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A NAVAL ARCHITECT'S INTRODUCTION TO ENGINEERING ECONOMICS

by

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Lecture notes for intensive course in ship design economics,
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ABSTRACT

In designing a ship or offshore platform, we naval architects are heavily involved in deciding between competing proposals. For each proposal we should predict the cash flow pattern (i.e., how much cash will flow in or out of the firm and when) as a result of adopting that particular proposal. We can then consider how to select between competing alternatives based on those cash flow projections.

In going through the above, we must recognize complicating factors such as taxes, inflation, borrowed capital, and decision making in the face of an unpredictable future. While these complicating factors are dealt with rather superficially here, attention is called to more thorough treatises.

Because of the wide diversity in background of my intended audiences no effort is made to present reliable data. My aim, rather, is to help you develop an understanding of the principles involved in the use of engineering economics as an aid in making rational decisions in designing ships, offshore platforms, or other long-term capital investments.

ABBREVIATIONS

A:	A uniform annual cash flow
A':	A uniform annual after-tax cash flow
AAB:	Average annual benefit
AABI:	Average annual benefit index
AAC:	Average annual cost
ACCR:	Annual cost of capital recovery
C:	Annual transport capability
CA:	Compound amount factor
CC:	Capitalized cost
CR:	Capital recovery factor
CR':	Capital recovery factor after tax
D:	Depreciation
ECT:	Economic cost of transport
F:	A future sum of money
g:	Gradient (incremental annual amount)
i:	Annual interest rate
i':	Annual interest rate applied to after-tax cash flows; also yield on an investment
LCC:	Life cycle cost
P:	A single initial amount; also investment
PBP:	Pay back period
PV:	Present value (same as PW)
PW:	Present worth (same as PV)
N:	Number of years in future
NPV:	Net present value
NPVI:	Net present value index
Rev.:	Annual revenue
RFR:	Required freight rate
SCA:	Series compound amount factor
SF:	Sinking fund factor
SPW:	Series present worth factor
t:	Tax rate
Y:	Annual operating costs

Notes

1. (SPW-10%-5): Signifies the series present worth factor for 10 percent interest and 5 years.

   Similar arrangements are used for all the interest relationships.

2. Other abbreviations are explained where used.

CONTENTS

1. INTRODUCTION

As we make decisions about designing and operating ships, we want to make the best possible use of scarce resources. That is what economics is all about.

In simplest terms, economic analysis almost always boils down to a question of whether future cash benefits justify their initial cost. The question is simple, but the solution is somewhat less so. We cannot just add future net incomes and see if they exceed the investment. Too many complicating considerations intervene. These include:

*The time value of money
*Taxes
*Risks and uncertainty
*Inflation or deflation
*Inventory costs
*Financing methods
*Timing of payments

My intent in preparing these notes is to introduce the practicing engineer to the elements of engineering economics. Supplied with these tools and a bit of common sense, one should be able to handle all those complicating factors in weighing the relative merits of competing proposals.

In all of this, I beg you to keep in mind that the principles are clear-cut and easily understood. The analysis may look horribly complex, but it is in most cases methodically assembled from simple components. Taken one step at a time, the task is easy.

If, for example we are talking about merchant ships, everyone can agree with the dictum that (a) such a ship is a capital investment that earns its returns as a socially useful instrument of transport, and (b) the best measure of engineering success is profitability. The only trouble is that business managers cannot agree on how to define <u>profitability</u>. We shall not take sides on this issue, but explain how to derive each of the more widely accepted, logical measures of economic merit.

2. SYSTEMS ANALYSIS

Engineering economics is closely akin to <u>systems analysis</u>, an organized approach to decision making. This is a systematic way of attacking a problem, using the following dicrete steps:

*Clearly define the objective in functional terms (e.g., move coal from A to B).

*State clearly under what constraints the system is to operate (e.g., national flag requirements, classification society requirements, port and canal requirements, etc.)

*Decide on what economic measure(s) of merit are to apply, and what affecting values (e.g., tax rates) are to be assumed.

*Generate a list of all conceivable strategies for attaining the objective in the face of the constraints.

*Predict the quantitative value(s) of the measure(s) of merit likely to be attained by each of the alternative strategies.

*Append some discussion of any important influencing considerations that cannot be reduced to monetary terms (e.g., political implications).

* * *

In preparing to carry out the next-to-last step we must predict as best we can how each decision will affect the cash flowing in or out of the organization. What are the added costs, what are the future net benefits, and when will they occur?

Computers may be brought to bear if large numbers of alternatives are to be considered. Whether we use computers, hand-held calculators, or backs of envelopes, however, one rule applies: The decision will be made by some person, or group of persons, and will <u>not</u> hinge simply on the best numerical projection of some measure of merit. Like nearly all else in our business, there is art as well as science in this. Indeed -- and roughly speaking -- the more important the decision the greater is the reliance upon art. That is what makes ship design so fascinating.

Until relatively recent years naval architects and marine engineers were not instructed in practical economics as part of their formal education. As an unfortunate result, most of the big and important studies bearing on ship* design were (and often still are) made by accountants. I refer to this as unfortunate. Accounting is an admirable and necessary profession. Those reared in its complexities are not, however, ideally suited to the task of analyzing alternative design proposals -- at least not by themselves. Accountants of course do not pretend to understand the technical matters involved in ship design. More than that, they are trained to look back, not ahead, and they allow the arbitrary strictures of bookkeeping rules to distort their thinking. Three examples:

*Accountants tend to ignore lost-opportunity costs because they are not entered in the books.

*Accountants tend to treat imaginary depreciation costs as though they actually existed.

*Accountants normally accept money at face value just as though inflation did not exist.

Wise ship design decisions require teamwork between engineers, business managers, and operating personnel.

Three additional observations are pertinent at this point:

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*Although these notes were prepared with ships in mind, the principles are also applicable to offshore platforms or other long-term engineering projects.

*Decisions are between alternative opportunities. In making comparisons, concentrate your attention on assessing those cost factors that would be different between the alternatives. Ignore past history except as an aid in predicting the future.

*Since much guess work is involved in predicting future conditions, cost projections are bound to be crude. Moral: do not carry computations beyond three or, at most, four significant figures.

*Most engineering decisions should be made on a basis of simple economic analysis. Prudent business managers usually select their options, and decide yes or no, on straightforward economics. Only after that will they seek the best method of financing. By that time, however, the big design decisions have been made. In short, do not adulterate your economic studies with confusing financial intricacies.

3. TIME VALUE OF MONEY

Money does you no good until you exchange it for immediate personal needs or desires. Human nature being what it is, we almost invariably prefer to have our needs or desires met as soon as possible. This means that a given amount of cash that exchanges hands today is more important than the same amount of cash exchanging hands in the future. This is a natural, human trait and one that must be recognized if we are to make proper decisions in satisfying human needs -- which is, after all, the central aim of engineering.

In more mundane terms, a sum of money in the hand today need not be spent, but could be put to work and allowed to generate rent money (i.e., interest). In so doing you have sacrificed the goods or services you could have acquired today in the hope of acquiring more or better in the future. Again, the concept is solidly based on human instincts and refutes those who claim to see evil in profitable enterprises.

We come, then, to a fundamental concept of economics: We must consider not only <u>how much</u> money flows in or out of an organization, but <u>when</u>.

The preceding paragraphs have explained, qualitatively, why we must assign some time value to money. We must also consider relative risks, recognizing that expectations may or may not be fulfilled. Riskier proposals naturally place greater emphasis on the time value of money.

Inflation is an altogether different matter that will be dealt with separately. See Section 13.

The quantitative recognition of time value of money is handled by means of standard compound interest formulas. I assume you are at least vaguely aware of these, and I shall make no attempt to prove the relationships. See References 8, 14, or 20 if you are curious.

We can think about interest in three distinct forms, although the mathematics remain the same regardless. The three forms are:

*Some contractural arrangement, such as the interest rate (and frequency of falling due) agreed upon before you borrow money from a bank.

*Lost opportunity costs, such as the potential gains rejected when you hoard cash, or fail to invest in a profitable enterprise when the chance is yours.

*Internally generated cash from a profitable enterprise, sometimes called yield.

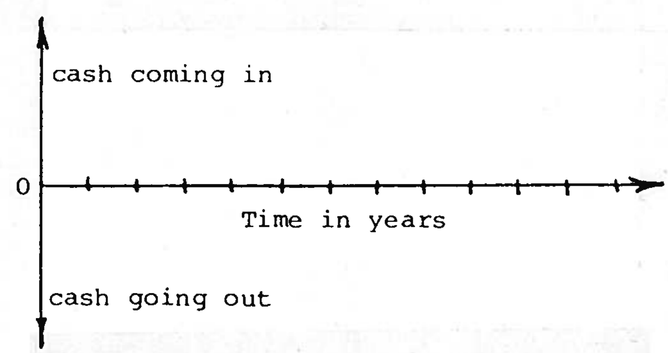
Interest relationships are used to weigh the relative merits of cash flows that occur at different times. A basic concept here is to equate a future cash flow to an equivalent amount right now. We call this imaginary immediate figure present worth, PW , or present value, PV . To find it, we discount the future amount by a factor that is affected by (a) the time value of money (i.e., interest rate), and (b) the remoteness of the event. The mathematics of this are easy, as explained in Section 5.

4. STANDARDS

Before discussing interest relationships we should understand a few standard assumptions and abbreviations. These are common to most engineering economy studies, although variations do exist.

Assumption number one is that all cash flows occur on the last day of the year. This assumption simplifies our mathematics. Although in fact cash may change hands almost continuously, any errors that result from our simplifying assumption are likely to be common to all alternatives under study. Common errors are neutral in their effects on decision making.

To help us visualize the amount and timing of cash entering or leaving the organization, we frequently use what we call a cash flow diagram. Time is represented on the horizontal scale. Annual cash amounts are shown on the vertical scale.



Zero on the time scale can be arbitrarily selected. It may mean:

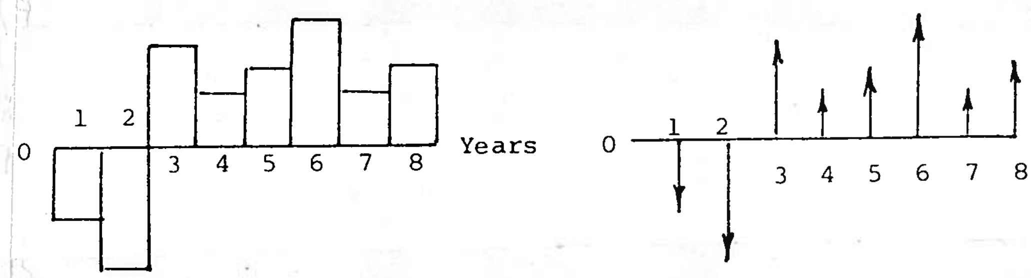
Now,

Time of decision,

Time when unit goes into service,

Etc.

Cash flows may be represented by bars or by arrows:



In the above, each end-of-year arrow represents the amount of cash that flowed in or out during that year.

Where annual cash flows are uniform we may use this convention:

Numerical values of the compound interest relationships will hinge on (a) the interest rate per compounding period and (b) the number of compounding periods. Under our assumption of year-end cash flows, we are talking about annual interest rates, i , and number of years, N . One standard shorthand method for specifying i and N is shown by this example. Suppose we are talking about the present worth factor for 12 percent interest and 15 years. We show it thus:

(PW-12%-15)

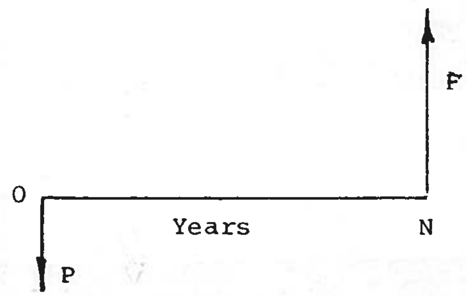
On occasion, in order to save time and space, we may append the numerical value, which in this case happens to be 0.1827:

(PW-12%-15)0.1827

This can be interpreted as, "the present worth factor for 12 percent annual interest and 15 years, which has a numerical value of 0.1827..."

5. INTEREST RELATIONSHIPS

5.1 Single Amounts



Here we have the basic relationship between a single amount at time zero and another single amount N years in the future.

$$F = (CA\text{-}i\text{-}N)P \quad (1)$$

and

$$P = (PW\text{-}i\text{-}N)F \quad (2)$$

where

F = future amount

P = present amount, principal, present worth, or present value

CA = compound amount factor

PW = present worth factor

Our algebraic relationships are:

$$(CA\text{-}i\text{-}N) = (1+i)^N \quad (3)$$

$$(PW\text{-}i\text{-}N) = \frac{1}{CA} = \frac{1}{(1+i)^N} \quad (4)$$

I shall assume that you own a programmable pocket calculator and so have no need for interest tables. If that is not the case, see References 8, 14, or 20.

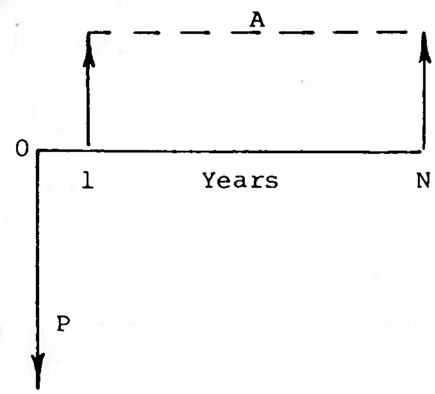
NOTE: In all of these cases, the cash flow arrows could be reversed without changing our relationships.

Here is a numerical example: Find the present worth of an expected $1000 payment 15 years in the future using an interest rate of 12 percent:

$$PW = (PW\text{-}12\%\text{-}15)0.1827\ \$1000 = \$182.70$$

5.2 Uniform Periodic Amounts

In many economic projections we assume uniform annual cash flows. We know that uniformity will not really occur, but we are unable to predict the ups and downs with any degree of accuracy. Again, any errors that result from this assumption are likely to be the same for all alternatives. If we also assume a single invested amount made on the day before the unit enters service, we have this common cash flow pattern:



If we know the amount of the investment, P , and want to find the corresponding uniform annual amount, A , we use the capital recovery factor, CR :

$$A = (CR\text{-}i\text{-}N)P \qquad (5)$$

Conversely, if we know the uniform annual amount and want to find its present worth, we use the series present worth factor, SPW :

$$P = (SPW\text{-}i\text{-}N)A \qquad (6)$$

The algebraic values are:

$$(CR\text{-}i\text{-}N) = \frac{i(1+i)^N}{(1+i)^N-1} \qquad (7)$$

$$(SPW\text{-}i\text{-}N) = \frac{1}{(CR\text{-}i\text{-}N)} = \frac{(1+i)^N-1}{i(1+i)^N} \qquad (8)$$

Here is a numerical example: A $1000 loan is to be repaid over a 10-year period with an interest rate of 15 percent. Find the annual payments.

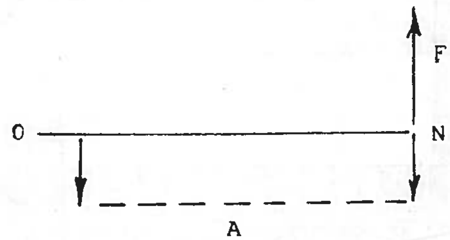
First use Equation 7 to find the capital recovery factor:

$$(CR\text{-}15\%\text{-}10) = \frac{i(1+i)^N}{(1+i)^N-1} = \frac{0.15(1.15)^{10}}{(1.15)^{10}-1} = 0.1993$$

$$A = (CR\text{-}15\%\text{-}10)P \qquad (5)$$

$$A = 0.1993\ \$1000 = \$199.30$$

We may also have a pattern in which uniform annual amounts are matched against a single future amount, F . If we know the uniform amounts, A , and want to find the future amount, F , we use the series compound amount factor, SCA :



$$F = (SCA\text{-}i\text{-}N)A \tag{9}$$

Conversely, if we know the future amount and want to find the corresponding uniform annual amounts, we use the sinking fund factor, SF :

$$A = (SF\text{-}i\text{-}N)F \tag{10}$$

The algebraic values are:

$$(SCA\text{-}i\text{-}N) = \frac{(1+i)^N-1}{i} \tag{11}$$

$$(SF\text{-}i\text{-}N) = \frac{1}{(SCA\text{-}i\text{-}N)} = \frac{i}{(1+i)^N-1} \tag{12}$$

Here is a numerical example. Find the uniform annual amounts you will need to bank at 10 percent interest in order to withdraw \$1000 in 5 years.

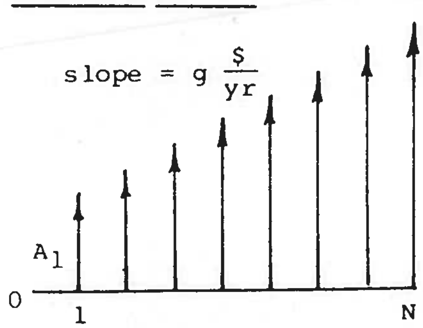
Our first step is to use Equation 12 to find the sinking fund factor:

$$(SF\text{-}10\%\text{-}5) = \frac{i}{(1+i)^N-1} = \frac{0.10}{(1.10)^5-1} = 0.1638$$

Then:

$$A = 0.1638\ \$1000 = \$163.80$$

5.3 Gradient Series



We may be able to predict a cash flow pattern showing a uniformly increasing amount, g , per year. The equivalent uniform annual amount of such a cash flow can be found as follows:

$$A = A_1 + \frac{g}{i} - \frac{Ng}{i}(SF\text{-}i\text{-}N) \tag{13}$$

The present value of the series can then be found using the series present worth factor based on the same values of i and N .

If the pattern shows a uniform downward slope, then the equivalent uniform amount will be:

$$A = A_1 - \frac{g}{i} + \frac{Ng}{i}\,(SF\text{-}i\text{-}N) \qquad (14)$$

Here is a numerical example: Find the present worth of a cash flow that starts at $1000 the first year and then increases by $200 per year for anothe 4 years (i.e., g = $200 and N = 5). Use 15 percent interest.

First find the sinking fund factor from Equation 12:

$$(SF\text{-}15\%\text{-}5) = \frac{i}{(1+i)^N-1} = \frac{0.15}{(1.15)^5-1} = 0.1483$$

Then apply the equation for an increasing gradient series:

$$A = A_1 + \frac{g}{i} - \frac{Ng}{i}\,(SF\text{-}i\text{-}N) \qquad (13)$$

$$A = \$1000 + \frac{\$200}{0.15} - \frac{5\ \$200}{0.15}\,(0.1483)$$

$$A = \$1345$$

To find the present worth, first find the series present worth factor from Equation 8:

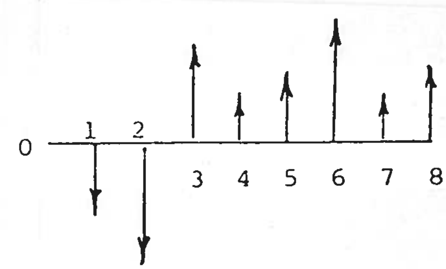
$$(SPW\text{-}15\%\text{-}5) = \frac{(1+i)^N-1}{i(1+i)^N} = \frac{(1.15)^5-1}{0.15(1.15)^5} = 3.352$$

Then:

$$P = 3.352\ \$1345 = \$4508$$

5.4 Random Series

To find the present worth of an irregular cash flow you must discount each amount individually to time zero and then find the cumulative present value. This cumulative amount can be converted to an equivalent uniform annual amount using the capital recovery factor. Such computations are best shown in tabular form.



As a numerical example, let us check the values of P and A found in the gradient problem that we solved a moment ago. Table 1 shows the step-by-step procedure.

TABLE 1

GENERAL SOLUTION FOR PRESENT WORTH AND
EQUIVALENT UNIFORM ANNUAL AMOUNT

Year N	Cash Flow	(PW-15%-N) $\frac{1}{(1.15)^N}$	PW
1	$1000	0.8696	$869.60
2	$1200	0.7561	$907.32
3	$1400	0.6575	$920.50
4	$1600	0.5718	$914.88
5	$1800	0.4972	$894.96
			P = $4507.26

(This compares with $4508 found before)

To find A , first find CR from Equation 7:

$$CR = \frac{i(1+i)^N}{(1+i)^N-1} = \frac{0.15(1.15)^5}{(1.15)^5-1} = 0.2983$$

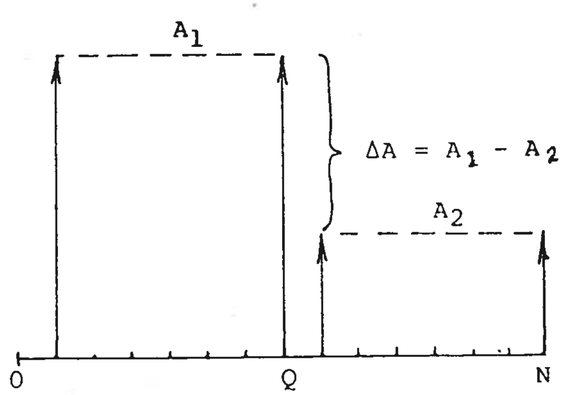
Then:

$$A = 0.2983 \ \$4507.26 = \$1345$$

(This agrees exactly with the value found before.)

5.5 Stepped Cash Flows

We frequently find cash flow patterns that exhibit a step up or down (or perhaps several such steps). There are alternative ways to find the present worth. Perhaps the easiest to understand is to:



a) Find the present worth of A_2 for N years, then
b) Add the present worth of ΔA for Q years:

In short:

$$PW = (SPW\text{-}i\text{-}N)A_2 + (SPW\text{-}i\text{-}Q)\Delta A \tag{15}$$

5.6 Non-Annual Compounding

If interest payments fall due at intervals other than once a year, all of our basic interest relationships still hold true. Simply treat i as the interest rate per compounding period and N as the total number of compounding periods involved. Be warned, however, that monthly compounding at one percent per month places a higher time value on money than does 12 percent compounded annually. References 14 and 15 explain the mechanics of relating various compounding periods.

6. TAXES

Most traditional maritime nations impose an annual tax on corporate earnings. Typical tax rates range from 40 to 50 percent of the before-tax cash flow minus certain tax shields. Notable among the latter is the depreciation allocation, D. In its simplest form (which we call straight-line depreciation), the annual allocation remains constant and is taken as the invested cost, P, divided by the anticipated money-earning life, N:

$$D = \frac{P}{N} \tag{16}$$

Figure 1 shows the distribution of cash based on this simple definition of depreciation, assuming that no other tax shields are in effect. This leads to the following relationship between cash flows before and after tax:

$$A' = A(1-t) + t\frac{P}{N} \tag{17}$$

or

$$A = \frac{A' - t\frac{P}{N}}{1-t} \tag{18}$$

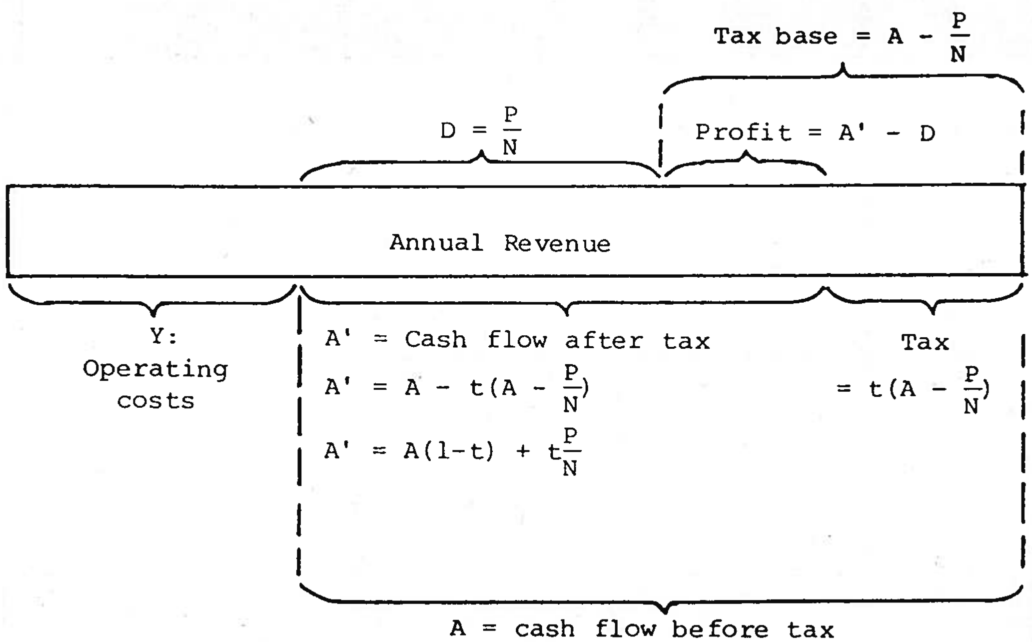


Figure 1: Distribution of Cash Assuming Straight-line Depreciation and No Other Tax Shields

These relationships can be extended to assessing the benefit of an incremental investment intended to reduce operating costs without affecting revenues:

$$\Delta A' = \Delta Y(1-t) + t\,\frac{\Delta P}{N} \tag{19}$$

where

$\Delta A'$ = incremental gain in cash flow after tax
ΔY = annual saving in operating cost
ΔP = incremental investment.

An important fact to note is that the measures of merit that we shall discuss later are all based on the after-tax cash flow (A') and <u>not</u> on profit (A'-D). Profit is misleading in that it distorts the question of <u>when</u> the cash changes hands.

There are many complications that we could explore with respect to taxes. These include other depreciation plans, tax credits, tax deferral schemes, and the tax shields often associated with fixed interest payments on borrowed capital. As implied in the section on Systems Analysis, however, most engineering decisions are based on the simple concepts embodied in Figure 1. Business managers will almost certainly apply more complex tax and financial arrangements, but not until after they have made their technical decisions based on the simple straight-line, all-equity (i.e., no borrowed capital) approach. For details see Reference 8.

Here is a numerical example in illustration of the simple concept explained above. A fuel-saving device is expected to save $75,000 per year over the ship's remaining life of 7 years. It will add $3000 per year to maintenance costs and $2000 per year to insurance costs. The tax rate is 40 percent. If the owner's time value of money is 9 percent, how much should he be willing to pay for the device, fully installed?

Our first step will be to find the net annual gain before tax: ΔA

$$\Delta A = \$75,000 - \$3000 - \$2000 = \$70,000$$

Next, we convert that to the after-tax level using a variation on Equations 17 and 19:

$$\Delta A' = \Delta A(1-t) + t \frac{\Delta P}{N} \qquad (20)$$

$$\Delta A' = \$70,000(1-0.40) + 0.40 \frac{\Delta P}{7}$$

$$\Delta A' = \$42,000 + 0.0571\Delta P$$

To find how much the owner should be willing to pay (ΔP) for that annual gain, we simply find its present worth. First we shall need to use Equation 8 to find the series present worth factor for 9 percent interest and 7 years:

$$(SPW\text{-}9\%\text{-}7) = \frac{(1.09)^7}{0.09(1.09)^7} = 5.033$$

$$\Delta P = 5.033\ \Delta A'$$

$$\Delta P = 5.033\ (\$42,000 + 0.0571\Delta P)$$

$$\Delta P = \$211,400 + 0.2874\Delta P$$

$$0.7126\Delta P = \$211,400$$

$$\Delta P = \$296,700, \text{ say } \$300,000.$$

That is the maximum amount the owner should be willing to pay.

7. MEASURES OF MERIT

My purpose here is to define the more commonly used, valid measures of merit in ship design. I shall not present an exhaustive discussion of their relative virtues, nor shall I take time to show what is wrong with various other misleading criteria with which our technical literature is infested. References 2, 4, 6, 7, 9, 12, and 13 discuss these matters in detail, for those of you who are interested.

Any valid 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 2 illustrates this.

TABLE 2

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	LCC, CC, RFR, ECT

In this table, the abbreviations stand for:

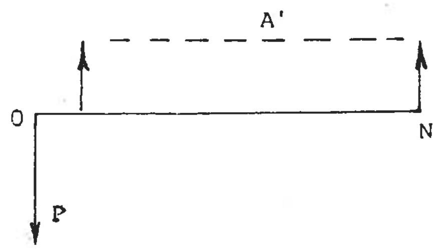
NPV: Net present value
NPVI: Net present value index
AAB: Average annual benefit
AABI: Average annual benefit index
CR: Capital recovery factor before tax
CR': Capital recovery factor after tax
PBP: Pay-back period
AAC: Average annual cost
LCC: Life cycle cost
CC: Capitalized cost
RFR: Required freight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

See text for definitions.

The rest of this section is given over to presenting bare-bone definitions of the measures of merit shown in Table 2.

7.1 Net Present Value and Its Derivatives

Net present value, NPV , is one of the most widely accepted and easily understood economic criteria in use today. It requires an estimate of future revenues and the assignment of an interest rate for discounting future cash flows. The discount rate is usually taken as the minimum rate of return acceptable to the business managers. As implied by its name, NPV is simply the present value of the projected after-tax cash flow, including the investments.



In the simple cash flow pattern shown above,

$$NPV = (SPW\text{-}i'\text{-}N)A' - P \tag{21}$$

Net present value has two inherent weaknesses: It tends to favor massive investments and it can be misleading if alternatives have different lives. The first weakness may be overcome by using the net present value per dollar of investment. We call this the net present value index (NPVI) or profitability index:

$$NPVI = \frac{NPV}{P} \tag{22}$$

If alternatives have different lives, NPV will tend to favor the longer lived. That distortion can be eliminated by multiplying each NPV by a capital recovery factor based on the same discount rate, but appropriate to the individual life expectancies. We call this criterion the average annual benefit, AAB :

$$AAB = (CR\text{-}i'\text{-}N)NPV \tag{23}$$

If we take the AAB per dollar invested, that will eliminate both weaknesses in the use of NPV . We call this third variation the average annual benefit index, AABI :

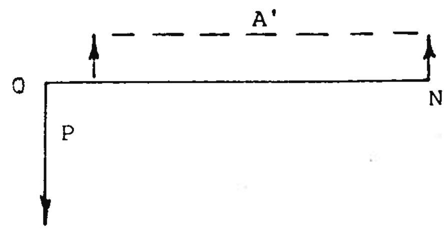
$$AABI = \frac{AAB}{P} \tag{24}$$

7.2 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.

Like NPV , yield requires a prediction of future revenues. Rather than assigning an interest rate, however, yield asks you to find that rate that will make the present worth of future after-tax cash flows equal to the present worth of the investments. In short, yield is that interest rate that leads to an NPV of zero.

If the cash flow pattern is complex, we are forced to use trial-and-error to find yield. In simple patterns, however, there is an easier way.



Given the simple pattern shown above, we can base yield on the after-tax capital recovery factor, CR' :

$$CR' = \frac{A'}{P} \tag{25}$$

Figure 2 can be used to convert CR' to interest rate, i' , or yield.

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. This is particularly true where the attainable yield differs markedly from the organization's actual time value of money. See Reference 2 for a fuller explanation.

If all alternatives have equal lives, then an examination of Figure 2 will show that the alternative with highest value of CR' will automatically have the highest yield. Moreover, the alternative with the highest capital recovery factor before tax (CR) will normally enjoy the highest capital recovery factor after tax (CR'). This means that CR may be a surrogate for yield.

$$CR = \frac{A}{P} \tag{26}$$

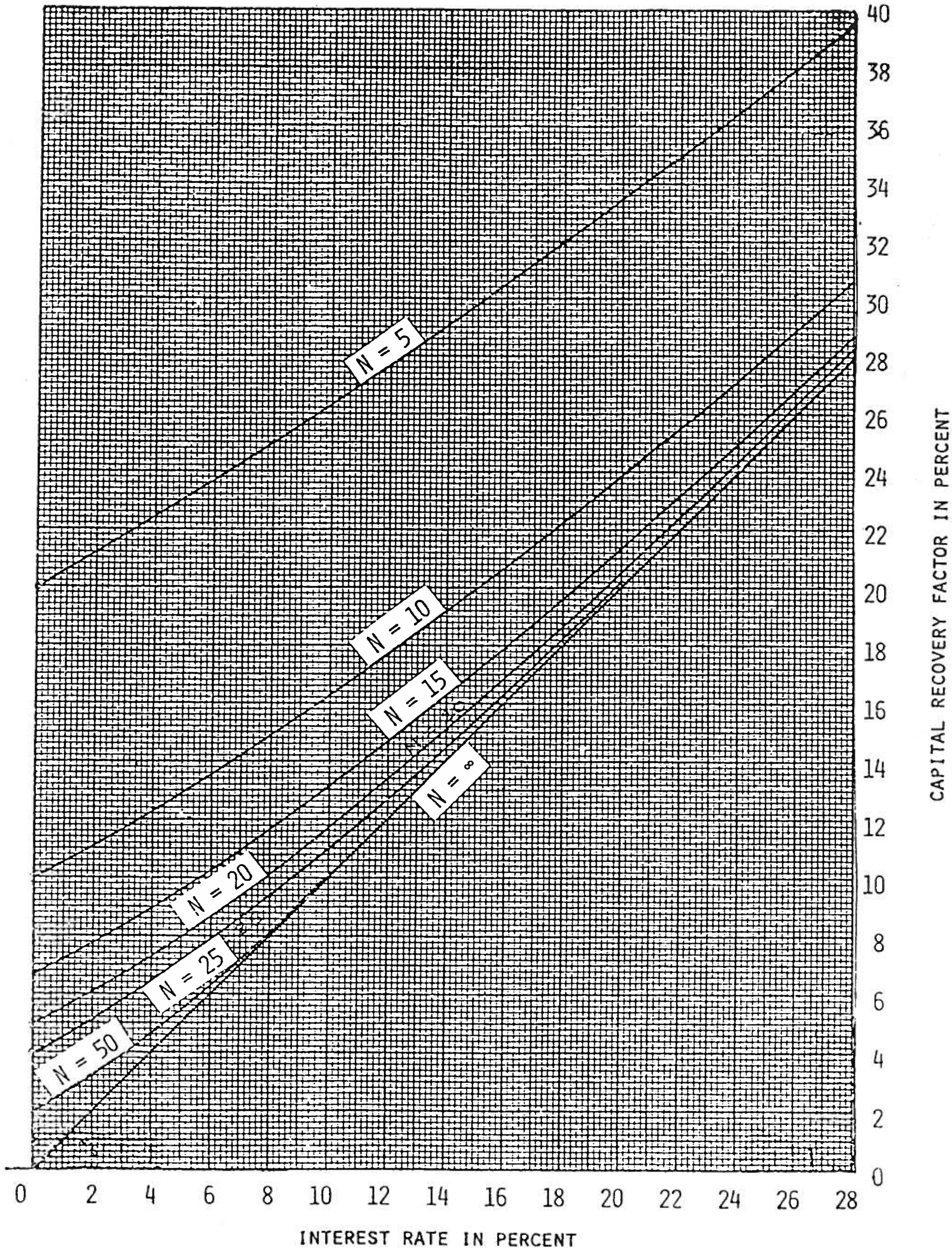


Figure 2. Capital Recovery Factor Versus Interest Rate

The truth of the above assertion is shown next. Recalling Equation 17:

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

Dividing through by the investment, P :

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

but

$$\frac{A'}{P} = CR' \tag{25}$$

and

$$\frac{A}{P} = CR \tag{26}$$

so

$$CR' = CR(1-t) + \frac{t}{N} \tag{27}$$

and

$$CR = \frac{CR' - \frac{t}{N}}{1-t} \tag{28}$$

Since t and N are the same for all alternatives, CR will vary directly with CR' which will, in turn, vary with the yield, i' .

Another surrogate for yield is the pay-back period, PBP , the number of years required to regain the initial investment:

$$PBP = \frac{P}{A'} \tag{29}$$

As is clear, PBP is the reciprocal of the capital recovery factor after tax, CR' . As such, it shares that criterion's strengths and weaknesses.

Let me stress that these surrogates for yield will be misleading unless all alternatives have equal lives and the standard, simple cash flow pattern (as shown on page 14) holds true. Other assumptions implied in that cash flow pattern are as follows:

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-value 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. You will find in dealing with many accountants 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.

7.3 The Nexus Between Yield and NPV

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

$$NPVI = \frac{NPV}{P} \qquad (22)$$

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-i'-N)CR' - 1 . (30)

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 explain a peculiarity 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 .

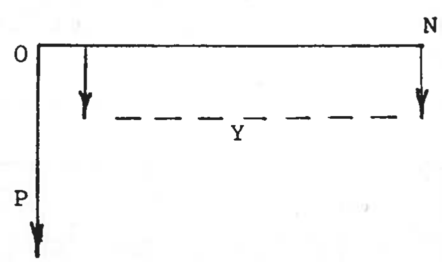
Equation (30) may upon reflection seem rather anomalous. Since SPW and CR are normally thought of as reciprocals, you might conclude that NPVI should always come out equal to zero. That is not the case, however, because as here defined CR' is derived (A'÷P) while SPW is based on an assigned interest rate, and the two will seldom be reciprocals.

7.4 Average Annual Cost

Average annual cost, AAC , is defined as that uniform annual cash flow that is equal in present value to some non-uniform pattern of largely negative cash flows. It usually looks only at investments and operating costs, ignoring revenues. If all alternatives have equal revenues (which includes the possibility of that being zero), then the one with minimum AAC will be the most desirable provided all are of equal capability.

The interest rate used in these calculations is usually taken as some target rate. This would normally be a few percentage points higher than the minimum acceptable rate used in NPV .

In its simplest form, our pattern of costs will be:



AAC = (CR-i-N)P + Y (31)

The expression (CR-i-N)P is called the annual cost of capital recovery, ACCR . Note that it is based on before-tax interest rates (in case revenues and taxes are both involved). To find CR , we start with the owner's target yield, i' , use that to find CR' (see Equation 7) and then convert that to CR by means of Equation 28.

In more complex cash flows, simply find the present value of the entire cash flow and multiply that by a capital recovery factor based on the same interest rate and for a number of years equal to the unit's life span.

7.5 Derivatives of Average Annual Cost

The present value of the entire cash flow, mentioned just above, is another useful criterion. It is usually called the life cycle cost, LCC . This criterion is closely akin to AAC :

$$LCC = P + (SPW\text{-}i\text{-}N)Y \qquad (32)$$

or:

$$LCC = (SPW\text{-}i\text{-}N)AAC \qquad (33)$$

Life cycle cost suffers one disadvantage in comparison to AAC in that it may be misleading if alternatives have unequal lives. That can be overcome by the use of the capitalized cost, CC , criterion. In this approach we assume an endless replication of each cash flow pattern and find the present worth of providing such a perpetual service:

$$CC = (SPW\text{-}i\text{-}\infty)AAC \qquad (34)$$

but

$$(SPW\text{-}i\text{-}\infty) = \frac{(1+i)^{\infty}-1}{i(1+i)^{\infty}} = \frac{1}{i} \qquad (35)$$

so

$$CC = \frac{AAC}{i} \qquad (36)$$

Average annual cost, life cycle cost, and capitalized cost are valid only when all alternatives have equal functional capabilities. Where capabilities differ, we must recognize those differences by taking the average annual cost per unit of capability. In a cargo ship, for example, we can find the cost per ton of cargo delivered on a given trade route. This we call the required freight rate, RFR :

$$RFR = \frac{AAC}{C} = \frac{ACCR + Y}{C} = \frac{(CR)P + Y}{C} \qquad (37)$$

where

C = annual transport capacity

This is a valuable criterion, much used in the marine industry for studying the feasibility of new engineering concepts or optimizing the details of any particular concept. It tells us, in effect, how much the shipowner must charge his customer if the shipowner is to earn a reasonable after-tax return on his investment. The theory behind RFR is that the best ship for any given service is the one that provides that service at minimum cost to the customer. Implicit here are the assumptions that (a) free market forces predominate in the trade, and (b) all competitors operate within the same frame of capital and operating costs.

In using RFR , you must remember to put capital costs on a before-tax basis. Here is a numerical example in illustration of that point.

A shipowner expects his proposed ship to carry 450,000 tons of cargo per year on a given trade route. The ship will cost $60 million and is expected to last for 20 years. Its annual operating costs will average $1.7 million. The tax rate is 42 percent. How much must the owner charge per ton of cargo if he is to earn a 12 percent yield on his investment? (Note: We shall accept all those simplifying assumptions shown on pages 16 and 17.)

To solve this problem we start by finding the after-tax capital recovery factor, CR' , corresponding to the stipulated 12 percent yield and 20-year life. Equation 7 applies:

$$(CR'\text{-}12\%\text{-}20) = \frac{0.12(1.12)^{20}}{(1.12)^{20}-1} = 0.1339$$

Then we use Equation 28 to convert CR' to CR :

$$CR = \frac{CR' - \frac{t}{N}}{1-t} = \frac{0.1339 - \frac{0.42}{20}}{1 - 0.42} = 19.47 \text{ percent}$$

Now we are ready to find how much the owner must charge, i.e., the required freight rate:

$$RFR = \frac{(CR)P + Y}{C} \qquad (37)$$

$$RFR = \frac{(0.1947)\$60,000,000 + \$1,700,000}{450,000}$$

$$RFR = \frac{\$11,680,000 + \$1,700,000}{450,000}$$

RFR = $29.74 per ton

Where valuable cargoes are involved, we may want to recognize that speed of delivery will affect the inventory cost of the goods in transit. One way to do this is to add the inventory cost per ton of cargo to the required freight rate. We call this modified value the economic cost of transport, ECT .

$$ECT = RFR + \frac{ivd}{(1-t)365} \qquad (38)$$

where

i = Interest rate reflecting cargo owner's time-value of money
v = Value of cargo, per ton, as loaded aboard
d = Days in transit

Reference 2 explains the derivation of this concept.

7.6 Comparative Results

Within the marine industry today the three leading measures of merit are NPV , yield , and RFR . Each of these criteria will usually steer us toward slightly different designs. This is largely because each uses a different time-value of money:

NPV uses a minimum acceptable rate,

RFR uses a (somewhat higher) target rate, and

Yield uses whatever rate drops out.

The three criteria will agree only when these conditions are met:

1. NPV and RFR both use the same interest rate, and

2. The revenue used in finding yield and NPV coincides with RFR .

7.7 The Incremental Approach

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 be tempered by the tax, which will in turn be tempered by a difference in the depreciation tax shield. As we showed in Section 6 (Taxes), the net annual gain, A' , from a saving in operating costs, ΔY , is:

$$\Delta A' = \Delta Y(1-t) + t\frac{\Delta P}{N} \qquad (17)$$

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 should not 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).

8. SELECTING AN INTEREST RATE

In real life, whenever an interest rate must be specified, that responsibility falls on management. On occasion, however, design engineers find it necessary to take on that task themselves. It is therefore important to develop some feeling for what prudent business managers look upon as reasonable rates. In this, we must keep clear that we are talking about numbers that have been corrected for inflation, i.e., based on constant-value dollars. (See Section 13 for comments on inflation.)

A baseline is the so-called cost of capital. For example, suppose a company raises 60 percent of its capital from the sale of common stock (i.e., equity) and the rest from bank loans. Suppose further that the company aims to earn, as a minimum, a 10 percent return on its equity and get its bank loan at 6.5 percent. Then its cost of capital is found by taking the weighted average of those amounts:

Equity:	$0.60 \times 0.10 =$	0.060
Borrowed:	$0.40 \times 0.065 =$	0.026
Cost of capital		0.086

Given that cost of capital, the typical business manager would round it up to 9.0 or 9.5 percent as his minimum acceptable rate. That would then be the number he would use in finding NPV for some minimum-risk investment. If greater risks are involved, he would assign higher rates. Be sure to note here that any investments chosen are likely to have high positive values of NPV. That implies that the actual rate achieved (i.e., yield) would exceed the cutoff rate.

Assigning the target rate used in RFR is more of an art. In theory, it is the rate that will effect a balance between supply and demand in the trade. Higher levels of profitability will attract more ships and drive down freight rates. Lower levels of profitability will see ships drawn to other trades. A yield (after tax, of course) of 10 percent is normally thought of as a minimum. In relatively risky ventures a figure of 15 percent would be easily justified.

Please be assured, all of the numbers cited above are highly debatable. Use them accordingly.

9. OWNER'S COSTS

The total investment in a ship includes not only the shipyard bill, but a highly variable increment for a variety of other costs. Reference 23 cites these approximate figures for large merchant ships (1978 dollars):

Spare parts	$600,000
Owner-furnished materials	$250,000

Plan approval	$1,000,000
Owner's supervision	$1,500,000
Administration and legal fees	$400,000
Total	$3,750,000

10. PAYMENT SCHEDULES

Remember, too, that the shipyard bill is not paid on the day before the ship starts in service. It is, rather, spread out over the entire building period -- which may be a year or two. There may be some studies in which you should recognize this reality. The principles explained in Section 5 are all you need.

Reference 23 shows some typical payment schedules.

11. LEVERAGE

Many business managers supplement their equity capital with borrowed funds, usually from a bank. This expansion of capital is referred to as leverage. Regardless of the source of these supplementary funds, they normally require periodic repayment of capital plus some fixed level of interest. These claims take precedence over dividends paid out to stockholders. This means that any significant degree of leverage adds to the stockholders' risk. This leads to the common sense conclusion that leverage, when employed, should be aimed at increasing the rate of return on equity capital commensurate with the added risk. In short, this approximate relationship should obtain:

$$f_o i_o + f_B i_B = i' \tag{39}$$

where

f_o = proportion of equity capital
f_B = proportion of borrowed capital = $1 - f_o$

i' = overall yield on total capital
Solving for i_o :

$$i_o = \frac{i' - f_B i_B}{f_o} \tag{40}$$

Suppose, for example, that a 10 percent yield is thought to be reasonable for an all-equity investment. If 75 percent of the investment is to be obtained from a bank at 7 percent interest, what should be the aimed-for yield on equity, i_o ? Applying Equation 40:

$$i_o = \frac{0.10 - 0.75 \times 0.07}{0.25} = 19\%$$

The main point of this section is that for design economics, we can usually ignore the presence or absence of bank loans. It is true that interest paid to a bank is usually treated as an operating expense, which means it is tax-free. Like those other tax advantages dealt with in Section 6, however, such gains are likely to be ignored by prudent managers in their initial economic assessments. In summary, design decisions should be based on sound economics, not finances.

12. UNCERTAINTY

We must be frank to recognize that all of our cost and income projections involve a good deal of guess-work about the future. We cannot eliminate all risks associated with those uncertainties, but there are logical ways of understanding how much risk is involved. There are also ways of making design decisions that will supposedly minimize risks. References 8, 15, 16, 17, and 22 may be consulted for help in this. You should be aware, however, that truly successful managers cannot explain exactly how they go about making decisions. Intuition clearly plays a part -- and for that there are no equations.

13. INFLATION

The continuing, world-wide deterioration in the purchasing power of paper money lends confusion to economic studies. Much of this confusion is needless. The best way to clarify your mind is to train it to think about constant-value (real) units, rather than face-value (nominal) units.

Consider the basic case where we expect all future costs (operations, taxes, and future replacement) to rise together on a common tide of inflation. Will an expectation of 20 percent inflation lead to a design decision different from an expectation of 10 percent? Let us think in constant-value terms, and assume that the owner will be allowed to let his freight rates float up with inflation. We can then easily conclude that our projected cash flows will be uniform when corrected for inflation. If that is the case we can stick to today's cost levels and apply with confidence any one of our economic criteria that assume uniform cash flows.

There is one frequent exception to the assumption of uniformly rising costs. Many governments do not recognize inflation when figuring depreciation. In constant-value terms that tax shield keeps shrinking. We can quantify this by double discounting to find its present value. The same idea can be applied to any other cost that is changing at a unique rate.

Here is an example. Find the net present value for a ship projected to cost $20 million and to produce annual revenues (in constant-value dollars, CV$) of $6 million. Annual operating costs are $1.7 million, in CV$. The tax rate is 40 percent. Expected life is 20 years. The owner stipulates a discount rate, r , of 9 percent in CV terms. The expected rate of inflation, d , is 15 percent. Inflation is <u>not</u> recognized in figuring depreciation.

To solve this, we must find the compound discount rate for those cost elements that remain constant in face-value dollars, FV$. In this case, the following rate would apply to the depreciation:

$$i = (1 + d)(1 + r) - 1 \tag{41}$$

$$i = (1.09)(1.15) - 1 = 25.35\%$$

Our expression for NPV then becomes:

$$NPV = (SPW\text{-}9\%\text{-}20)A(1-t) + (SPW\text{-}25.35\%\text{-}20)t\frac{P}{N} - P \tag{42}$$

$$(SPW\text{-}9\%\text{-}20) = \frac{(1.09)^{20}-1}{.09(1.09)^{20}} = 9.129 \qquad (8)$$

$$A = Rev - Y = \$6M - \$1.7M = \$4.3M$$

Note: M = million

$$(1-t) = (1-0.40) = 0.60$$

$$(SPW\text{-}25.35\%\text{-}20) = \frac{(1.2535)^{20} - 1}{.2535(1.2535)^{20}} = 3.902 \qquad (8)$$

$$\frac{P}{N} = \frac{\$20M}{20} = \$1M$$

$$NPV = 9.129\$4.3M\times0.60 + 3.902\times0.40\$1M - \$20M$$

$$NPV = \$5.114 \text{ million}$$

Another approach to this problem is to prepare a year-by-year table showing all cash flows in constant value terms. Use this to derive NPV , yield, or whatever measure of merit you wish. This method becomes increasing appropriate as scenarios become more complex. Examples are shown in Reference 1.

14. EXPANDED HORIZONS

Throughout this paper we have directed our thoughts to but one ship at a time. In many instances that is a valid approach. In other settings, however, optimizing a single new unit may lead to inefficiencies of the overall fleet. Or, it may lead to inefficiencies in the door-to-door transport system in which the ship is but a link.

As an example of the latter situation, consider the relationship between ships and terminals. What is good for the ship (i.e., large size) may be bad for the terminal, where great costs may be required for dredging and pier construction. Large ships, too, require large terminal storage capacity and that leads to high cargo inventory costs. See References 3 and 18.

Converting from the micro-economics of a single ship to the macro-economics of an entire fleet is seldom a precise operation. Simplifying assumptions are in order, and careful judgment is required. See References 6, 7, 11, 13 and 19.

15. FINALE

I have tried here to present the highlights of what a ship designer should know about practical economics. I have deliberately erred on the side of simplicity so as to make the principles easily understood. In most real-life settings these simple approaches are entirely adequate. Where more elaborate structures are required, these principles should still provide all the building blocks you will need. Guided by common sense and a firm resolve to keep extraneous details in perspective, you should be able to analyze even relatively complex real-life problems. There will be occasions, of course, where additional background knowledge will be required. The appended list of references and additional bibliography should provide much of what is needed.

I have made no attempt to supply factual cost information or details regarding tax structures. Those facts and figures are obviously necessary in any economic analysis. I can only urge you to develop such data on your own, and to keep them current as best you can.

Economic analysis is the vital link between engineering and business management. The naval architect or marine engineer who develops his or her cost estimating techniques and knows how to apply simple economic principles will always find useful and interesting work in the marine industry. Moreover, for the ambitious young engineer who aspires to high managerial position, engineering economics is the first sure step to success.

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