known

Where the incomes of the alternatives can be predicted, or are treated parametrically, there are two leading methods of analysis commonly used by well-informed businessmen: net present value (NPV) and discounted cash flow (DCF), or yield. In normal usage the two lead to different results and therefore merit some little discussion.

References 2 and 3 are typical of publications advocating the exclusive use of the NPV criterion. References 4 and 5 adopt the view that DCF is the only proper approach. References 6, 7, 8, and 9 discuss the relative merits of both approaches but reach no concise conclusions, although Reference 8 favors NPV for most situations.

The net present value criterion is a number, with dollar units, found by discounting all cash flows to time zero. (Time zero can be any convenient reference time: the present, the time of making the decision, or the time when the investment starts generating returns.) Discount factors are based on a somewhat arbitrary interest rate, usually dictated by management. This is the cut-off rate, and any investment promising a lower yield is considered unacceptable. In United States oil corporations the current cut-off rates are running about 8 to 11 percent. Proposals are compared as to their net present value, in dollars, above this level, and the one with highest NPV is considered best (assuming all have equal risks). Figure 1 shows the mathematical relationships appropriate to a rather realistic cash flow for a merchant ship, involving an investment spread out over several years, fluctuating returns, some disposal value, and eventual



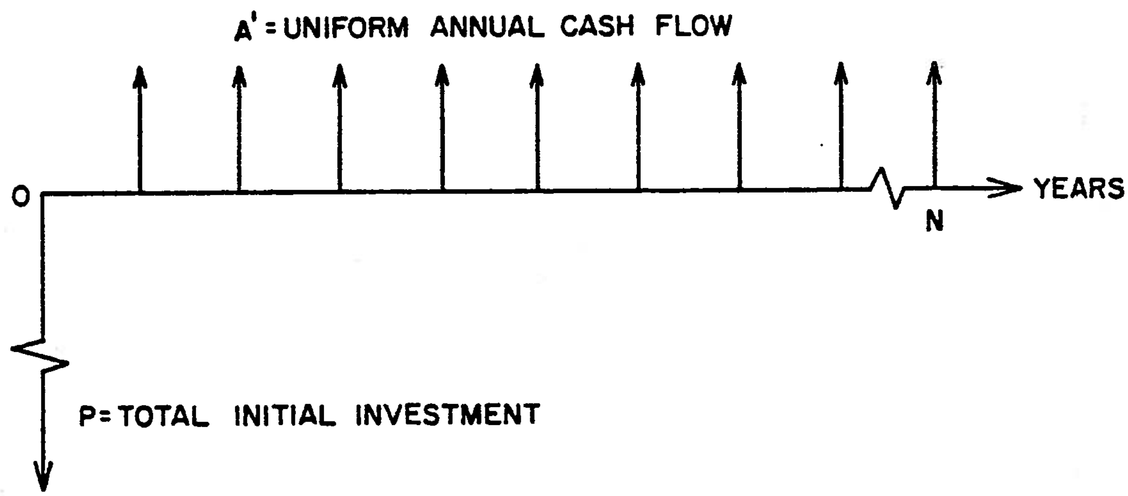
$$NPV = \sum_{o}^{x} (PW\text{-}i\%\text{-}N)S_j \qquad (1)$$

where S_j = net cash flow in year j

$$NPV = (PW\text{-}i\%\text{-}1)(S_1) + (PW\text{-}i\%\text{-}2)(S_2) + (PW\text{-}i\%\text{-}3)(S_3)$$
$$+ (PW\text{-}i\%\text{-}4)\ S_4 + (PW\text{-}i\%\text{-}5)\ S_5 + \cdots$$

Notes: Negative cash flows are shown in parentheses.
Zero on the time scale is usually the time of decision.
Cash flows shown are those that result from the decision under study.

Figure 1. Complex Cash Flow Analysis



$$NPV = (SPW\text{-}i\%\text{-}N)A' - P \quad (2)$$

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

Notes: Yield is interest rate based on CR'.
Zero on the time scale is the time of delivery of the ship.
A' is found by dividing total predicted positive cash flow by the number of years, N .

Figure 2. Simplified Cash Flow Analysis

recapture of the working capital. NPV is found by tabulating year-by-year the cash flow, the appropriate discount factor, and the product of the two; the net sum is NPV.

Figure 2 is a simplified version of the complex cash flow shown in Figure 1. It is less realistic, but is far easier to analyze, and is usually as accurate as forecasting techniques permit. Its simplicity makes it particularly suited for analyses involving large numbers of alternatives. NPV is found by subtracting the investment from the easily-derived net present value of the future after-tax returns (A'). No tables of year-by-year figures are required.

DCF, the discounted cash flow method, is used to derive the yield, i.e. the interest rate of return on an investment. The method is also called profitability index, or equated interest rate of return (EiRR). It is the interest rate that makes the NPV equal to zero. In complex cash flows such as in Figure 1, that rate can be found only be trial and error. In the simplified cash flow of Figure 2, trial and error is not required because the interest rate can be derived from CR' and contours such as those shown in Figure 3. DCF and yield are used here more or less synonomously, although the term "DCF" usually implies the trial and error approach to finding "yield."

Advocates of NPV argue that the central aim of most corporations is to maximize net present value. From this they conclude that competing proposals for investment funds should be priority ranked in terms of NPV. A weakness in this line of reasoning is that it is valid only in those cases where an organization has more funds than it wants to invest internally. Here is an example:

> A corporation has six proposed investments totaling $200 million, but only $100 million available (both equity and borrowed). All bear equal risk and none incurs problems of resource constraints other than investment funds. Table 1 shows those proposals ranked in order of NPV. Manager Alpha, an advocate of NPV, would select Proposals A and B, which would employ the entire $100 million and promise an increase in the corporate net present value of $14 million plus $10 million, or $24 million. This is indicated by the lower line in Figure 4.

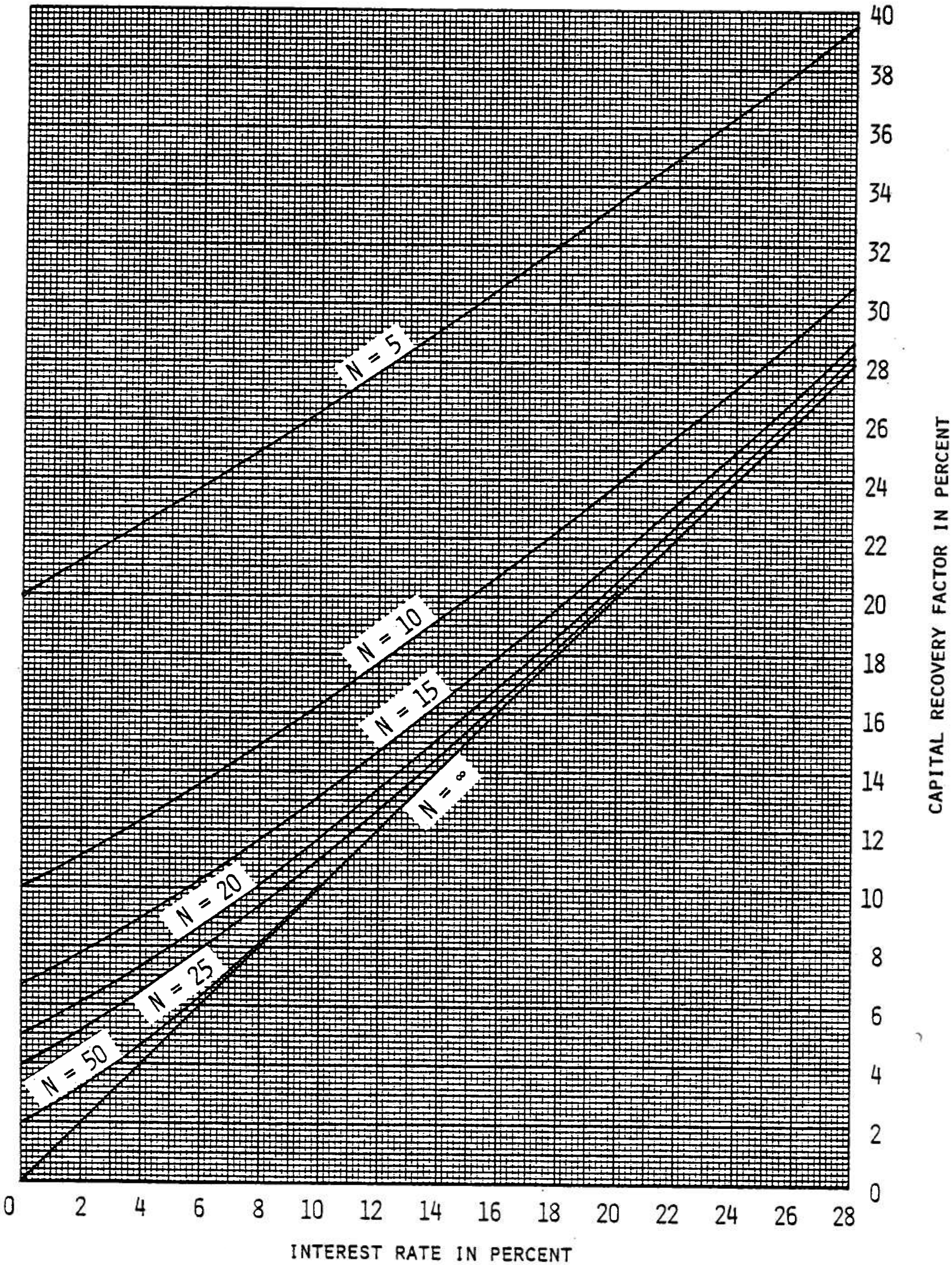


Figure 3. Capital Recovery Factor Versus Interest Rate.

Table 1

Investment Opportunities Ranked According to Net Present Value

Proposal	Invested Cost in Millions of Dollars	NPV in Millions of Dollars
A	60	14
B	40	10
C	30	9
D	30	8
E	20	7
F	20	6

Table 2

Investment Opportunities Ranked According to Net Present Value Index

Proposal	Invested Cost in Millions of Dollars	NPVI
E	20	0.350
C	30	0.300
F	20	0.300
D	30	0.267
B	40	0.250
A	60	0.233

Manager Omega agrees with the wisdom of trying to maximize the corporate net present value. He notes, however, that the NPV criterion is biased toward the larger individual projects. He realizes, since total investment funds are limited, that the maximum corporate NPV comes from selecting those projects that have the highest NPV per dollar invested. He therefore employs an indicator that we shall call net present value index: NPVI.

$$NPVI = \frac{NPV}{P} \tag{4}$$

Table 2 ranks the same six proposals in order of NPVI. Manager Omega selects Proposals E, C, F, and D, in that order, and finds they promise an increase in corporate NPV of $30 million, a $6 million improvement over the results promised by Manager Alpha. The upper line in Figure 4 indicates the outcome of selecting on a basis of NPVI.

When predicted cash returns are uniform, NPVI is fundamentally equivalent to the yield, or DCF, criterion. That is, either method will lead to the same design decision. The common roots of NPVI and DCF are shown in the following extension of the relationships outlined in Figure 2.

$$NPVI = \frac{NPV}{P} \tag{4}$$

but

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

therefore

$$NPVI = \frac{(SPW\text{-}i'\%\text{-}N)A' - P}{P} \tag{2}$$

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

but

$$\frac{A'}{P} = CR' \tag{3}$$

therefore

$$NPVI = (SPW\text{-}i'\text{-}N)CR' - 1 \tag{5}$$

Since the series present value worth factor (SPW-i'-N) will be the same for all alternatives, assuming equal lives, we can see that NPVI is directly related to the capital recovery factor after tax (CR') which is, in turn, directly related to DCF. From this we must conclude that an optimal design indicated by NPVI will be exactly that indicated by DCF and CRF. This also explains a pecularity of the NPVI criterion: it shows the same optimum regardless of the discount factor assumed.

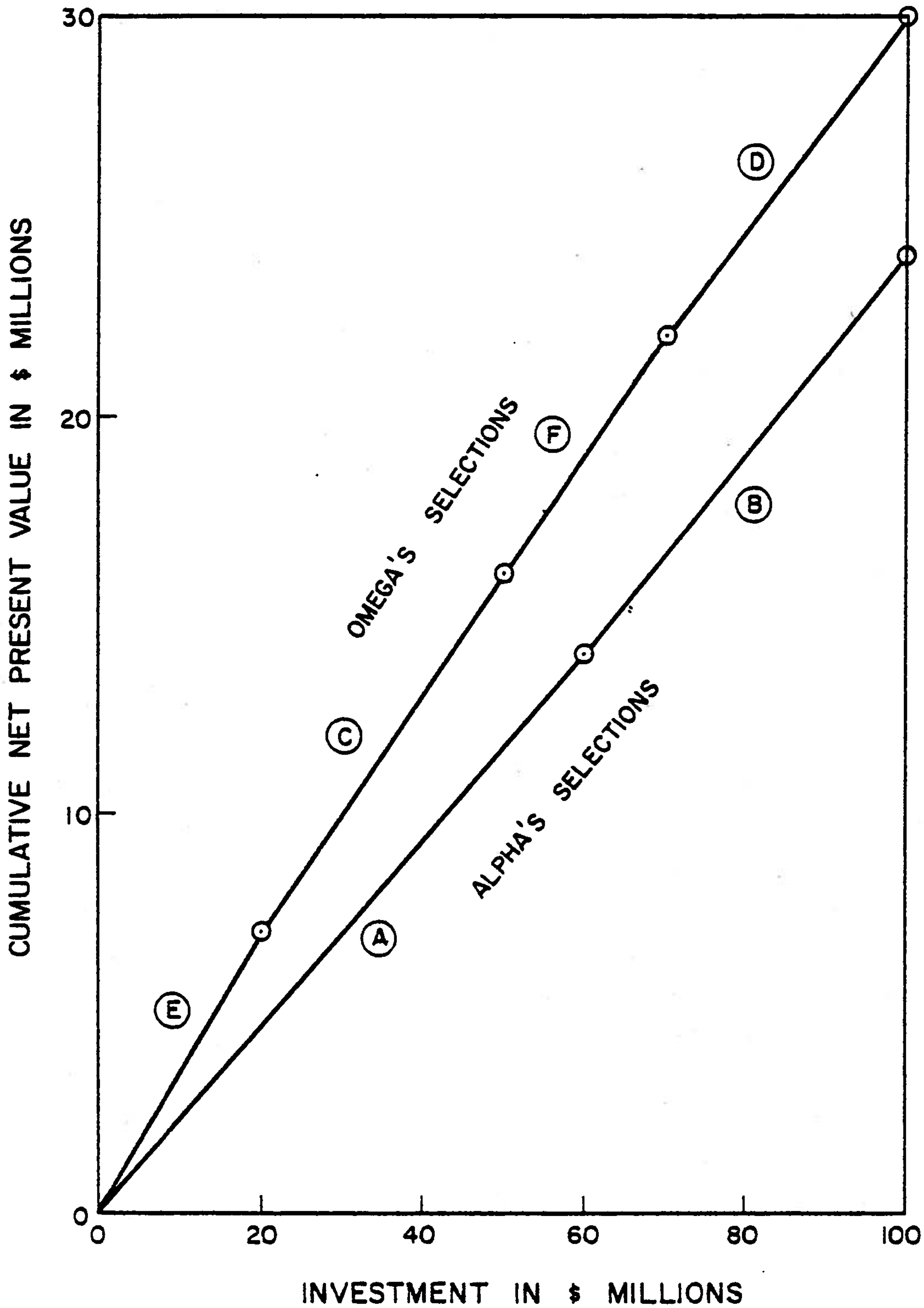


Figure 4. Outcome of Two Approaches to Selecting Alternative Investment Opportunities

Reference 10 develops an elaboration on the NPVI technique, one that points to exactly the same optimal design as DCF when cash returns are uniform--which, of course, is our normal assumption.

Proponents of the NPV method (11) point out that NPVI and CRF have the weakness of relying on a well-defined denominator, namely the investment: P . Actual cash flow figures do not differentiate between expense outlays and capital ourlays. The true amount of the investment is, therefore, not always easily discernible. This will seldom be a factor in ship design studies, however.

A more pertinent point is that investment funds may not be the limiting factor in maximizing the corporate NPV; there may be more serious shortages of raw materials or skilled labor, for example. In those cases the index should be based on the net present value per unit of scarce resource (11).

Figure 5 summarizes the findings of a series of sensitivity studies. These were aimed at showing the influence of different measures of merit in indicating the most economical power and speed for the typical bulk carrier analyzed in Tables 14a and 14b of Reference 12. Where income has to be assumed, two cargo rates are used: $27 and $42 per ton. The lower figure is considered a nominal standard rate, one that will give an owner an 11.5 percent yield, assuming a 50 percent tax, a 25-year life, and an all equity investment. The higher rate will produce a 20 percent yield and is introduced to show the effect of changes in revenue. Entry 1 uses the DCF criterion. The targets show the exact point of optimality. Where a bar is shown, it represents the "reasonable range," which indicates the extent to which the design can depart from optimal and still come within 2.5 percent of the yield attained at that point. The generous extent of the reasonable range is typical of the flat laxity of most measures of merit when related to design parameters. As expected, the higher freight rate leads to higher optimal speed. The difference, however, is slight; a 44 percent increase in rate produces only a six percent increase in optimal power and a one percent increase in optimal speed.

Entry 2 in Figure 5 shows the optimal points based on NPV with a discount rate of eight percent. The criterion's bias toward the bigger

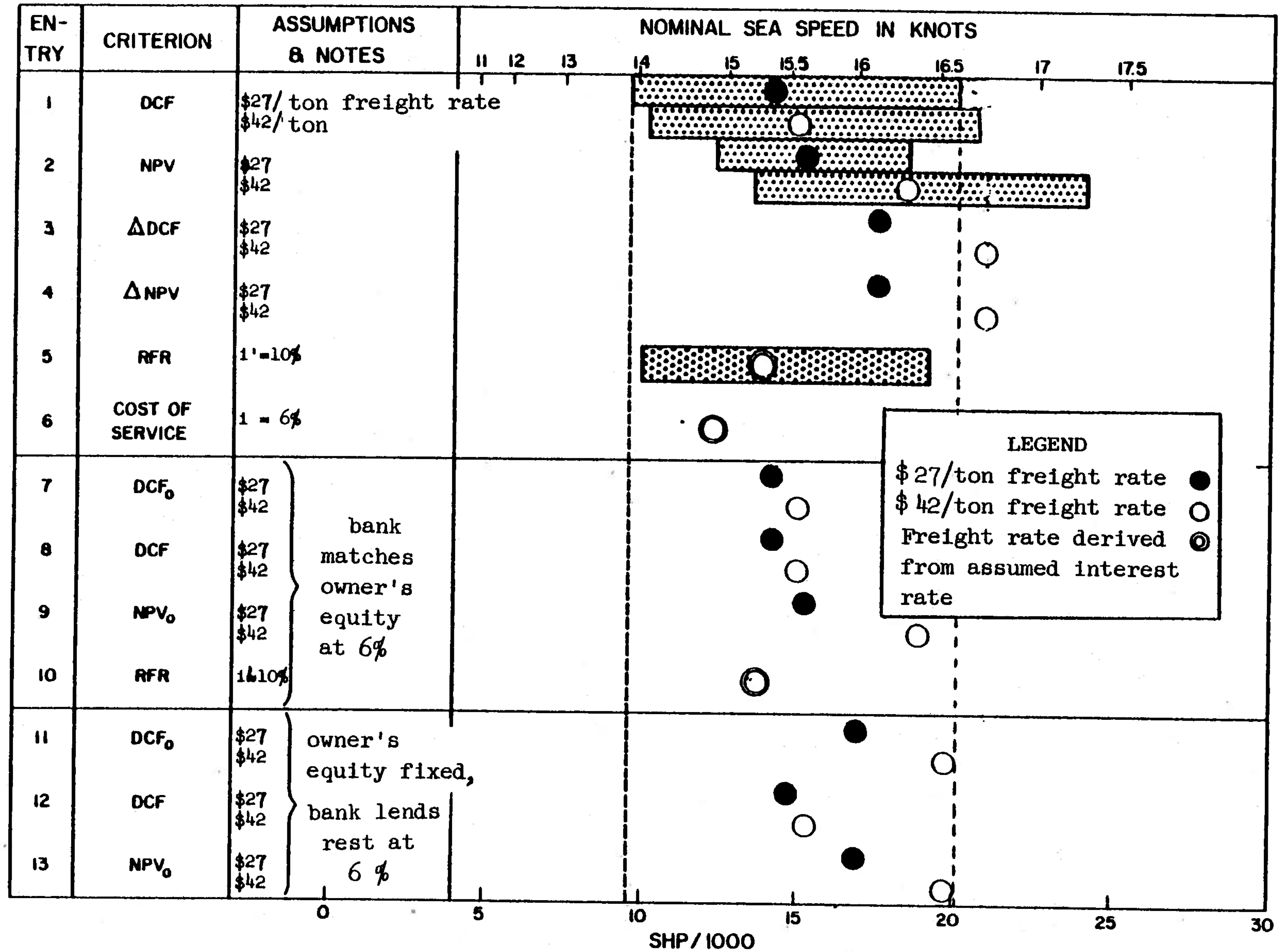


Figure 5. Optimal Points and Reasonable Ranges Indicated by Various Criteria

projects results in an indication of greater optimal speed, particularly with the higher freight rate. At the lower rate, the optimal point is not significantly different from that indicated by DCF. An auxiliary study (not shown) using zero interest rate indicates optimal points at 18,000 shp for the $27 rate and 20,700 shp for the $42 rate.

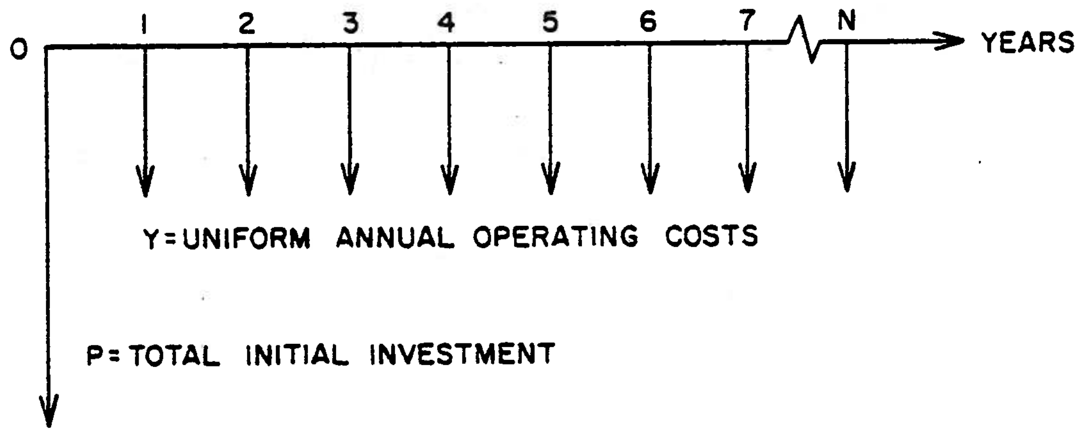
Entries 3 and 4 in Figure 5 are based on the incremental limit variant of the DCF and NPV criteria. In this approach, we list the proposed designs in order of increasing first cost. We then analyze the difference in returns and difference in investments if we select the second design instead of the first. We can use either DCF or NPV. We continue this process step-by-step until DCF of the increments comes down to the cut-off rate (eight percent in this case) or NPV of the increments comes down to zero. As may be seen in Figure 5, these procedures lead to overdesign. As a rule, the incremental variants are to be avoided, their weakness being that they treat the cut-off rate as a target rather than as a baseline. Entries 3 and 4 show identical results because both enforce the same arbitrary level of profitability: an eight percent yield. Some experts (18) strongly favor the incremental methods and we can concur as long as they are willing to let us use target interest rates in place of cut-off (i.e. minimum acceptable) rates.

The Appendix contains a typical calculation sheet showing how Entries 1 and 2 were derived.

Measures of Merit When Incomes Are Unknown

The preceding paragraphs have dealt with measures of merit suitable to the situations in which the analyst has some indication of attainable freight rates. In many instances, however, freight rates are either unknown or are nonexistent. Clearly, neither DCF nor NPV can then be used directly, since both require some estimate of revenues. Indirect ways to use DCF will be discussed later.

Let us look first at cases where incomes are unknown but equal for every alternative, or are simply zero. Figure 6 shows a simplified cash flow diagram corresponding roughly to the simplifications applicable to Figure 2. The first two criteria shown are present value (PV) and average annual cost (AAC). They are equivalent and will



$$PV = P + (SPW\text{-}i\%\text{-}N)Y \tag{7}$$

$$AAC = (CR\text{-}i\%\text{-}N)P + Y \tag{8}$$

$$RFR = \frac{AAC}{C} \tag{9}$$

where C = annual transport capacity

Figure 6. Simplified Cash Flow Analysis Without Reference to Income.

indicate indentical optima when all alternatives have equal lives. When lives differ, PV may become misleading, but AAC will remain valid. The present value criterion is sometimes called life cycle cost (LCC).

The PV and AAC concepts are simple and widely understood. What is often confused, however, is the rationale behind the selection of the interest rate. Analysts frequently overlook the fact that the owner's stipulation of a reasonable level of profitability is based on after-tax conditions. One way to handle the corporate income tax is to recognize that any change in operating cost, whether up or down, will be tempered by the tax, which may itself be tempered by a tax shield arising from depreciation. Remember, we are dealing here with situations in which all alternatives may be assumed to have identical income potentials. Therefore, any change in operating cost will have an equal and opposite effect on taxable income. If you have a 40 percent tax, then each dollar saved in operation will benefit the owner by only 60 cents. If there are also differences in first cost between alternatives, then the effect of different depreciation tax shields must also be introduced. Our relationship then becomes:

$$A' = A(1-t) + t\frac{P}{N} \qquad (6A)$$

If we are considering the difference between two alternatives, we have:

$$\Delta A' = \Delta Y' = \Delta Y(1-t) + t\frac{\Delta P}{N} \qquad (6B)$$

In the above:

- A' = uniform annual return after tax
- A = uniform annual return before tax
- t = tax rate
- P = initial investment
- N = economic life
- $\Delta A'$ = difference in annual returns after tax
- $\Delta Y'$ = difference in annual operating costs adjusted for differences in tax
- ΔP = difference in invested cost

A word of caution is due here: Expressions 6A and 6B assume the following:

Straightline depreciation

Zero disposal value

Depreciable life equal to economic life

All-equity investment

These are standard simplifying assumptions that most analysts use in preliminary assessments even though the eventual tax structure may be more complicated.

An alternative approach to the above is to modify the interest rate so that it can properly be applied to the before-tax cash flow condition. This must be done indirectly through the expedient of modifying one or more of the interest relationships such as the capital recovery factor. This is explained in Reference 13. The usual procedure is to start with a specified after-tax yield (i'); look up the corresponding after-tax capital recovery factor (CR') in your interest tables, and then solve for the before-tax capital recovery factor:

$$CR = \frac{CR' - \frac{t}{N}}{1 - t} \tag{6C}$$

where

t = tax rate

N = economic life of the ship, and depreciation period for taxes.

These expressions are again based on straightline depreciation, zero disposal value, and an all-equity investment. The before-tax interest rate can be found by entering Figure 3 with the CR value found above.

The required freight rate criterion (RFR) is found by dividing the average annual cost by the annual transport capacity in whatever units are appropriate: long tons, measurement tons, containers, passengers, or whatever. RFR is used in situations where PV or AAC are made invalid by differences in transport capability between the various design alternatives. The concept implies that the best ship for the trade is the one that can offer the service at the lowest unit cost to the customer while returning to the owner a fixed, reasonable level of profitability after tax. The required freight rate is generally similar to what economists call a shadow rate. Adam Smith (19) called it the natural rate. The concept is principally applicable to ships in the bulk trades, particularly where free-market economic conditions are allowed to exist.

What constitutes a reasonable level of profitability is hard to say. Under United States economic conditions, a steamship 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 yield on total capital of from 10 to 15 percent. Captive fleets, with secure sources of income, might favor the lower figure; common carriers might favor the higher. (See Reference 13 for further details with respect to levels of profitability considered appropriate by United States 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 20 percent.

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 may be applied to the PV, AAC, or RFR criteria. The mathematics are exactly the same but the logic (and usually the conclusions) are fundamentally different and fundamentally 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 about 20 percent, the minimum-cost-to-owner method usually uses rates of only five or six percent.)

Entry 5 in Figure 5 shows the result of an optimization study using RFR based on an all-equity investment and a yield of ten percent. The indicated optimum point is close to that indicated by DCF, using $27 per ton freight rate. The two results would have been exactly the same had the specified yield used in RFR been the same as that derived by the DCF approach.

Entry 6 in Figure 5 shows that the cost-of-service criterion leads to moderate underdesign when applied to cases where the alternatives have different income potential. When income is fixed, however, it can lead to serious overdesign. Examples of this are cited in subsequent paragraphs.

In a mid-1960's military supply ship study, the Navy asked the bidders to use two figures of merit: the discounted present value of all costs (initial and future) and an inverted variation of RFR. The latter was defined as the product of the cargo capacity times the speed divided by the discounted present value of all costs. When this criterion is applied to the optimization study of Reference 12, with a specified yield of ten percent corrected for taxes, the derived optimal horsepower is 14,500--reasonably close to the 13,900 shp indicated by RFR.

Figure 7 is a graphical presentation of the factors entering into the calculations of unit cost of service and RFR. It shows the strikingly different emphasis 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. This underscores the importance of reducing United States shipbuilding costs.

In many design problems income is unknown simply because the object under consideration is a sub-unit of an income-producing system. We can, nevertheless, often use the DCF measure of merit through the expedient of implied incomes. One approach is to consider the alternative possibility of paying someone else to provide the function for which the object is intended. A decision to invest in the object can then be weighed against the annual amounts saved by not paying another party for the service. DCF or NPV can thereby be used to optimize the design. Another approach is similar to the incremental limit variants already discussed: list the proposed designs in order of increasing first cost; then use DCF to judge the desirability of accepting the second proposal instead of the first. Repeat, comparing third to second, and so on, until the yield on the incremental investment comes down to that attainable by the overall system.

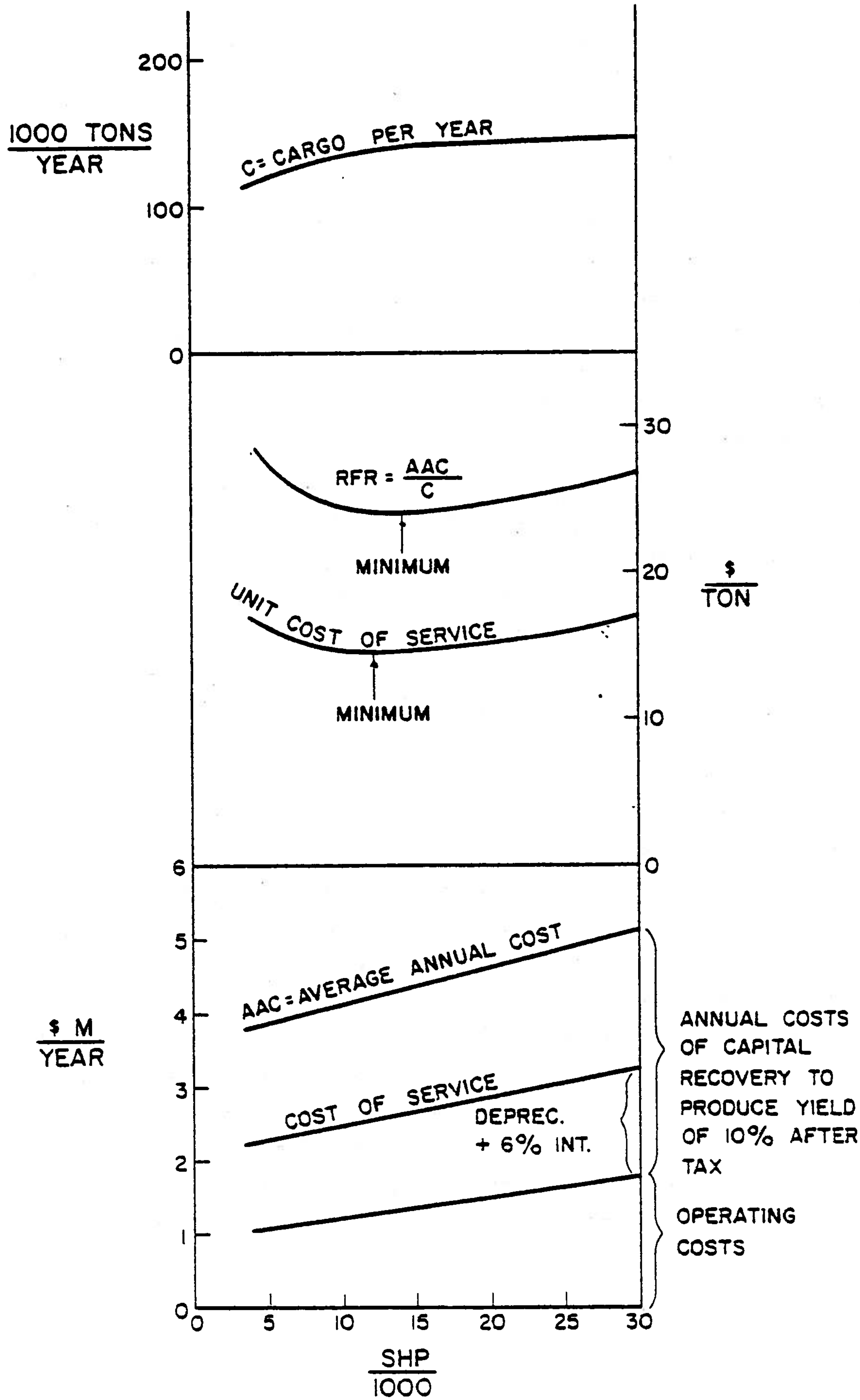


Figure 7. Factors Entering Into Unit Cost of Service and Required Freight Rate.

TAXES

The corporate income tax is essentially a hidden sales tax. That is, any change in the tax rate must eventually be reflected in a compensating change in the price of the goods or services offered. This is clearly shown in the RFR criterion. In the long run, high taxes lead to high freight rates (ignoring the alternative of bankruptcy) and high freight rates lead to higher optimal speeds--as may be seen in Figure 5--and other design parameters. For a fixed tax rate, however, we can often ignore the tax because an analysis based on before-tax returns will usually point to the same optimum as one based on after-tax returns. This is obvious if we solve Equation 6C for the after-tax capital recovery factor (which is directly related to the yield):

$$CR' = CR(1-t) + \frac{t}{N} \tag{10}$$

Since t and N are presumably the same for every alternative, the maximum values of CR' and CR are of necessity tied to the same design. If alternatives have different lives, however, this shortcut is no longer valid and conclusions should be based on after-tax returns.

The true impact of the tax is perhaps best illustrated in feasibility studies. These studies involve a proposal for a new technology (the challenger), whose advantages must be weighed against the traditional technology (the defender). In most cases the challenger will have a radically greater first cost but lower operating costs (or more income) than the defender. The time-value of money thus becomes supremely important in the comparison. Furthermore, to make the conclusions as general as possible (and in recognition of free market conditions), most feasibility studies use the RFR criterion or something equivalent. The analyst must therefore select his stipulated yield with great care; he must also recognize the effect of taxes on the annual revenue required to attain the stipulated yield.

The following cost figures are from a recent feasibility study, the technical details of which are omitted in order to keep emotions, passions, and prejudices to a minimum:

		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):

$$AAC = ACCR + Y$$

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

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 and, by implication, assuming that none of the income will be taxed. They use, in short, the cost of service 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 (4, 9, 13)

	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 straightline 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'-10%-25) = 0.1102 (from interest tables)

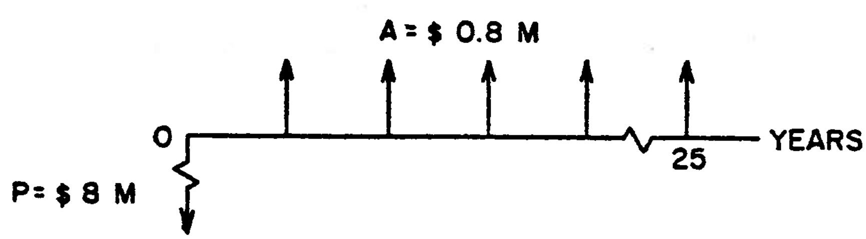
$$CR = \frac{CR' - \frac{t}{N}}{1 - t} = \frac{0.1102 - \frac{.50}{25}}{1 - .50} \qquad (6)$$

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 Congressional Record. 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:



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

$$CR' = CR\ (1-t) + \frac{t}{N} \qquad (10)$$

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

i' = 4.9% (Figure 3)

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:

$$A' = A(1-t) + t\,\frac{P}{N} \tag{11}$$

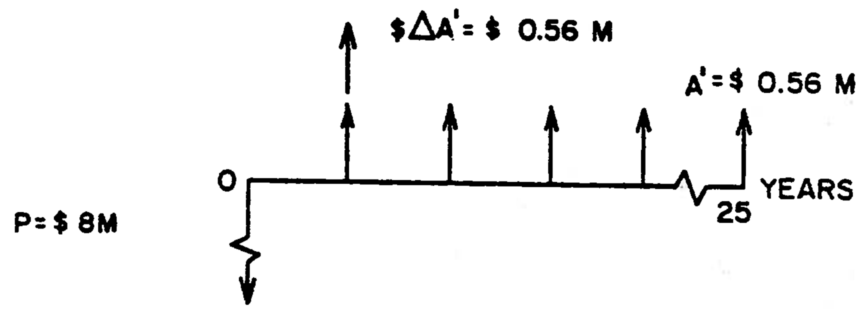
$$A' = \$0.8(0.5) + 0.5\,\frac{\$8M}{25} = \$0.56M$$

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

$$i' = 4.9\% \text{ (as before)}$$

When the seven percent* tax credit is in effect in the United States, it allows a corporation to reduce its tax by seven percent 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 seven percent credit:

$\Delta A'$ in first year = 0.07\$8M = \$0.56M. (That $\Delta A'$ 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:

$$P = (SPW\text{-}i'\text{-}25)\$0.56M + (PW\text{-}i'\text{-}1)\$0.56M$$

*The figure may vary from one year to the next. Seven percent is typical.

Let us first try $i' = 5$ percent:

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

$$\$8M = \$7.89M + \$0.53M$$

$$\$8m \neq \$8.42M$$

Error = \$0.42M

Let us next try $i' = 6$ percent:

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

$$\$8M = \$7.15M + \$0.53M$$

$$\$8M \neq \$7.68M$$

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 straightline 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 straightline depreciation. (See Reference 14 for details of this procedure.)

In summary of the above paragraphs, we can conclude that tax-reducing devices (such as the seven percent 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 investment tax credit or accelerated writeoff. Methods for analyzing cases where the tax life is shorter than the economic life are covered in Reference 15.

LEVERAGE: THE INFLUENCE OF BORROWED CAPITAL

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 posession 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. Some firms like to maintain a debt-equity ratio of about 60:40, buying in their own stock when investment opportunities are too limited to maintain that ratio (16). Another tempering factor is that the entrepreneur need pay no tax on that part of his gross income that he turns over to the bank or bondholder for interest. This, in effect, cuts his cost of borrowing about in two. To save words, from here on when we refer to bank loans, the term should be interpreted as also including the possibility of bonded indebtedness.

Reference 15 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, 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 straightline depreciation and zero disposal value. Our expressions for conditions before and after tax now become:

$$A' = A(1-t) + t\frac{P}{N} + tI_B \qquad (12)$$

and

$$CR' = CR(1-t) + \frac{t}{N} + t\frac{I_B}{P} \qquad (13)$$

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:

$$I_B = A_B - \frac{P_B}{N} \qquad (14)$$

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:

$$A_B = (CR\text{-}i_B\text{-}N)P_B \qquad (15)$$

where i_B = bank interest rate. Substituting Equation 15 into Equation 14:

$$I_B = \left[(CR\text{-}i_B\text{-}N) - \frac{1}{N} \right] P_B \qquad (16)$$

We can get a feeling for the impact of the bank interest tax credit be 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 in the paper.) 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 13:

$$CR = \frac{CR' - \frac{t}{N} - t\frac{I_B}{P}}{1 - t} \qquad (17)$$

where

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

and

$$I_B = \left[(CR - 6\% - 25) - \frac{1}{25} \right] P_B \qquad (16)$$

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

or

$$I_B = 0.0382 \times 0.6P = 0.0229P$$

so

$$CR = \frac{0.1102 - \frac{0.50}{25} - 0.50 \times 0.0229 \frac{P}{P}}{1 - 0.50} \qquad (17)$$

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

(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:

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

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

$$\Delta A' = \Delta A(1-t) + t\,\frac{\Delta P}{N} + t(\Delta I_B) \qquad (12)$$

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

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

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 3, we find $i' = 6.3\%$ (up from 4.9% without the tax credit for bank interest).

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 a slight degree. This should be apparent from the numerical examples shown in the preceding section.

In cases where income is not fixed, the added tax shield will have a neutral effect on DCF, assuming that the bank loan remains as a fixed proportion of the total investment for each alternative (which is perhaps the most common case). This can be seen by comparing Entry 8 with Entry 1 in Figure 5. If our measure of merit is RFR, we will find that the tax shield tends to reduce the optimal level of productivity by a slight amount. Entry 10 in Figure 5, for example, applies to a bank loan of 50 percent but is otherwise the same as Entry 5. The indicated point of optimality drops from 13,900 to 13,700 shp. This can be understood by returning to Figure 7. Remember that any reduction in tax will lower the average annual cost; which means that the minimum point on the RFR curve will tend to move back toward the minimum cost of service.

In cases where the income is variable and the owner's equity is fixed and the bank will lend whatever else is needed, the tax shield tends to favor the larger, faster, or otherwise more expensive ship. This can be seen by comparing Entry 12 with Entry`1 in Figure 5, which shows an approximately four percent increase in optimal horsepower and a one percent increase in optimal speed. The lower overall interest rate exaggerates the future benefits of the more productive ships. The hooker in this is that you are asking the banker to take greater risks, so that higher debt-equity ratios generally dictate higher bank interest rates.

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 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.

In any event, businessmen recognize the element of risk entailed in leverage and most of them simply aim for the same total yield irrespective of the degree of leverage. For example, a shipowner who was satisfied with an 11 percent yield on all-equity investment would probably settle for nothing less if he borrowed half the capital at 6 percent--which would mean that the yield on equity would have to be 15 percent. This is reflected in the ICC decision (17), 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'.

In view of what is outlined above, for design purposes, we would normally not take the trouble to separate the owner's returns from the total after-tax returns. In unknown income studies, we would start with the same yield regardless of leverage. In known income studies, there is little if anything to be gained from examining the yield on equity. If the bank loan is fixed percentage of the total investment, then the owner's yield (i_o or DCF_o) will point to exactly the same design as that indicated by yield on total investment (i' or DCF). Compare Entry 7 with Entry 1 in Figure 5. Where the owner's equity is fixed and the bank is willing to lend whatever else is needed at a fixed rate (which in itself is an optimistic assumption), optimizing purely on a basis of owner's yield will lead to overdesign. Compare Entry 11 with Entry 1 in Figure 5. That approach is misleading because it fails to recognize the added risks of increased leverage. None of our measures of merit is truly valid when comparing alternatives with different degrees of risk.

If we consider the net present value of the owner's investment and returns (NPV_o) we find, as before, a strong tendency toward overdesign. See Entries 9 and 13 in Figure 5. Entry 9 shows much the same results as Entry 2 because when the bank lends a fixed proportion, the owner's view always turns out to be exactly the same as that of owner plus bank.

Entry 13 (NPV_o) produces the same results as Entry 11 (DCF_o). This is expected because, with the owner's equity (P_o) fixed, NPV_o and $NPVI_o$ become directly proportional--and, as already demonstrated, $NPVI_o$ and DCF_o are also proportional.

CONCLUSIONS

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 DCF when incomes and expenses are taken to be uniform during the life of the investment.

When incomes are the same 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 the owner's desired level of profitability; it is 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.

When income can be predicted and lives are the same, decisions can 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.

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 a 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 exactly 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 will 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.

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 the most doctrinaire economists.

APPENDIX

Typical Calculations

Entries 1 and 2 with freight rate of $27 per ton; all cost are in $1000. (See Reference 12 for further details.)

Line Item and Notes						
1.* shp/1000 (arbitrary)	5	10	15	20	25	30
2.* Design speed in knots	11.2	14.1	15.6	16.6	17.3	17.8
3.* Cargo per year in 1000 tons	138.9	168.3	180.9	187.1	189.9	191.5
4.* Investment	$15,474	16,123	16,782	17,410	18,025	18,610
5.* Annual operating costs	$1,070	1,222	1,361	1,493	1,627	1,762
Assumed revenue: $27 per ton						
6. Annual revenue	$3,750	4,544	4,884	5,052	5,127	5,171
7. Annual return (Line 6 - Line 5)	$2,680	3,322	3,523	3,559	3,500	3,409
8. Deprec. allocation (Line 4 ÷ 25)	$619	645	671	696	721	744
9. Taxable (Line 7 - Line 8)	$2,061	2,677	2,852	2,863	2,779	2,665
10. Tax at 50%	$1,030	1,338	1,426	1,432	1,389	1,332
11. Cash flow (Line 7 - Line 10)	$1,650	1,984	2,097	2,127	2,111	2,077
12. CR′ (Line 11 ÷ Line 4)	.1066	.1231	.1250	.1222	.1171	.1116
13. DCF or yield: Entry 1	.0955	.1150	.1170	.1140	.1070	.1015
14. PW of cash flow @ 8%	$17,609	21,173	22,379	22,699	22,529	22,166
15. NPV @ 8%: Line 14 - Line 4: Entry 2	$2,135	5,050	5,597	5,289	4,504	3,556

* Figures from Reference 12

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