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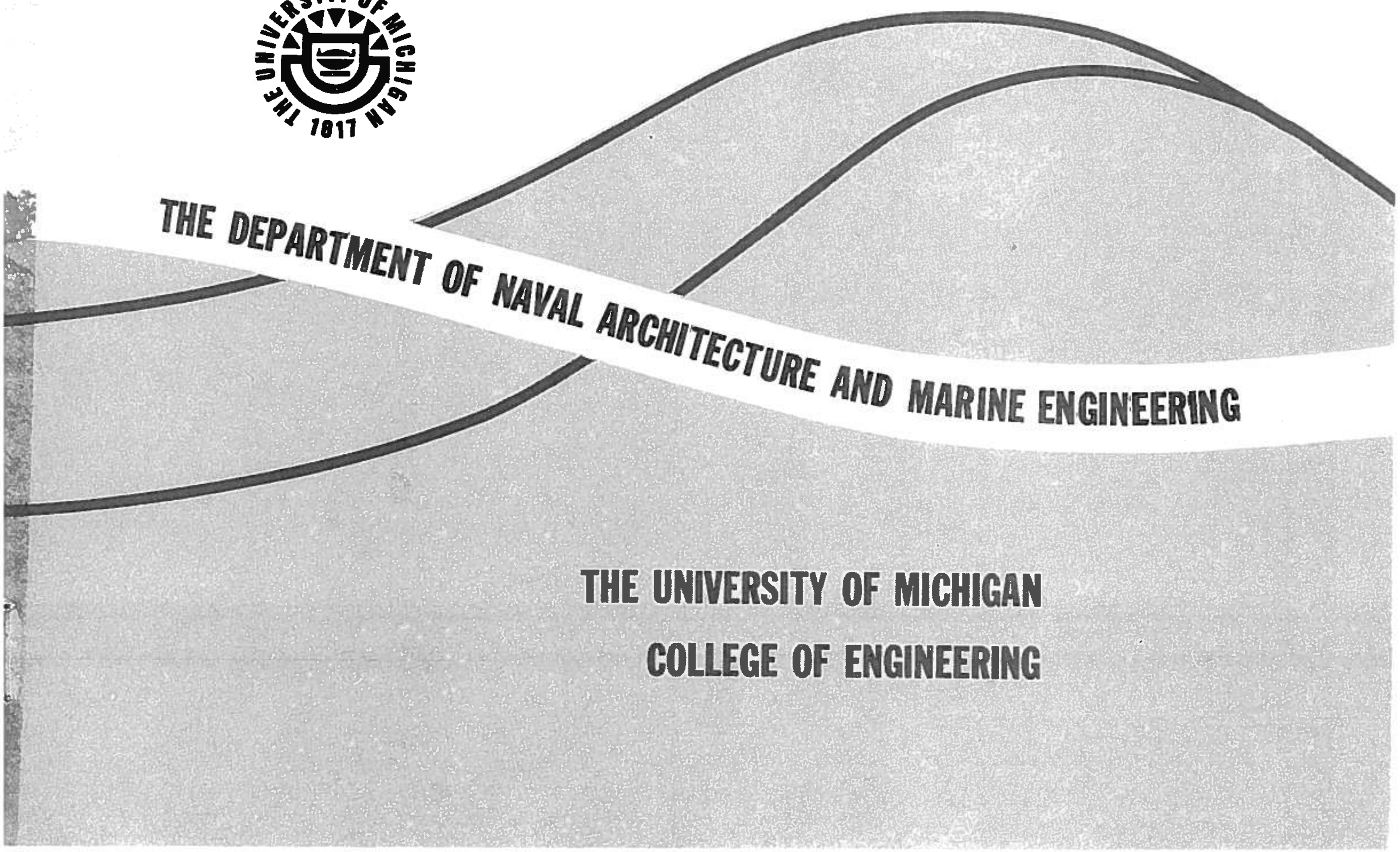
COST ESTIMATING - SHIP DESIGN AND CONSTRUCTION

Charles E. Dart



THE DEPARTMENT OF NAVAL ARCHITECTURE AND MARINE ENGINEERING

THE UNIVERSITY OF MICHIGAN
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COST ESTIMATING - SHIP DESIGN AND CONSTRUCTION

by

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AND DRY DOCK COMPANY
NEWPORT NEWS, VIRGINIA 23607
A MAJOR COMPONENT OF TENNECO TENNECO INC.

NOTE: OPINIONS AND DATA EXPRESSED IN THIS PAPER ARE THE AUTHOR'S OWN AND DO NOT NECESSARILY REPRESENT THOSE OF NEWPORT NEWS SHIPBUILDING AND DRY DOCK COMPANY

Prepared for

The University of Michigan's
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The author is indebted to many persons in the preparation of this paper. He especially wishes to acknowledge the valuable assistance provided by personnel in the Cost Engineering Department and the constructive comments offered by others in the Newport News Shipbuilding and Dry Dock Company organization.

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INTRODUCTION

Traditionally, cost estimating has been the tool the shipbuilder has used to arrive at the cost he expects to experience in the construction of a particular ship design.

In the past, and to a large degree in the present, the shipbuilder has been given the particulars of a ship design by the ship owner or the Government and he has estimated and priced the design provided him. The question of whether or not the owner or the Government has selected the most cost effective design for the intended use has not been presented to him.

This is not to state that shipbuilders engaged in ship design have not used cost estimating in the process. A certain amount of systems and component cost trade-off studies has always been conducted. On those occasions where the owner has used a shipbuilder to assist his staff in the development of a ship design, the scope and depth of these cost trade-off studies have been widened to the extent necessary to produce a more cost effective ship.

In recent years, increased emphasis has been placed on the economic value of products and systems which of necessity requires a much greater involvement of cost estimating in the ship design process. There are numerous reasons for this increase in emphasis, some of them being:

1. Competition between competing systems, i.e., pipeline vs. tanker.
2. Narrowing profit margins and the resulting difficulty in attracting and holding capital.
3. Reduction in the relative availability of capital and the resulting increase in the cost of money.
4. The continuing impact of inflation, i.e., cost escalation.
5. Erosion of labor productivity.
6. The theory of systems effectiveness, life-cycle costing and trade-off analyses given prominence by the Pentagon in weapon system procurement and adapted in varying degrees for application in other areas.
7. Foreign competition.

This emphasis on cost effectiveness is a good thing. It disciplines the engineer to consider the cost impact of his design decisions and provides a tool to make better use of resources whether these be capital, man-hours or materials.

The shipbuilder has to be involved in cost effectiveness studies because he needs to maintain his market share in the transportation area and because he is logically the best source of the data needed for the inputs to the initial investment cost. By becoming involved, the shipbuilder will be better able to improve his methods and processes of construction, and incorporate design simplifications and improved materials. As he develops expertise in this area, it is logical to assume that prospective owners will seek his assistance.

SECTION I

MARKET

The initial step in the process of cost effectiveness in ship design for commercial vessels is to determine what cargo is to be carried in what mix, in what volume, over what trade routes. In the instance of Naval vessels, one of the first steps is to determine a mission scenario, or a possible set of conditions, under which the vessels will be required to operate.

Although neither of these instances involves cost estimating for ship design per se, the determination of this information provides the foundation upon which the ship design will be based. The goal, in the case of commercial vessels, is to determine the most economical ship that will fulfill the cargo transportation needs. In the case of Naval vessels, the goal is to determine the most cost effective ship which will perform its mission under the postulated conditions and environment in which it will operate.

For commercial vessels, the ship operators are the most logical source for cargo and trade route information upon which the shipbuilder will base his design development. In addition, the shipbuilder must not ignore development of these data, for he must be constantly assessing his potential commercial markets and developing his plans to gain the share of that market which best meets his sales objectives. The shipbuilder must be alert for information as to competitive products - not in the sense that he should attempt to copy or follow them, but in the sense that technological advances cannot be ignored in cost effectiveness analyses.

For Naval vessels, the Government ordinarily formulates the requirements that must be met to fulfill the designated missions. In some cases, however, only the mission parameters are provided, and the Government leaves the determination of requirements up to the ship designer, who may or may not be a shipbuilder.

In the market of Naval vessels the shipbuilder must also keep abreast, as well as he can, with the constantly shifting threats from potential enemies so that he may be aware of what his future market will be in the types of Naval vessels likely to be constructed. Only by awareness of new and advanced weapon system development can the shipbuilder provide facilities and expertise in a timely fashion to take advantage of this market and meet U.S. defense needs.

Commercial market trade forecasts made by a ship owner presumably are based on his intimate knowledge of the trade in which he is engaged, plus his judgment as to the future effect on this trade by developments in other related areas. In addition to data from ship owners and operators, a shipbuilder making market forecasts requires access to all current published data plus any he can glean from unpublished sources. Census data is one valuable published source since they provide information on import/export tonnage, origin/destination, cargo characteristics and ship types. Published forecasts also exist on major bulk commodities such as:

Forecast of U. S. Oceanborne Foreign Trade in Dry Bulk Commodities, prepared for the U. S. Maritime Administration by Booz-Allen Applied Research, Inc., March 28, 1969.

Projections Principal U. S. Dry Bulk Commodity Seaborne Imports and Exports for 1975 and 1995, prepared for the U. S. Maritime Administration by Stanford Research Institute, February, 1969.

Oceanborne Shipping: Demand & Technology Forecast, Parts 1 and 2, prepared for the U. S. Department of Transportation by Litton Systems, Inc., June, 1968.

Analysis of World Tank Ship Fleet, prepared by the Sun Oil Company, Economics Department, December 31, 1968.

Data such as the above must be carefully analyzed for methodology and currency. Census data can be synthesized for those commodities normally classed as general cargo in order to classify the usual transportation mode, i.e., unitized, containerized, reefer, etc., and then sorted by trade routes or trading areas. The forecasts require evaluation based on the latest estimates of future economic conditions. Factors such as Gross National Product, population trends, foreign aid, quotas, balance of payment, technological changes, etc., must be considered, as applicable, to the particular trade being analyzed.

Once the market trade analysis is made by the shipbuilder, or furnished to him, cost estimating, as related to the parameters of ship design, becomes an essential element in the selection of the most cost effective ship design to answer the particular trade requirements.

SHIP OPTIMIZATION

The translation of a trade forecast or mission profile into the final ship design necessitates a ship optimization process. Various methods may be used to produce this optimization. They all have common elements which must be considered. Variations occur primarily:

1. In the selection of the criteria, or measures of merit, that will indicate which alternative ship design is the optimum,
2. In the development of and weighting given the Cost Estimating Relationships (CER's), and
3. In the construction of the life-cycle cost methodology and related computer programs used to obtain the answers.

Let us examine the conceptual methodology required in order to perform the function of ship optimization.

The first basic function of ship design which must be performed is the development of design parameters. This development of design parameters must be preceded by the market analysis or mission profile analysis previously addressed.

The Naval Architect obviously does not design a vessel which merely conforms to sound principles of engineering and which utilizes acceptable shipbuilding practices. He must develop his design to meet the purposes for which the ship is needed in the most cost effective, or mission effective, manner.

Another element essential to the process of ship optimization is derived from the market or mission analysis. This element is called the "measure of merit." In order for optimization to take place, some criteria, or measure of merit, must be developed which will form the basis of evaluation of one design versus another.

With the ship's requirement data available the designer may now begin to develop his design parameters. Parameters, such as, speed, manning, weight, length, etc., are expressed in terms of a matrix covering a range of values for specific characteristics within the limits imposed by the ship requirement analyses. For instance, speed may be a function of mission response time or of cargo type and voyage distance; whereas dimensional characteristics such as weight, or length, or cargo capacity may be constricted and determined by canal limitations, cargo type, or harbor considerations. Manning may be dictated by the owner based on union agreements.

The important point in this step is to include in each parameter matrix as complete a range of values as requirements allow, so that the ultimate optimum design will involve the consideration of maximum possible alternative designs. This results, then, in a set of matrices for various design characteristics which will yield the alternate candidate ship designs acceptable from an engineering point of view.

It should be emphasized that, at this point, cost estimating relationships are not a part of the equation. There has only been an examination of the many interrelationships between the various design characteristics. The basic gross parametric design data, which includes all possible candidate ships, are now available; and with the application of cost estimating relationships, the optimum candidate ship will emerge. The application of the many cost estimating relationships to the parameters defining the characteristics of each possible candidate ship obviously involves a mathematical exercise of monumental proportions. Consequently, a computer program must be developed and used for ship optimization.

What we have then, for each ship program, are four critical areas requiring creative development. These are:

1. Measures of Merit.
2. Life-Cycle Cost Methodology.
3. A Computer Model for computations involving design/cost sensitivities.
4. Selecting Optimum Ship Design.

MEASURES OF MERIT

Measures of merit are judgmental. They are based on many factors, including operational environment, purpose, customer demands and preferences, and economic conditions.

For commercial ship optimization, minimum life-cycle cost per ton mile (Required Freight Rate) is one very appropriate measure of merit. There is little or no difference, from the standpoint of use as a measure of merit, between required freight rates computed from:

(a) Pro forma costs for a given year, using a capital recovery factor for capital costs; and

(b) Life-cycle cost, discounted to present value,

as long as the same discount rate is used in both calculations. In the latter case, of course, the ton-miles performed each year must be discounted to present value also. Again the same discount rate must be used, since these ton-miles are a surrogate for revenue.

For Naval vessels several measures of merit are often used. For example, military effectiveness, life-cycle cost, and technical design characteristics may be used to measure the merit of a ship design. The nature of these categories is such that each must be considered individually, and their integration into a final analysis, while difficult, does provide the evaluation authority with a measure of flexibility in the selection of a design.

LIFE-CYCLE COST METHODOLOGY

Life-cycle cost is used as the discipline for estimating cost for ship design and includes the total cost of a ship from inception to retirement. It is a costing technique which focuses attention on the total cost of ownership.

Certain basic assumptions must be made in the life-cycle cost computations. These assumptions include the following:

1. Life of the vessel after delivery.
2. Learning curve for construction costs of multiple ship quantities.
3. Residual value of the vessel at the end of its life.
4. Escalation rate compounded annually to be applied to Operation and Support Costs, Voyage Costs, and Owner's Costs.
5. Present value Discount Rate to be applied to Operation and Support Costs, Voyage Costs, and Owner's Costs.
6. Base period for costs.
7. Ship utilization factor for cargo movement.
8. Trade route distances.
9. Port time.

Ship System Life-Cycle Cost Element Structure

A typical life-cycle cost element structure for a merchant ship is shown in Figure 1. Figure 5 in Section III gives a typical Naval life-cycle cost element structure. The total life-cycle cost of a commercial ship system is the summation of four (4) major cost categories. These categories are Initial Investment (100), Operation and Support (200), Voyage Costs (300), and Owner Costs (400).

The Initial Investment cost (100) includes all costs associated with the delivery of the vessel to the owner. These costs include the Hull (110), the Outfit (120), the Machinery (130), and the Auxiliary Systems (140). They will encompass the material, labor, overhead, and profit which makes up the shipbuilder's selling price to the owner.

The Operation and Support costs (200) contain the cost of operation to the ship operator. These costs include Manpower (210), Consumables (220), Maintenance and Repair (230), and Insurance and Other (240).

The Voyage Costs (300) contain those costs associated with utilization of the vessel in trade route conditions. This cost element includes the costs of Cargo Handling (310), Terminal Costs (320),

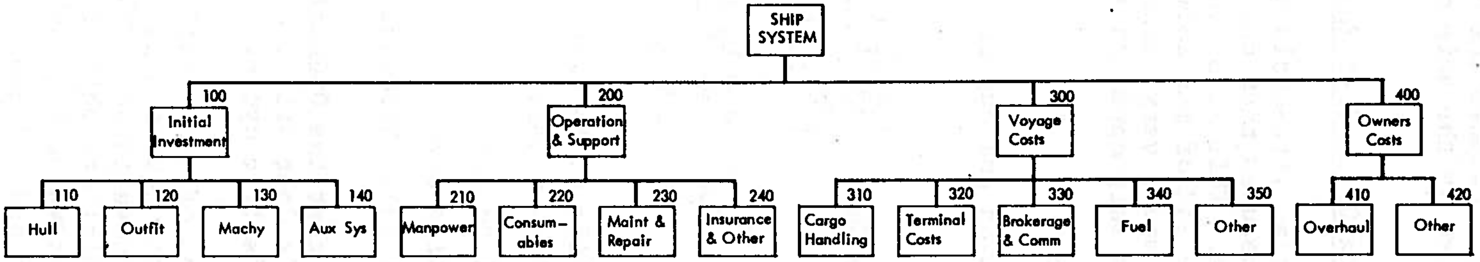

Figure 1. TYPICAL MERCHANT SHIP SYSTEM LIFE-CYCLE COST ELEMENT STRUCTURE

Brokerage and Commissions (330), Fuel (340), and other costs (350), such as canal tolls.

The Owner's Cost (400) includes the overhead cost (410) and any other costs (420) experienced by the ship operator because of the operation of the fleet.

Life-Cycle Cost Equation

Computation of the total life-cycle cost may be accomplished by the following equation, which assumes that the residual value of the ship is zero at the end of its life. This is a reasonable assumption to make, since a ship's value at the end of its normal life is usually scrap value and this scrap value would vary insignificantly between the alternatives addressed in a ship optimization program.

$$\begin{aligned} \text{LCC} = {} & \text{Investment Cost} \\ & + \text{Annual Operation and Support Cost} \sum_{n=1}^{n=L_f} \frac{(1+r_1)^n}{(1+r_2)^n} \\ & + \text{Annual Voyage Cost} \sum_{n=1}^{n=L_f} \frac{(1+r_1)^n}{(1+r_2)^n} \\ & + \text{Annual Owner's Cost} \sum_{n=1}^{n=L_f} \frac{(1+r_1)^n}{(1+r_2)^n} \quad \text{where} \end{aligned}$$

LCC = Total Life-Cycle Cost of a Ship System

L_f = Ship Life in Years

n = Year (1 to L_f)

r_1 = Escalation Rate

r_2 = Present Value Discount Rate

The equation assumes that the Operation and Support Cost, the Voyage Cost, and the Owner's Cost will occur at the same average annual rate throughout the vessel's life cycle.

The escalation portion of the equation is $(1 + r_1)^n$. The present value discount portion of the equation is $1 \div (1 + r_2)^n$. Using readily available tables, such as those found in <u>Mathematics of Finance</u> by Stephen P. Shao, PHD (see Bibliography), factors may be tabulated for both escalation and discount value for each year of a ship's life and $\sum_{n=1}^{n=L_f} \frac{(1+r_1)^n}{(1+r_2)^n}$ may be solved and used as a constant in the equation.

In addition, a different assumed ship life, escalation rate or present value discount rate can be tested for a sensitivity.

Required Freight Rate

The Required Freight Rate is calculated by the following formula:

$$RFR = \frac{LCC}{TC_A \times VM_A \times \left(\sum_{n=1}^{n=L_f} \frac{1}{(1+r_2)^n} \right)} \quad \text{where}$$

RFR = Required Freight Rate in dollars per ton-mile
LCC = Life-Cycle Cost (as previously defined)
TC_A = Tons of cargo carried per year
VM_A = Voyage miles over which cargo is carried per year
L_f = Ship Life in Years
r_2 = Present Value Discount Rate
n = Year (1 to L_f)

Again $\left(\sum_{n=1}^{n=L_f} \frac{1}{(1+r_2)^n} \right)$ may be solved by the use of present value (discount) tables. Ton-miles were introduced into this formula in order to test different trade voyage lengths. Ton-miles per year is simply the number of tons of cargo carried per voyage times the voyage distance in miles over which cargo is carried times the number of voyages per year. If it is not used, the equation would omit VM_A. As stated earlier, ton-miles must also be discounted to present value, thus the presence of the discount factor $\frac{1}{(1+r_2)^n}$. Discounting tons or ton-miles may seem odd but is sound in principle since tons or ton-miles correspond to revenue, hence the discount factor should be applied to find the present dollar value of RFR.

Cost Estimating Relationships

Using the Life-Cycle Cost Element Structure, the basic assumptions made, and the definition of each life-cycle cost element, Cost Estimating Relationships (CER's) are developed for the various elements. This is necessary in order to relate costs to the range of values of the parameters within the ship design study being investigated.

This process of development of cost estimating relationship requires the determination of the factors in the ship design, construction, and operation which, if varied, have an effect on costs. Historical data, cost returns, and ship operation data form a basis for the development of cost estimating relationships. For example, a cost estimating relationship can be developed for the machinery plant using the shaft horsepower as a basis since cost is sensitive to shaft horsepower.

Returned costs or cost estimates for several steam plant shaft horsepowers are plotted (Figure 2) with shaft horsepower being the X-axis and total price being the Y-axis. A mean line is drawn between the points plotted, producing a graphic regression line.

The equation for the regression line can be estimated directly from the plot (Figure 2) by utilizing the two point formula from analytical geometry. This formula requires only that we know the coordinates of any two points on the regression line. Choosing any two points on the line, their coordinates X_1 Y_1 and X_2 Y_2 are read directly from the plot. Using the following two point formula, which expresses the computed values of the dependent variable Y as a function of the independent variable X, an estimated equation for the line may be developed:

$$Y = Y_1 + \frac{Y_2 - Y_1}{X_2 - X_1} (X - X_1)$$

In this typical case

Y = Total price in \$ $(\times 10^6)$

X = Shaft Horsepower Max $(\times 10^{-3})$

If from Figure 2

$Y_1 = 3.92$

$Y_2 = 5.20$

$X_1 = 14.0$

$X_2 = 25.4$

Then $Y = 3.92 + \frac{5.20 - 3.92}{25.4 - 14.0} (X - 14.0)$

$Y = 3.92 + .112 (X - 14.0)$

$Y = 3.92 + .112 X - 1.568$

$Y = 2.352 + .112 X$ (this is the estimated equation for the line in Figure 2) or

Millions \$ $= .112 (\text{SHP} \times 10^{-3}) + 2.352$

Solving this equation for a particular point letting

$X = 20$

$Y = 2.24 + 2.352 =$ \$4.592 million

Further information on the use of regression analysis may be found in Managerial Economics by Spencer and Siegelman (see Bibliography).

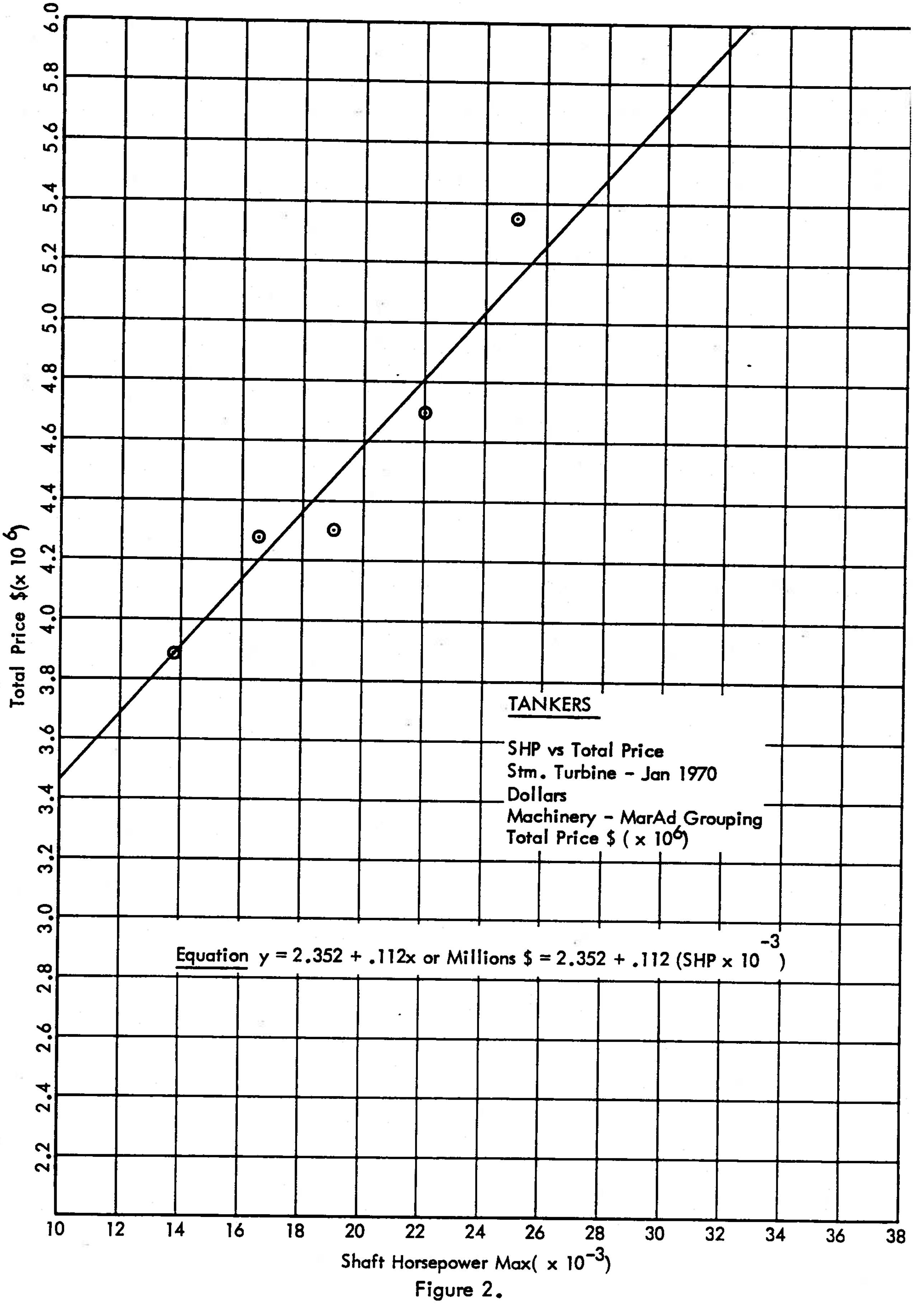
Total Price $(x 10⁶)
6.0
5.8
5.6
5.4
5.2
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
Shaft Horsepower Max(x 10⁻³)
TANKERS
SHP vs Total Price
Stm. Turbine - Jan 1970
Dollars
Machinery - MarAd Grouping
Total Price $ (x 10⁶)
Equation y = 2.352 + .112x or Millions $ = 2.352 + .112 (SHP x 10⁻³)

Figure 2.

This method may be used to develop other cost estimating relationships such as structural steel weight versus steel cost.

Once the cost estimating relationships (CER's) are established, we are ready to apply them to the ship design. It must be remembered that these relationships are only valid for the ship type for which they are developed. They will not be the same for every ship type, and variations in the design input may also require changes to the CER's used for a particular ship type. Other cost estimating functions will affect the CER's, such as the results of cost trade-off studies of systems and components which will be addressed next.

Cost Trade-Off Methodology

Much of the effort in achieving ship optimization revolves around cost trade-off studies. Various system designs and proposed component selections must be examined and decisions made as to which of several alternatives, in each instance, is most cost effective in meeting the requirements. The knowledge upon which to base such decisions comes from detailed cost trade-off studies involving thorough analysis of alternative solutions.

In order to restrict the data to a workable volume, the first step in cost trade-off study methodology is to purge the study of solutions which are not feasible and data which are unnecessary. To begin with, limits should be established within which the study will be made. For example, if the study involves power plants, then the power plant range to be considered might be limited to those plants supplying from 20,000 to 30,000 shaft horsepower. Or if the study involves hull structure, then perhaps it would be limited to two or perhaps three of the most probable fabrication and assembly methods.

Also, some limitation exists due to requirements that are outside of the designer's scope of work. For instance, the American Bureau of Shipping, the Coast Guard, and other regulatory agencies obviously set many rules and regulations which must be complied with; rules and regulations which, in effect, limit the scope of the trade-off study. We are all familiar with the recognized engineering standards which limit the use of certain materials for certain purposes. This provides another limiting factor. The customer's preferences could further limit the studies.

The designer working within constraints, such as those cited above, still must further reduce the scope of each trade-off study to a manageable volume of data. This is accomplished by his knowledge of ship requirements. Certain alternatives would obviously not be feasible from an engineering viewpoint. Others would be eliminated after preliminary engineering analysis. Some might require the further step of preliminary cost investigation before elimination. For example, on normal commercial trade routes nuclear power plants have not yet been proven to be cost effective; consequently, a trade-off study involving alternate power plants might well have nuclear power plants eliminated from consideration at the beginning. Power plants utilizing exotic fuels which are not readily available likewise would be eliminated.

Based on trade route data, the designer may decide that a certain cargo handling system would not be compatible with dock facilities existing in the trade locations serviced. It should be emphasized that this elimination process is not intended to unnecessarily restrict the trade-off study data, but rather to limit the study to a volume of data which is complete, manageable, and meaningful.

Having reduced the trade-off studies to the consideration of only that data which are considered pertinent, it is then necessary to consider which elements of information should be included in the study. Since a trade-off study may involve practically any aspect of ship design, this discussion will be limited to general terms. Even so, certain basic requirements must be considered for any type of study. If structural work is involved, for example, what choices of material are suitable? What are the strength considerations? What are the relative costs involved for various types of suitable material? If the study involves equipment, then the fuel or power consumption and the relative costs of various types of suitable fuel, if applicable, would be considered. If the equipment is not automated, then manning requirements become a factor. Analysis of the respective degrees of reliability for each item of equipment, and consideration of what degree of reliability is desirable in view of the relative costs may be required. When dealing with life-cycle costs, another very important element is that of maintenance costs. In fact, it quite often happens that maintenance costs may well outweigh initial investment costs.

Each of these detailed elements must be considered as to their effect on more general overall considerations. For example, would the weight of alternative components have a significant effect on the overall ship design? One type of cargo handling gear might well limit the cargo capacity more than some alternative approach. Effects of trade-off studies upon the speed and range of the ship must be carefully analyzed and weighed against the purposes for which the ship is intended. In the case of a cargo vessel, turn-around time might be affected by trade-off studies, and this factor might prove to be extremely significant in terms of overall ship design.

Each trade-off study should include a detailed analysis of each alternative considered, or each approach considered. The analysis should provide a detailed discussion of the pros and cons of each alternative. Sufficient design data should be included in the study to support the discussion of each alternative. The analysis of each alternative should include detailed treatment with supporting data covering all applicable life-cycle cost elements. Organization and management of the mass of data involved in a complex trade-off study would most probably involve a computerized analysis. For the usual trade-off study, however, where many of the cost elements are held constant, the use of a computer is not necessary. Each life-cycle cost element should be analyzed in detail and a cost analysis in dollar terms provided for each element as well as total life-cycle cost figures.

The final section which should be included in any trade-off study is the conclusion and recommendation. This section of the study should present a discussion of which alternatives were selected and why. The same information might be included for a second choice if considered desirable by the designer. In addition, if pertinent and not obvious from study data, an explanation should be included of why other approaches were not utilized. Cost effectiveness should be the key to the evaluation of alternative approaches in a trade-off study.

Since the naval architect already possesses extensive ship design experience, he would have knowledge of certain system parameters prior to the development of the complete parametric design data. Therefore, it is sometimes possible to conduct trade-off studies for certain major systems early in the development stage. In this case, the Cost Estimating Relationships initially developed would reflect the results of the cost trade-off studies. In other instances, the results of these studies could require modification to previously established cost estimating relationships.

Appendix A provides an example, in abbreviated form, illustrating the trade-off study concept as applied to a merchant vessel.

Multiple Ship Pricing (Learning Curves)

Since a study of this degree of depth would rarely, if ever, be undertaken for a single ship purchase, the results of a study of this nature require the pricing of multiple ship quantities. The effect of a learning curve for successive duplicate ships must be introduced into the Life-Cycle Cost Methodology.

The reduction for successive ships (learning curve) would be based on historical data available to the cost estimator plus his considered judgment on the facts relating to the particular study being addressed. The learning curve can vary with the complexity of the ship type, the facilities to be used, the production methods contemplated, the labor force to be utilized, the effectiveness of management controls, and the conditions of the marketplace for procurement of components, to name some of the more important variables involved.

The final selection of the reductions to be used for each successive ship is a matter of educated judgment which, if wrong, may result in the shipbuilder's booking a loss rather than a profit on any resulting contract.

Figure 3 depicts some typical learning curves based on production man-hours for general cargo liners. Curve A is typical of the learning curve for highly automated foreign shipyards where preproduction planning, scheduling and design for production have been intensively carried out. Curve B is typical of the learning curve for a U. S. shipyard having an experienced labor force, good management controls, good production planning and scheduling, and confining the work undertaken to that having essentially the same complexity during any one period of time. Curve C is typical of a learning curve experienced in the majority of instances by U. S. shipyards. It should be understood that curves B and C are typical. Actual learning curves for individual shipyards will vary, depending on the individual circumstances in each shipyard and on the ship type involved. In all cases, development of the design is excluded.

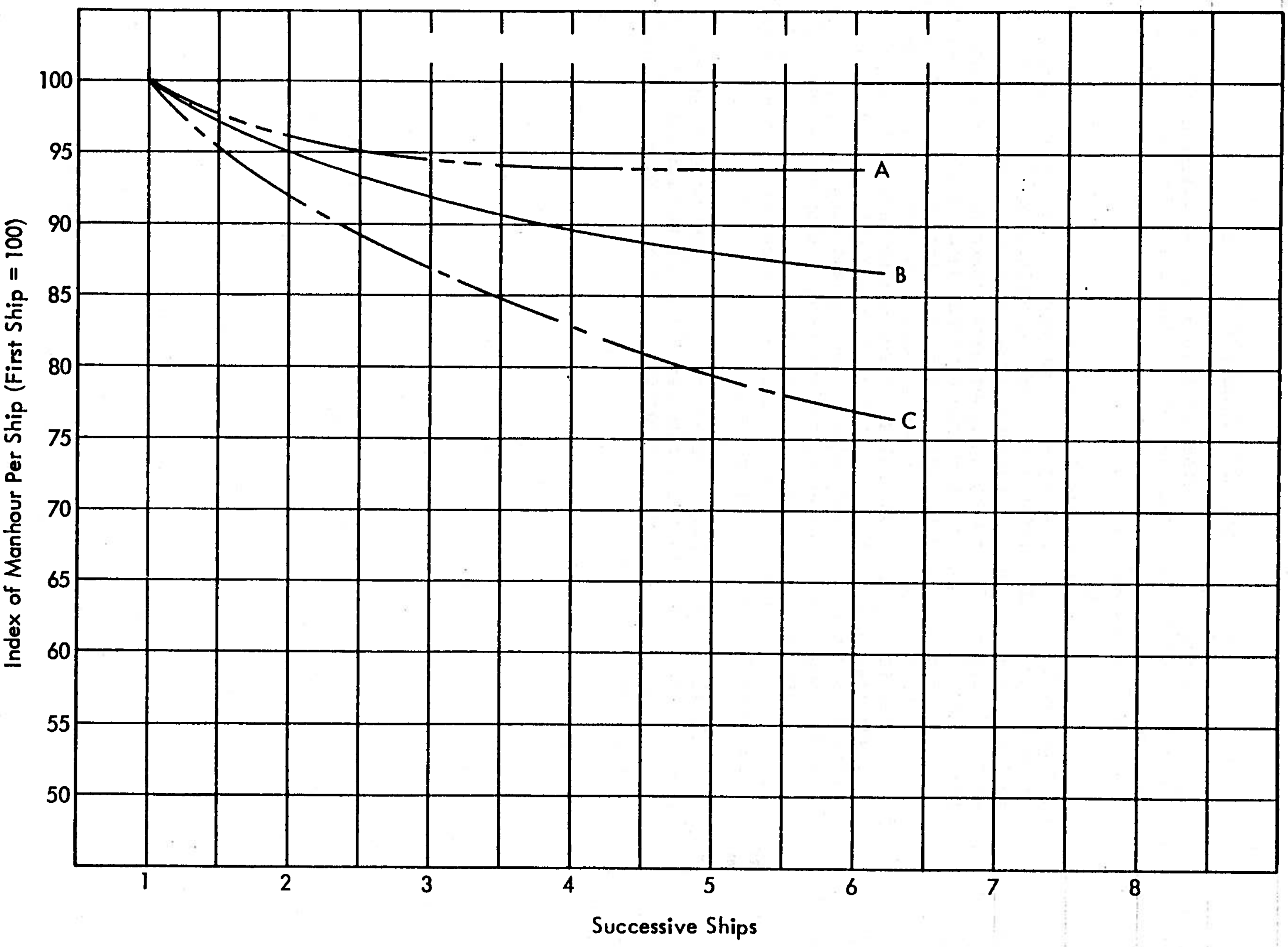

Figure 3. TYPICAL LEARNING CURVES – GENERAL CARGO LINERS

DEVELOPMENT OF COMPUTER MODEL

It is not within the scope of this paper to examine the intricacies of computer program design; however, the necessity for, and the value of, an effective computer model for determining the most cost-effective ship should not be underemphasized.

The computer model should generate accurate and timely output data indicating life-cycle cost on a present value basis for each cost element as well as total ship life-cycle cost, in addition to other detail information as required by the analysts. The model should be constructed so as to require the least complex input data possible. In other words, the analyst should be able to vary only certain basic factors and have the computer carry the calculations through the entire range of values for those factors for all applicable cost estimating relationships, providing meaningful life-cycle cost analysis between alternate ship designs. Analysts then may devote their time to analysis efforts instead of clerical routines. In fact, when the myriad mathematical relationships existing among the characteristic elements of a ship are considered, and all the various cost estimating relationships are applied for a complete range of values, then deriving life-cycle cost by any way other than by computer would obviously be inconceivable.

Finally, a very real by-product of an effective computer model is that it lends itself to the development of complete historical design and cost data in a form that is readily accessible and easily stored for future use.

SELECTING OPTIMUM SHIP DESIGN

Selecting the optimum design from all the possible candidates is not a simple matter of reading a computer printout and spotting the lowest life-cycle cost. At this stage of the procedure, there is available the engineering and cost data upon which to make the decision as to the most cost-effective ship for a given purpose. The data have been subjected to pertinent design criteria, resulting in a sound technical structure. Cost estimating relationships have been developed, as well as computer models with which to handle the mass of data relationships involving the interplay between the design function and the costing function. Life-cycle cost methodology has been applied not just to acquisition cost, but total cost of the entire ship system over its expected life, including costs for investment, operation and support, voyage and owner's cost. Trade studies have been made on a system and component level to determine the most cost-effective alternate at each design step. All of this effort has been performed under the basic tenets of what has previously been referred to as "measures of merit." Figure 4, a simplified flow chart, depicts graphically the relationships of cost estimating for ship design with the other elements involved in ship optimization.

After completing all of these elements of the ship optimization procedure, an optimum ship design for a specific trade route will have been determined. The candidate ship must next be analyzed as a whole from the standpoint of how does it fulfill its overall requirements. A summary level of analysis must be accomplished at this point; in effect, the basic design model is beginning to be transformed into a marketable product. Obviously, owner's preferences would be significant at this point: Will the ship be used solely on one trade route, or will it possibly be utilized on several? Should it be made more adaptable to types of cargo other than that for which it is initially intended? These and other similar questions must be considered, and unfortunately there are no pat answers. Judgment thus becomes an important factor despite the large degree of detailed technical effort required in the other stages of the ship optimization process.

Another vital factor to be considered is producibility. What facilities are required to build the candidate ship? Does it lend itself to efficient production methods, or might some modification lead to better utilization of available manpower and equipment? A reasonably accurate assessment of the market demand in terms of numbers of ships might well have an effect on production methods and facilities; so here again there is a tie-in between marketability and producibility.

Perhaps the most important consideration relative to the modern shipbuilding environment is the concept of standardization. In this instance the competitive capability of a standardized ship series versus individually optimized designs for particular owners' requirements must be considered. The savings in acquisition cost resulting from standardization have to be evaluated in terms of possible reduction of ship utility as well as probable increase in operating costs. Some analysis of this type will have resulted from previous detailed life-cycle cost

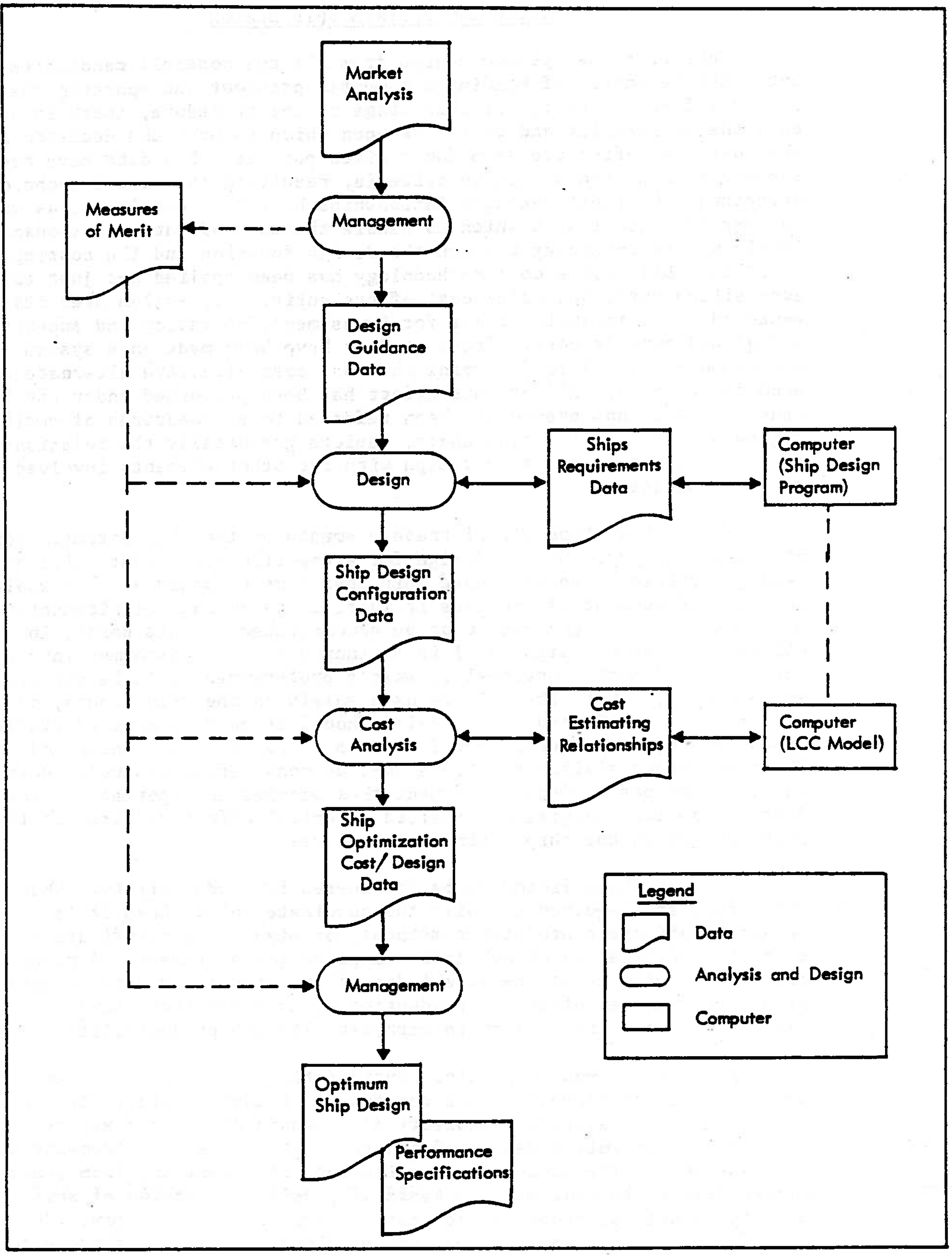

Figure 4. SIMPLIFIED FLOW CHART FOR SHIP OPTIMIZATION

calculations; however, an overview of the ship system at this stage of the procedure is necessary in finalizing the concept.

The culmination of the considerable effort involved in ship optimization is the optimized cost-effective ship for a given set of requirements. For an individual shipbuilding company, this may involve one or more designs, depending upon the market that the company is trying to service and depending upon their judgment, of course, as to what configuration of shipping system best answers the shipping interests' needs. In the final analysis the optimum ship is the one which is the most profitable.

SECTION II

EXAMPLE OF LIFE-CYCLE COST METHODOLOGY

To illustrate the concepts discussed, an application has been made to a bulk oil carrier ship type.

The application includes some rationalization for the sake of brevity. For example, it does not address market analysis. It has been assumed that there is a market for 79,000 deadweight ton tankers.

The application does not investigate a complete range of ship characteristics. Certain inputs to the concept design data computer program have been fixed. Therefore, some constraints have been introduced into the problem to be solved. To demonstrate the effect of changing the input to the computer program, two alternates will be addressed. In the first, a different speed will be used. In the second, the draft will be restricted.

In each instance the design characteristics of a tanker and its Required Freight Rate will be determined.

Table A tabulates the input data to the Concept Design Computer Program for the basic ship. Alternate No. 1 uses the same input data except that the speed has been increased by approximately 1.5 knots. Alternate No. 2 again uses the same input data except that, in this instance, the draft is restricted to 42.5 feet.

Solutions will be made for tankers having a trade route distance (range) of 5,000 miles based on multiple ship construction for each of three, each of five, and each of ten ships. Construction is assumed to take place in a new modern facility. The cargo utilization factor will be 50 percent; that is, cargo will be carried one way only of a two-leg voyage.

Basic assumptions for the life-cycle cost computations are as follows:

(a) The vessels will have a 25-year life after delivery. All costs will be assumed to cease at that time. The residual value of the ship at the end of 25 years and the cost of disposal will be assumed to equal zero.

(b) Operation and Support Costs, Voyage Costs, and Owner's Cost are to be estimated for a 25-year period escalated at 4 percent compounded annually and discounted at 10 percent starting at delivery of vessel, on a present value basis. These costs will be assumed to occur annually throughout the vessel's life cycle. See Table VIII in Appendix B for combined factors.

(c) All costs will be in terms of January 1970 dollars.

(d) The following multiple reduction percentages will be used:

Each of 1 ship = 1.00
Each of 3 ships = .88
Each of 5 ships = .84
Each of 10 ships = .80

(e) Port time per voyage has been assumed to be 3.3 days.

(f) Total port days per year for maintenance has been assumed to be 20 days.

Table B tabulates the Cost Estimating Relationships (CER's) for Initial Investment Cost. These relationships were derived from analysis of cost returns and estimates. The information was converted into a cost breakdown structure compatible with the breakdown structure of the ship computer program and then the mathematical relationship determined for each element.

Table C tabulates the Cost Estimating Relationships for Annual Costs. These CER's were developed from data available in the files of the shipbuilder and from data provided from outside sources.

The information contained in Tables A, B, and C provides the input to the computer program and the results are shown in Tables D, E, and F. Table D tabulates the preliminary characteristics of the basic tanker and the two alternates. Table E tabulates the preliminary weights and centers of gravity for the basic tanker and the two alternates. Table F tabulates the cost data and the Required Freight Rate for the three designs.

Comparisons of the three designs tabulated indicate the variations resulting from varying speed on the one hand and restricting data on the other hand. The results could have been predicted without using a computer program. They merely point out how variations in input can be solved and indicate how results can be produced if a range of values is used.

TABLE A

CONCEPT DESIGN COMPUTER PROGRAM INPUT TABLE

INPUTS				
		Basic	Alternate 1	Alternate 2
Ship Type		Oil Tanker	(Same as Basic except as noted)	(Same as Basic except as noted)
Length Between Perpendiculars (LBP)	(F)	821.25 Ft.		
Beam (B)	(F)	106 Ft.		
Draft (d) Max.		50 Ft.		42.5 Ft.
Draft (d) Min.		40 Ft.		
Total Deadweight (DWT)	(F)	79,000 Tons		
Block Coefficient (C_B)	(F)	0.815		
Machinery Plant	(F)	Steam Turbine		
No. of Propellers	(F)	1		
Speed (Looking for 26,000 SHP Max. ABS)		16.83 Knots	18.3 Knots	
Service Margin		0.250		
Number of Crew	(F)	35		
Range	(F)	5,000 Miles		
Specific Volume of Cargo	(F)	$\frac{40\ \text{Feet}^3}{\text{Ton}}$		
Specific Volume of Fuel	(F)	$\frac{37.25\ \text{Feet}^3}{\text{Ton}}$		
Total Voyage Distance (Round Trip)		10,000 Miles		

(F) = Fixed

TABLE B

INITIAL INVESTMENT COSTS - COST ESTIMATING RELATIONSHIPS

Cost Estimating Relationships for Tank Vessel Computer Program by Light Ship Weight Output Items

Item	CER ($ in Millions)
1.0 STEEL	
1.1 Cargo Section	(0.0004524 W + 0.78)
1.2 Ends	(0.0005678 W + 0.3963)
1.3 Superstructure	(0.000835 W + 0.031358)
1.4 Houses	
2.0 OUTFIT	
2.1 Passenger and Crew	(0.00338 W + 0.704)
2.2 Cargo	
2.2.1 Heating Coils	(0.002264 W + 0.2032)
2.2.2 Cargo Pumps	
2.2.3 Cargo Oil Sys. and Misc.	
2.3 Electric Plant	(0.00045 P_{kw} + 0.450)
2.4 Fixed	
2.4.1 Steering Gear and Rudder	(0.00106 W + 0.10163)

TABLE B (Cont'd)

INITIAL INVESTMENT COSTS - COST ESTIMATING RELATIONSHIPS

Item	CER ($ in Millions)
2.4.2 Dk. Mach'y, Incl. Anchors, Chain, Windlass, Warping Gear, Winches	$(0.00145\ W + 0.0178)$
2.4.3 Misc. Items	$(0.00503\ W + 0.161)$
3.0 **MACHINERY, STEAM TURBINE PROPULSION**	$[0.103\ (SHP \times 10^{-3}) + 2.160]$

Definitions

CER ($) = Cost Estimating Relationships in Millions of Dollars

W = Weight in Long Tons

P_{kw} = Power in Kilowatts

SHP = Shaft Horsepower

TABLE C

COST ESTIMATING RELATIONSHIPS - ANNUAL COSTS

			TANKER
Operation and Support (200)			
(210)	Manpower	\$/Year	\$19,345 per man
(220.10)	Stores/Supplies	\$/Year	$1.84 \quad 4500 + (\frac{SHP}{3} + 10,000) + .21\ (DWT + 9500)$
(220.11)	Subsistence	\$/Year	\$986/man
(230)	Maintenance and Repair	\$/Year	$\$90400 + .69(CN - 1500) + .49(CN)$
(240.10)	Insurance, H & M	\$/Year	$(I.C.)(.01 + \frac{.00006\ DWT}{1000})$
(240.11)	Insurance, P & I	\$/Year	$750\ N_c + .61\ CN$
(240.12)	Other	\$/Year	\$5475
Voyage Cost (300)			
(310)	Cargo Handling		Free in and out
(320)	Terminal Costs \$/Port Day		\$600
(330)	Brokerage and Commission \$/Cargo Ton/Trip		\$0.30
(340)	Fuel	\$/BBL	\$2.10

TABLE C (Cont'd)

COST ESTIMATING RELATIONSHIPS - ANNUAL COSTS

			TANKER
Voyage Cost (300) (Cont'd)			
(350.10)	Canal Toll (Panama)		
	$/Net Ton - Ballasted		$0.72 } Not used
	$/Net Ton - Loaded		$0.90 }
(350.11)	Other		
	$/Day at Sea		$20
Owner's Cost (400)			
(410)	Overhead	$/Year	$50,000
(420)	Other		Included with (410)

Definitions

SHP = Normal Shaft Horsepower
CN = Cubic Number
DWT = Dead Weight
N_c = Total Crew
I.C. = Initial Investment Cost (100)

TABLE D

CONCEPT DESIGN COMPUTER PROGRAM OUTPUT TABLE

Preliminary Characteristics of Tanker

Outputs		Basic	Alternate 1	Alternate 2
Principal Characteristics				
Length Between Perpendiculars	(Ft.)	821.25	821.25	958.8
Molded Beam	(Ft.)	106.0	106.0	106.0
Molded Depth	(Ft.)	62.2	62.2	57.0
Design Draft	(Ft.)	47.0	47.3	42.5
Total Deadweight	(Tons)	78,993.1	79,000.2	78,991.0
Cargo Deadweight	(Tons)	76,834.3	76,241.8	76,861.1
Total Displacement	(Tons)	95,459.5	95,957.6	100,585.7
Tons Per Inch of Immersion	(Tons/Inch)	184.8	184.8	215.8
Moment to Trim One Inch	(Ft. Tons)	10,526.7	10,526.7	14,349.7
Machinery Type		Steam Turbine	Steam Turbine	Steam Turbine
SHP, Max. Continuous		26,047.03	37,285.11	25,609.24
Service Speed	(Knots)	16.83	18.3	16.83
Clean Ballast Capacity	(Tons)	32,539.96	31,297.87	43,614.31
Cargo Capacity, Tanks	(Cu. Ft.)	3,073,647.0	3,049,664.0	3,074,804.4
Total Deadweight at Freeboard Draft	(Tons)	79,026.0	79,148.7	79,185.4
Range	(Miles)	5000	5000	5000
Fuel Rate (Sea)	(Tons/Hour)	5.58	7.99	5.4
Fuel Rate (Port)	(Tons/Hour)	0.75	0.75	0.75
Number of Tank Bays		5	5	5

TABLE D (Cont'd)

CONCEPT DESIGN COMPUTER PROGRAM OUTPUT TABLE

Preliminary Characteristics of Tanker (Cont'd)

Outputs		Basic	Alternate 1	Alternate 2
Form Parameters				
Block Coefficient		.816	.815	.815
Prismatic Coefficient		.819	.819	.819
Midships Coefficient		.995	.995	.995
Length Over Breadth		7.748	7.748	9.046
Length Over Depth		13.202	13.118	16.821
Beam Over Draft		2.255	2.241	2.494
Powering Data				
Propellers		1	1	1
Effective Horsepower		14,268.6	21,068.7	13,948.4
Propeller Coefficient		0.685	0.706	0.681
Propeller Diameter	(Ft.)	30.00	30.00	29.75
Revolutions Per Minute	(RPM)	80.00	80.00	80.00
Pitch/Diameter		0.699	0.840	0.719
Blade Area Ratio		0.400	0.445	0.400
Length and Volume Summary				
Fore Peak - Length	(Ft.)	41.06	41.06	47.94
Volume	(Cu. Ft.)	72,869.94	73,376.32	78,760.75
Deep Tanks - Length	(Ft.)	39.83	54.32	19.52
Volume	(Cu. Ft.)	192,481.96	282,203.82	74,547.09
Cargo Tanks - Length	(Ft.)	582.51	551.41	729.03
Volume	(Cu. Ft.)	3,859,943.18	3,696,316.95	4,382,181.78
Pump Room - Length	(Ft.)	26.50	26.5	26.5
- Volume	(Cu. Ft.)	144,850.51	155,300.94	122,879.06

TABLE D (Cont'd)

CONCEPT DESIGN COMPUTER PROGRAM OUTPUT TABLE

Preliminary Characteristics of Tanker (Cont'd)

Outputs		Basic	Alternate 1	Alternate 2
Length and Volume Summary (Cont'd)				
Engine Room - Length	(Ft.)	100.55	117.25	99.9
Volume	(Cu. Ft.)	339,656.11	431,873.53	286,747.94
Aft Peak - Length	(Ft.)	30.80	30.80	35.96
- Volume	(Cu. Ft.)	19,893.11	20,033.10	21,578.65
Freeboard and Stability Data				
Required Freeboard	(Ft.)	15.18	15.28	14.48
Available Freeboard	(Ft.)	15.19	15.34	14.56
Displacement at Freeboard Draft	(Tons)	95,492.4	96,106.1	100,780.2
GM - Uncorrected	(Ft.)	12.57	12.38	14.92
Free Surface Correction	(Ft.)	0.00	0.00	0.00
GM - Corrected	(Ft.)	12.57	12.38	14.92
Trim Characteristics				
Burned Out Arrival - LCG	(Ft.)	26.33	26.29	30.04
Full Load Departure - LCG	(Ft.)	21.53	20.30	25.75
Burned Out Arrival - Trim	(Inches)	30.22 (By Bow)	30.01 (By Bow)	22.37 (By Bow)
Full Load Departure - Trim	(Inches)	13.30 (By Stern)	24.59 (By Stern)	7.70 (By Stern)

Legend:

GM = Distance between metacenter and center of gravity
LCG = Longitudinal center of gravity
KG = Vertical center of gravity

TABLE E

CONCEPT DESIGN COMPUTER PROGRAM OUTPUT TABLE

Preliminary Weight and Centers of Gravity Data - Tanker

Outputs	Basic			Alternate 1			Alternate 2		
	Weight Tons	KG Ft.	LCG Ft.	Weight Tons	KG Ft.	LCG Ft.	Weight Tons	KG Ft.	LCG Ft.
Steel									
Cargo Section	9,985.73			9,593.45			15,926.55		
Ends	2,756.14			3,357.75			1,796.36		
House	390.55			390.55			390.55		
Focsle	127.33			150.01			106.20		
Poop	0.00			0.00			0.00		
Total Steel	13,259.76	35.18	-7.61	13,491.76	35.44	-6.67	18,219.67	31.83	-7.42
Outfit									
Passengers & Crew Outfit	338.95			339.17			341.39		
Electric Plant	86.32			86.49			88.08		
Steering Gear	27.31			28.88			27.76		
Rudder	74.24			83.70			76.94		
Anchors, Chain & Lines	173.94			174.52			177.11		
Deck Machinery	91.86			92.16			94.89		
Misc. Fixed Outfit	307.86			309.25			322.92		
Cargo Piping & Misc. Cargo Outfit	480.08			476.70			480.24		
Heating Coils	72.67			72.16			72.69		
Cargo Pumps	24.66			24.49			24.67		
Total Outfit	1,677.88	43.31	-85.08	1,687.51	43.57	-83.80	1,706.68	39.90	-101.43
Machinery									
Total Machinery	1,049.16	28.21	-314.47	1,284.23	30.46	-303.62	1,039.43	28.12	-378.54

TABLE E (Cont'd)

CONCEPT DESIGN COMPUTER PROGRAM OUTPUT TABLE

Preliminary Weight and Centers of Gravity Data - Tanker (Cont'd)

Outputs	Basic			Alternate 1			Alternate 2		
	Weight Tons	KG Ft.	LCG Ft.	Weight Tons	KG Ft.	LCG Ft.	Weight Tons	KG Ft.	LCG Ft.
Margin	479.60			493.91			628.97		
Light Ship	16,466.40	35.58	-35.88	16,957.41	35.88	-37.74	21,594.74	32.30	-33.47
Fuel	1,907.67	24.96	-168.29	2,485.17	26.01	-168.09	1,879.59	20.30	-144.41
Cargo	76,834.32	31.14	39.66	76,241.85	31.34	40.53	76,861.12	28.53	47.88
Misc. Deadweight	251.16	52.94	-319.50	273.23	53.28	-309.48	250.30	48.50	-383.53
Total Deadweight	78,993.14	31.06		79,000.25	31.25		78,991.0	28.40	
Total Displacement	95,459.55	31.66		95,957.66	31.88		100,585.75	29.03	

TABLE F

CONCEPT COMPUTER PROGRAM OUTPUT TABLE

Cost Data and Required Freight Rate - Tanker

Outputs	Basic	Alternate 1	Alternate 2
Initial Investment			
Each of 3 Ships	$17,133,070	$18,324,862	$19,069,069
Each of 5 Ships	16,354,294	17,491,913	18,202,293
Each of 10 Ships	15,575,518	16,658,965	17,335,517
Operation & Support Cost Per Year			
Each of 3 Ships	1,258,810	1,284,068	1,294,018
Each of 5 Ships	1,247,339	1,271,791	1,281,242
Each of 10 Ships	1,235,867	1,259,513	1,268,466
Voyage Cost - Each of 3, 5, and 10 Ships	893,091	1,149,711	884,032
Owner's Cost - Each of 3, 5, and 10 Ships	50,000	50,000	50,000
Total Cost Per Year			
Each of 3 Ships	2,201,901	2,483,779	2,228,050
Each of 5 Ships	2,190,430	2,471,502	2,215,274
Each of 10 Ships	2,178,958	2,459,224	2,202,498
Escalated & Discounted Cost for 25 Years			
Each of 3 Ships	28,774,883	32,458,521	29,116,603
Each of 5 Ships	28,624,977	32,298,082	28,949,644
Each of 10 Ships	28,475,059	32,137,631	28,782,684
Total Cost			
Each of 3 Ships	45,907,953	50,783,383	48,185,672
Each of 5 Ships	44,979,271	49,789,995	47,151,937
Each of 10 Ships	44,050,577	48,796,596	46,118,201
Required Freight Rate $/Ton Mile			
Each of 3 Ships	.001071	.001109	.001123
Each of 5 Ships	.001049	.001087	.001099
Each of 10 Ships	.001027	.001065	.001075

SECTION III

SHIP OPTIMIZATION FOR A NAVAL VESSEL

Although the methodology involved in determining the optimum Navy ship follows the same basic pattern as previously described, there are some significant differences involved where a Naval vessel is concerned. Comment on these differences should be included in any discussion on cost estimating for ship design, since Naval vessels constitute a major impact on the American shipbuilding industry.

Measures of merit for each project must be considered on an individual basis, since applicable criteria will be subject to considerable variance between ship types.

For purposes of discussion a Naval ship will be addressed which had a functional requirement to load, transit, land, and re-embark landing forces and their equipment. The main objective in the design of the ship was the achievement of maximum military effectiveness in the major performance elements identified by the Navy as critical to the accomplishment of the basic ship mission. These were: assault capability, operational flexibility, availability, reliability, vulnerability, survivability, overhaul cycle and duration, and manning.

In the development of the ship design, every effort was made to accomplish the design to meet the performance and operational requirements and, at the same time, maintain the lowest possible life-cycle costs. In several instances, as a result of trade study conclusions, it was necessary to sacrifice reduced acquisition cost in favor of lower total life-cycle cost. In each case where acquisition cost was traded against total life-cycle cost, every effort was made to achieve optimum balance between these two cost elements.

Having achieved a ship design with the required characteristics, capabilities and military effectiveness, a series of analyses were performed to determine the most effective number of ships of the proposed design to support the deployment of a constant force size. As a result, the most cost effective ship design and the number of ships required to best meet the objectives were determined.

In the case of a military vessel, it is extremely difficult, if not impossible, to establish a quantified measure of merit. The difficulty in finding a quantified unit of measurement of merit stems from the fact that military effectiveness does not lend itself to quantification. In this particular case the three items upon which source selection was based were the equivalent of a measure of merit. These items were: (1) military effectiveness, (2) life-cycle cost, and (3) technical design characteristics. It should be noted, in the case of military procurement, that although all three of these items are significant, there is a stronger emphasis on operational (military) effectiveness than would be placed on a commercial vessel. Of course, this results from the intended use or purpose of the ship. Conversely, a project dealing with development of a commercial design would place relatively more importance upon economic considerations.

The Naval vessel is inherently more complex than the commercial ship. Not only are the standard systems, such as communications, much more sophisticated and complex but there usually is a considerable degree of premium attached to the reliability factors of such equipment. Design analysis of such equipment and additional installation and test effort obviously results in higher acquisition cost. Increased costs do not stop with acquisition. These systems usually must be maintained in peak operating condition since a breakdown could be critical to mission effectiveness. Consequently, from a life-cycle cost standpoint this may mean increases in acquisition, maintenance, and manning costs, as well as additional support costs such as added inventory items, depot facilities, etc.

If life-cycle costs are to be estimated to the level of detail required for a Naval ship, additional concepts must be introduced into the estimating procedures. For example, if costs of repairs to, or replacement of, various parts are going to be accurately determined, then such things as utilization rate, mean time between failures and mean time to repair must be considered. This obviously involves an extensive, detailed analysis that is costly, time consuming and sometimes very difficult to do to obtain a reasonable degree of accuracy. Figure 5 gives a typical life-cycle cost element structure for a Naval ship. Comparison with that for a commercial ship (Figure 1) makes the complexity readily apparent.

Another major difference in ship optimization methodology for Naval ships involves Government-furnished equipment including electronics. This equipment is often an integral part of some advanced type of hardware system which is not in commercial distribution and, consequently, pricing data is difficult to obtain and unreliable. In fact, it is not uncommon for such equipment to be in a research and developmental stage at the time the ship optimization process is taking shape. The problem is further compounded by the rapid obsolescence of such equipment. New equipment can certainly be anticipated during the life cycle of the ship; a fact which adds uncertainty to the life-cycle cost methodology. Since much of the Government-furnished equipment is operational for such a short time and on such a limited basis, reliability and maintainability data is sparse and, even when available, may not have a high degree of credibility. Consequently, the usual practice is for the Government to provide some standard guidelines as to methodology, and constant cost factors to be applied where certain GFE life-cycle cost elements are concerned. Even so, GFE and other advanced systems hardware remain a difficult problem in life-cycle costing.

The last major difference between Naval and commercial ship optimization that will be considered is the operational profile. We can develop a relatively simple pattern of operations for a merchant ship. It will service one or maybe several trade routes, not too dissimilar in nature, and will be limited to one of several types of cargo. The operations of the Naval ship are considerably more involved, however. Any conceivable climatic condition may be encountered over many varied

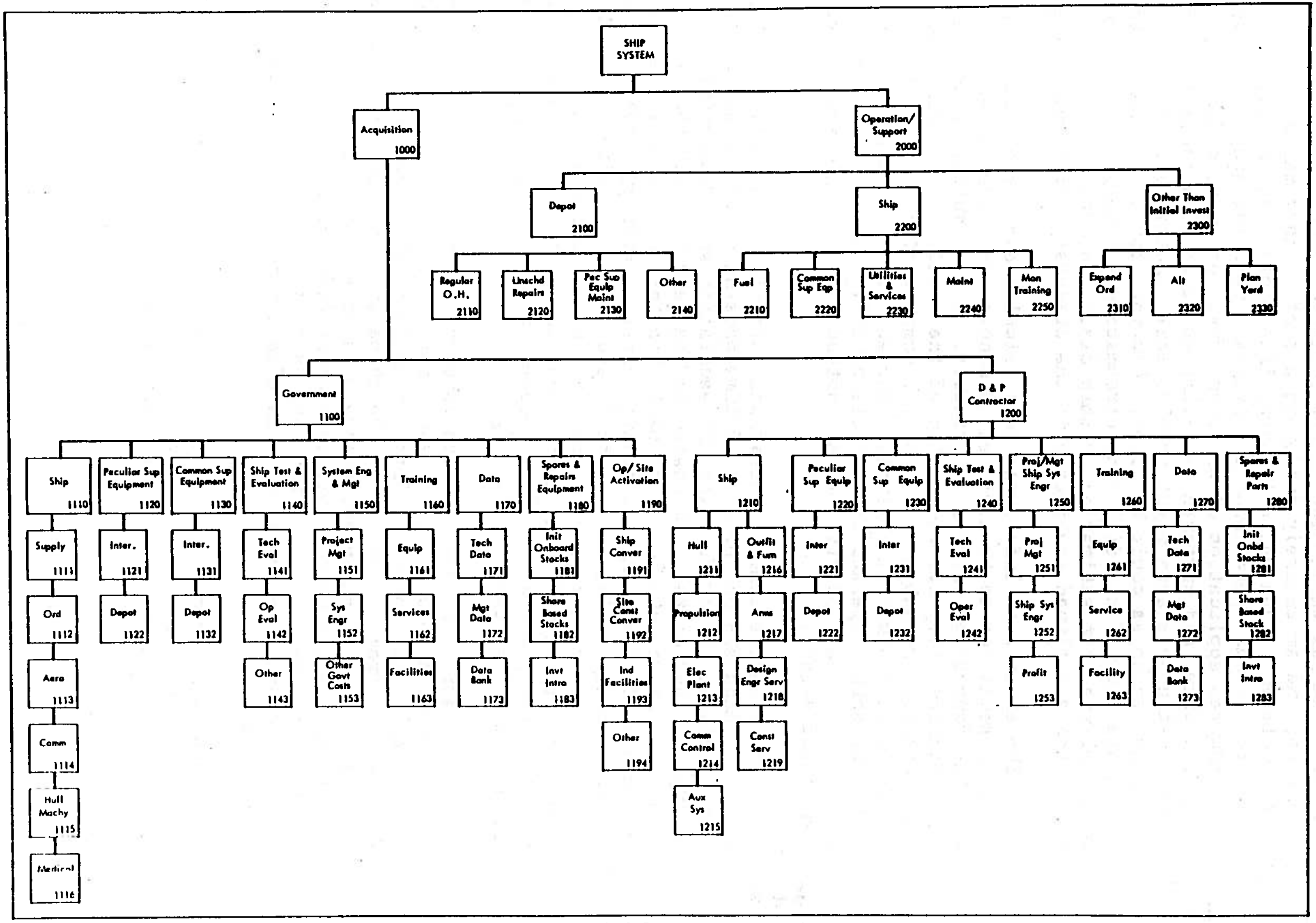

Figure 5. TYPICAL NAVY SHIP SYSTEM LIFE-CYCLE COST ELEMENT STRUCTURE

routes. Steaming takes place under different conditions of operational readiness, and an entirely different set of factors may be involved for each condition. Even while in port, life-cycle cost considerations will vary with various operational conditions. Overhaul status with engines cold requires application of different fuel consumption factors, perhaps a partial crew, and different utilization factors on certain equipment. Whereas, standby status might involve still another set of cost variables. Many other examples could be cited. However, for our purposes, these illustrate some of the different circumstances likely to be encountered when applying cost estimating to ship design in optimizing a Naval ship versus those outlined previously in the discussion of commercial ships.

The effects on life-cycle cost calculations are obvious. The computer model has to be designed to handle the complexities involved with the Navy ships operational profile. This results, of course, in a more detailed, complicated version of the model. Cost estimating relationships are subject to the same complications and require considerable developmental analysis. The additional complexity of the combatant ship's operational profile usually results in a longer operational cycle, say, of five years, instead of a normal one-year cycle for a merchant vessel.

The relative complex operational profile of the Navy vessel puts much more emphasis on the task of time phasing costs. Since our methodology includes the calculations of escalating and discounting, it is imperative that costs be allocated to the year in which they will be incurred. In the case of a merchant ship this is relatively easy, since we can usually figure most operating costs as averaging out on an annual basis. The Navy ship, on the other hand, involves different operating and support costs each year, since no two year's operations will be the same. Some major costs may spread over parts of two separate years. In these cases, costs must be allocated to the appropriate year and then discounted and escalated accordingly.

The basic ship optimization concepts apply for both the merchant and the Naval ship and use the same basic cost estimating techniques; but as can readily be seen, differences in detail treatment are numerous. This results from the fact that the ships are designed for different purposes, and perform in accordance with an entirely different set of operational requirements. Although total life-cycle costs are applicable to each, we have relatively more emphasis on profitability in the instance of the merchant ship and on mission effectiveness in the instance of the Naval vessel.

Appendix B provides an example of a cost trade-off study as applied to a Naval vessel. It illustrates the differences between commercial and Naval work in the method of handling operating costs.

SECTION IV

SUMMARY

This has been a brief and relatively simple discussion of the role cost estimating can play and is playing in the determination of economical ship design and construction methods. It is a role which, in my opinion, will be increasingly important in the future for the reasons cited in the Introduction.

It is doubtful, because of the many variables we have to deal with in cost estimating and ship design, that we will ever be able to say that a particular selection is the optimum. However, we can improve so that the selection range will narrow to a much smaller band, and the ship design selected will more nearly approach the optimum goal. This will require continued effort for improvement in many areas, including the following:

1. Cost estimating is not an exact science. It does not give precise values. If it did, there would be no unexpected losses in ship construction contracts. We can improve this area by:

    (a) Developing a better, more refined cost accounting structure to provide more precise construction cost returns for the many systems, components, and sections that make up a ship. This would improve our ability to develop cost estimating relationships and trade-off studies between alternate designs, components, etc.

    (b) The art of cost estimating itself needs research to improve its capabilities in predicting costs.

2. Because of the tailor-made nature of shipbuilding since World War II, emphasis has not been given to standardization and the production planning and methods engineering which go hand in hand with standardization. To achieve economies in initial cost, a greater degree of standardization than we now have will be necessary. There is need for further work to eliminate the emotion involved with this issue and to determine the point where standardization no longer pays off due to increased operational costs. We must recognize that any standardized design will contain compromises to enable its use in varying roles. Consequently, a standardized design will not be as cost-effective as a specialized design in the area for which the specialized design was developed.

3. The use of learning curves can be improved. More analysis of the data available is required and additional data should be developed so that application may be made with more assurance.

4. Market analysis and the data available for analysis never will be precise since here we are predicting far into the future. This should not discourage efforts to improve the presently available information and techniques.

5. Computer programs employed for ship design and the determination of life-cycle cost are far from perfect. Speaking solely from my own observations, computer programs usually have been developed for some basic purpose, such as ship design, and have had the cost sensitivities added on. If one is to deal with both design and cost, then the program should be developed from the beginning with both requirements incorporated into it. There is a need to bring the cost estimating function into computer program design at the beginning.

There is a lot of development work required before the results obtained, by any method currently employed, will provide results with desired precision. At the present time, we can identify and eliminate a larger number of the poorer candidate designs. Thus, narrowing the range to a smaller number of designs having better cost effective and/or mission effective performance. We cannot point with complete assurance and say this particular design is better than any other. But we can select a design and say, with assurance, that this design is better because the selection has been narrowed to one of the more effective ships by the best use of the techniques and data we now have available.

One last observation, don't lose sight of judgment and reason in the use of these techniques. Tailor the depth of any study to the information available. Imprecise and scanty data does not deserve or require in-depth study.

APPENDIX A

COST TRADE-OFF STUDY ON PROPULSION SYSTEM EFFICIENCY - MERCHANT VESSELS

SECTION 1

PURPOSE

1.1 Objective of the Study

Marine power plant development has been concentrated on reducing the specific fuel rate; the expenditure of considerable effort, both in funds and manpower, has resulted in gains of as little as one percent. However, there is a potential for substantially greater gains in the proper selection of the propeller or propulsion device. This study reviews some of the selection possibilities and indicates the cost-effective direction for propeller diameters and propeller revolutions for the types of ships under study, i.e., dry bulk and tankers using geared turbine propulsion systems.

SECTION 2

ANALYSIS

2.1 Kort Nozzles

While Kort nozzles have definite theoretical advantages in cases where the propeller is highly loaded, e.g., large tankers or bulkers, lack of detailed design or operating experience precludes investigation of such a device in this study.

2.2 Contra-Rotating Propellers

Contra-rotating propellers also offer distinct propulsion efficiency gain for certain ship types but are precluded from investigation in this study because of extensive mechanical problems associated with the necessary concentric shafts, bearings, and unique reduction gears.

2.3 Controllable Pitch Propellers

The controllable pitch propeller has made a rapid entry abroad in the larger merchant ship field during the past few years, and there is no doubt that this trend will continue. This propeller is of considerable value in connection with multi-engined, medium speed, diesel ships and should be advantageous in gas turbine powered ships. Insofar as efficiency is concerned, the well-designed controllable pitch propeller will approach but not quite reach that of a good fixed pitched propeller because of the large hub diameter of the controllable pitch propeller. For the above reasons, controllable pitch propellers were not included in this study to be applied to geared turbine driven dry bulk cargo ships and tankers.

2.4 Fixed Pitch Propellers

This trade-off study will be confined to investigation of the range of fixed pitch propeller diameters and propeller revolutions which will produce the highest propulsion coefficient for the ship's stern configuration and provide for optimizing life-cycle cost.

2.5 Propulsive Coefficients

Major characteristics for dry bulk cargo ships and tankers are selected for the study and tabulated in Table 1. They are assumed characteristics and, while reasonable and typical, do not represent a significant design effort.

Propulsion estimate calculations are prepared based on these characteristics, using existing computer programs. The following conditions form the basis for the study:

- EHP estimate employed Taylor Series data as reworked by Gertler.
- Wake fractions and thrust deduction coefficients by Schoenherr formulations, modified by applying Series 60 data and published data for forms with block coefficients greater than 0.80.
- Propeller characteristics are Troost, five-blade "B" series.
- Service speed corresponds to a 25 percent margin on SHP.
- Maximum allowable propeller diameter of 30 ft.
- Minimum RPM = 80.

The developed data are listed in Table 2 and are adequate for the purposes of preliminary trade-off studies. For hull configurations established during the preliminary design phase, more detailed calculations would be required for the selection of optimum propellers.

2.6 Reduction Gears, Shafting, Propeller Weights, and Fuel Consumption

Trade-off studies must be made over a range of propeller diameters and propeller revolutions to determine the most cost-effective combination. Based on the results in Table 2, minimum shafting diameters and estimated shafting lengths were determined, and propeller weights were estimated. A speed was selected in each case, and barrels of fuel consumed per hour were then determined for each variation in propeller diameter. The resulting information is tabulated in Table 3.

2.7 Cost-Effectiveness Evaluation

Based on the data in Table 3, costs of propellers and shafting were estimated. Costs of reduction gears were also estimated, and basic acquisition costs for the transmission unit and propulsion device were then determined. Summation of these values provided the initial investment costs in each instance. Fuel costs over representative operation profiles were then determined and reduced to a net present value, representing voyage costs in each instance. Since there are no other significant factors distinguishing the various combinations of propeller diameters and revolutions, the sum of the investment costs and of the voyage costs provides proper comparison for life-cycle costs.

2.8 Costing Results

The results of the costing study are tabulated in Table 4. The results reveal that for the approaches studied, the total life-cycle cost of any alternate is a function of fuel consumption. Differences in initial investment costs were found to be insignificant where fuel consumption rates could be reduced.

SECTION 3

CONCLUSIONS

In each type of ship studied, the combination of propeller diameter and propeller revolutions that produced the highest propulsive coefficient, and with it the lowest fuel consumption for a desired speed, also turned out to be the most cost-effective.

SECTION 4

RECOMMENDATIONS

When preliminary designs for the proposed ships are developed, propeller studies should be conducted in depth in each instance to determine the propeller diameter as well as its revolutions per minute that will maximize the propulsive coefficient. Such combinations must also meet cavitation and vibration criteria and be compatible with the stern configuration for the design under consideration. Propeller combinations meeting these criteria will probably also be the most cost-effective.

SECTION 5

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TABLE 1

SHIP CHARACTERISTICS

	SHIP TYPES			
	Dry Bulk	Dry Bulk	Tanker	Tanker
Deadweight (DWT), Approx.	30,000	60,000	60,000	120,000
Displacement ($\triangle$), Molded, Approx.	40,000	70,000	76,000	150,000
Length Between Perpendiculars (LBP), Ft.	650	690	735	900
Beam, Molded, Ft.	100	105	105	143
Draft, Molded, Ft.	29.25	42.00	42.75	50.00
Block Coefficient (C_b)	0.736	0.804	0.806	0.816
Prismatic Coefficient (C_p)	0.740	0.808	0.810	0.820
Shaft Horsepower (SHP), Max. ABS Continuous	20,000	20,000	20,000	35,000

TABLE 2

PROPULSION CALCULATIONS

Type/DWT	Dry Bulk 30,000 DWT			Dry Bulk 60,000 DWT		
Prop. Dia.	18	20	22	24	28	30
RPM	140	118	100	86	80	80
η_o	0.486	0.527	0.563	0.524	0.546	0.511
P.C.	0.619	0.665	0.702	0.693	0.707	0.655
V_k (*1)	17.31	17.63	17.87	16.13	16.23	15.93

Type/DWT	Tanker 60,000 DWT			Tanker 120,000 DWT		
Prop. Dia.	24	26	28	26	28	30
RPM	86	80	80	94	82	80
η_o	0.528	0.551	0.549	0.461	0.487	0.506
P.C.	0.688	0.711	0.701	0.638	0.670	0.689
V_k (*1)	16.04	16.18	16.12	6.41	16.62	16.75

NOTE

*1 V_k estimated for 25% margin on effective horsepower

LEGEND

Prop. Dia. = Propeller diameter
RPM = Revolution per minute
η_o = Open water propeller efficiency
P.C. = Propeller coefficient
V_k = Sustained sea speed in knots

TABLE 3

SHAFTING, PROPELLER WEIGHTS, AND FUEL CONSUMPTION

DRY BULK SHIP 30,000 DWT 20,000 SHP SINGLE SCREW

Prop. Diam.	RPM	Prop. Weight	Line Shaft Diam.	Length Line Shaft	Tail Shaft Diam.	Tail Shaft Length	Speed Knots	BBLs Fuel/Hr. (17.2 Knots)
18'	140	48,000	18.3"	45'	21.0"	45'	17.2	28.4
20'	118	56,000	19.3"	45'	22.2"	45'	17.2	26.6
22'	100	67,000	20.4"	45'	23.4"	45'	17.2	25.0

DRY BULK SHIP 60,000 DWT 20,000 SHP SINGLE SCREW

Prop. Diam.	RPM	Prop. Weight	Line Shaft Diam.	Length Line Shaft	Tail Shaft Diam.	Tail Shaft Length	Speed Knots	BBLs Fuel/Hr. (16.0 Knots)
24'	86	80,000	21.6"	45'	24.8"	45'	16.0	26.8
28'	80	88,000	22.0"	45'	25.4"	45'	16.0	26.3
30'	80	90,000	22.0"	45'	25.4"	45'	16.0	28.4

TANKER 60,000 DWT 20,000 SHP SINGLE SCREW

Prop. Diam.	RPM	Prop. Weight	Line Shaft Diam.	Length Line Shaft	Tail Shaft Diam.	Tail Shaft Length	Speed Knots	BBLs Fuel/Hr. (16.0 Knots)
24'	86	55,000	21.6"	45'	24.8"	45'	16.0	28.4
26'	80	80,000	22.0"	45'	25.4"	45'	16.0	27.4
28'	80	88,000	22.0"	45'	25.4"	45'	16.0	27.9

TANKER 120,000 DWT 35,000 SHP SINGLE SCREW

Prop. Diam.	RPM	Prop. Weight	Line Shaft Diam.	Length Line Shaft	Tail Shaft Diam.	Tail Shaft Length	Speed Knots	BBLs Fuel/Hr. (16.4 Knots)
26'	94	100,000	25.2"	50'	28.9"	50'	16.4	49.7
28'	82	130,000	26.1"	50'	30.3"	50'	16.4	47.5
30'	80	135,000	26.4"	50'	30.5"	50'	16.4	46.1

NOTE: All Shafting - ABS Grade 2
Propellers - Nikalium or Novoston - Weights are estimated

TABLE 4

COST COMPARISON MATRIX

Per Ship ($ in 000)

Approach	LCC	Investment	Voyage
Dry Bulk Ship - 30K DWT			
1 - Screw; 20K SHP; 18' Dia. Prop.	5,381.4	731.9	4,649.5
1 - Screw; 20K SHP; 20' Dia. Prop.	5,111.2	738.0	4,373.2
1 - Screw; 20K SHP; 22' Dia. Prop.	4,895.0	767.5	4,127.5
Dry Bulk Ship - 60K DWT			
1 - Screw; 20K SHP; 24' Dia. Prop.	5,212.1	802.9	4,409.2
1 - Screw; 20K SHP; 28' Dia. Prop.	5,158.9	826.5	4,332.4
1 - Screw; 20K SHP; 30' Dia. Prop.	5,492.5	832.5	4,660.0
Tanker - 60K DWT			
1 - Screw; 20K SHP; 24' Dia. Prop.	5,425.4	765.4	4,660.0
1 - Screw; 20K SHP, 26' Dia. Prop.	5,316.3	810.3	4,506.0
1 - Screw; 20K SHP, 28' Dia. Prop.	5,409.5	826.5	4,583.0
Tanker - 120K DWT			
1 - Screw; 35K SHP; 26' Dia. Prop.	8,967.5	1,041.3	7,926.2
1 - Screw; 35K SHP; 28' Dia. Prop.	8,693.4	1,105.3	7,588.1
1 - Screw; 35K SHP; 30' Dia. Prop.	8,490.9	1,118.0	7,372.9

Investment cost includes propeller, shafting, bearings, and reduction gears only. Voyage cost includes fuel costs only.

APPENDIX B

COST TRADE-OFF STUDY - NAVAL PROCUREMENT

The following example is presented in order to illustrate the trade-off study concept as applicable in Naval procurement. Because of time and space considerations, the study has been simplified and some of the technical discussion omitted; however, it contains the basic elements indicative of ship cost/design optimization.

The alternates. The sample is a trade-off study between three alternate approaches for the prime movers used to drive the ship's service generators. Table I shows the alternates and their characteristics.

The outstanding differences between the three approaches are: (a) the choice of diesel power versus gas turbine, and (b) the choice between Vendor Y which supplies a gas turbine operating at 1200 RPM and Vendor Z which supplies a gas turbine operating at 1800 RPM.

An engineering analysis has determined that all approaches are feasible and that the effectiveness of each alternate is considered essentially equal. Therefore, component selection will be based on lowest total life-cycle cost.

Acquisition costs. Table II shows the acquisition costs associated with the various approaches. Two of the cost elements are based on Navy-supplied cost factors. These are the cost of introduction of new items into the Federal supply system and the Government overhead factor that must be accounted for when the Government procures additional capital investments. The required factors are determined by the Navy and need only be applied by the cost analyst.

The procurement and installation costs cover the acquisition of all material from vendors and the installation into the system under study. In the case of the sample study the costs included the generator sets, their related mufflers, air-starting systems, cooling system, fuel system, lubricating oil system, intake air and exhaust system, and foundations. This scope of investigation was necessary because of the two different designs of the prime mover. Diesel drive and gas turbine drive differ quite radically in the required auxiliary equipment. This study would have been incomplete if it had been limited to just the cost of the units. The cost of the initial on-board spares was provided by the vendor furnishing the units and did not include a cost of stowage aboard ship since this was considered approximately equal among the alternate approaches.

Operating costs. Tables III, IV, and V show the operating costs of the approaches for a twenty-year life. The estimates of cost for the operation of the equipment included fuel cost, a supply overhead cost based on a Navy-supplied factor of $100 per year for each new item introduced into the Federal supply system, the cost of spares consumed during operation, required equipment exchanges, manning costs, and costs of overhauls. As shown by the tables, these costs were calculated for the year in which they occurred. This was accomplished by utilizing an operation profile which provided the information needed as to the time occurrence of each event such as steaming, in-port operation, repair availability and overhaul activity. It is important to be able to time-phase these costs as the next step is to escalate them at a rate of 4 percent and then discount them by the present value concept at an interest rate of 10 percent. This was accomplished by multiplying each year's cost by an appropriate combined factor, Table VIII, and summing them into a total escalated/discounted operating cost. Table VI shows the total escalated and discounted operating cost of each approach.

Total life-cycle cost. The final calculation of the total life-cycle cost of each approach requires the addition of total acquisition costs to the total escalated and discounted operating costs. Table VII shows this calculation and presents the total life-cycle cost of each approach.

Analysis. As shown by Table VII, the approach having the lowest life-cycle cost is Approach A, the diesel driven generator sets. It should be noted that this was not the approach having the lowest acquisition cost. If the equipment selection had been made on the basis of acquisition cost, then Approach C would have been selected. Approach C was the gas turbine driven generator sets supplied by Vendor Z.

This study shows that the operating costs of the gas turbines are quite significant when compared to the operating costs of diesel driven generator sets. The outstanding differences occur in the cost elements for fuel and exchanges. The increased cost in fuel is understood, since the gas turbines require a higher grade fuel and are known to have a higher fuel consumption. The cost element called "exchange" is somewhat unique in that there is no cost associated with this element for the diesel units but it is quite substantial for the gas turbines. The reason for this is that the workmanship required for repair of gas turbines is so sophisticated that it is the practice of the ship operator to simply exchange his turbines for new units after so many operating hours rather than an overhaul as is the case with the diesel engines.

TABLE I

CHARACTERISTICS OF ALTERNATE APPROACHES FOR SHIP SERVICE GENERATOR SETS

Characteristics	Approaches		
	A	B	C
Number of sets required per vessel	2	2	2
Type of prime mover	Diesel	Gas-Turbine	Gas-Turbine
Source of prime mover	Vendor X	Vendor Y	Vendor Z
Operating RPM of gas turbine	--	1200	1800

NOTE: Vendors X, Y, and Z are acceptable vendors as a source of supply for this equipment.

TABLE II

ACQUISITION COSTS OF THE ALTERNATE APPROACHES FOR SHIP SERVICE GENERATOR SETS
COST IN THOUSANDS

Cost Element	Approaches		
	A	B	C
Inventory Introduction	0.5	2.0	2.0
Procurement and Installation	919.5	944.0	852.0
Initial On-board Spares	24.5	25.0	25.0
Government Overhead Factor	160.5	165.0	149.0
Total Acquisition Costs	1105.0	1136.0	1028.0

NOTE: 1) The Inventory Introduction cost is based on a Navy supplied cost factor of $250 per new item introduced into the supply system.

2) The Government Overhead Factor is based on a Navy supplied cost factor of 17 percent of the sum of procurement, installation, and initial on-board spares costs.

3) All costs above are per ship in a six-ship system.

TABLE III

OPERATING COSTS OF THE ALTERNATE APPROACH A FOR SHIP SERVICE GENERATOR SETS COST IN THOUSAND DOLLARS

Year	Fuel	Supply	Spares	Exchanges	Manning	Overhaul	Total	* Total Discounted & Escalated
1	115.0	.2	5.2	--	57.7	--	178.1	168.4
2	136.0	.2	5.2	--	57.7	--	199.1	178.0
3	166.0	.2	5.2	--	57.7	--	229.1	193.6
4	166.0	.2	5.2	--	57.7	--	229.1	183.1
5	162.0	.2	5.2	--	57.7	14.4	239.5	180.9
6	162.0	.2	5.2	--	57.7	--	225.1	160.8
7	166.0	.2	5.2	--	57.7	--	229.1	154.7
8	136.0	.2	5.2	--	57.7	--	199.1	127.1
9	166.0	.2	5.2	--	57.7	--	229.1	138.3
10	162.0	.2	5.2	--	57.7	16.0	241.1	137.6
11	162.0	.2	5.2	--	57.7	--	225.1	121.5
12	166.0	.2	5.2	--	57.7	--	229.1	116.9
13	166.0	.2	5.2	--	57.7	--	229.1	110.5
14	136.0	.2	5.2	--	57.7	--	199.1	90.8
15	161.0	.2	5.2	--	57.7	17.8	241.9	104.3
16	162.0	.2	5.2	--	57.7	--	225.1	91.8
17	166.0	.2	5.2	--	57.7	--	229.1	88.3
18	166.0	.2	5.2	--	57.7	--	229.1	83.5
19	166.0	.2	5.2	--	57.7	--	229.1	78.9
20	115.0	.2	5.2	--	57.7	--	178.1	58.0
							4413.2	2567.0

* See Table VIII for Discounting and Escalation Factors.

TABLE IV

OPERATING COSTS OF THE ALTERNATE APPROACH B
FOR SHIP SERVICE GENERATOR SETS
COST IN THOUSAND DOLLARS

Year	Fuel	Supply	Spares	Exchanges	Manning	Overhaul	Total	* Total Discounted & Escalated
1	161.0	1.0	1.8	150.0	54.8	--	368.6	348.5
2	190.0	1.0	1.8	150.0	54.8	--	397.6	355.4
3	227.0	1.0	1.8	150.0	54.8	--	434.6	367.3
4	227.0	1.0	1.8	150.0	54.8	--	434.6	347.2
5	222.0	1.0	1.8	150.0	54.8	12.3	441.9	333.8
6	222.0	1.0	1.8	150.0	54.8	--	429.6	306.9
7	227.0	1.0	1.8	150.0	54.8	--	434.6	293.5
8	190.0	1.0	1.8	150.0	54.8	--	397.6	253.8
9	227.0	1.0	1.8	150.0	54.8	--	434.6	262.3
10	222.0	1.0	1.8	150.0	54.8	14.0	443.6	253.1
11	222.0	1.0	1.8	150.0	54.8	--	429.6	231.8
12	227.0	1.0	1.8	150.0	54.8	--	434.6	221.7
13	227.0	1.0	1.8	150.0	54.8	--	434.6	209.7
14	190.0	1.0	1.8	150.0	54.8	--	397.6	181.3
15	221.0	1.0	1.8	150.0	54.8	15.7	444.3	191.5
16	222.0	1.0	1.8	150.0	54.8	--	429.6	175.1
17	227.0	1.0	1.8	150.0	54.8	--	434.6	167.5
18	227.0	1.0	1.8	150.0	54.8	--	434.6	158.4
19	227.0	1.0	1.8	150.0	54.8	--	434.6	149.7
20	161.0	1.0	1.8	150.0	54.8	--	368.6	120.0
							8460.0	4928.5

* See Table VIII for Discounting and Escalation Factors.

TABLE V

OPERATING COSTS OF THE ALTERNATE APPROACH C FOR SHIP SERVICE GENERATOR SETS COST IN THOUSAND DOLLARS

Year	Fuel	Supply	Spares	Exchanges	Manning	Overhaul	Total	* Total Discounted & Escalated
1	147.0	1.0	1.8	150.0	54.8	--	354.6	335.3
2	173.0	1.0	1.8	150.0	54.8	--	380.6	340.2
3	207.0	1.0	1.8	150.0	54.8	--	414.6	350.4
4	207.0	1.0	1.8	150.0	54.8	--	414.6	331.3
5	203.0	1.0	1.8	150.0	54.8	12.3	422.9	319.5
6	203.0	1.0	1.8	150.0	54.8	--	410.6	293.3
7	207.0	1.0	1.8	150.0	54.8	--	414.6	280.0
8	173.0	1.0	1.8	150.0	54.8	--	380.6	243.0
9	207.0	1.0	1.8	150.0	54.8	--	414.6	250.3
10	203.0	1.0	1.8	150.0	54.8	14.0	424.6	242.3
11	203.0	1.0	1.8	150.0	54.8	--	410.6	221.6
12	207.0	1.0	1.8	150.0	54.8	--	414.6	211.5
13	207.0	1.0	1.8	150.0	54.8	--	414.6	200.0
14	173.0	1.0	1.8	150.0	54.8	--	380.6	173.6
15	202.0	1.0	1.8	150.0	54.8	15.7	425.3	183.3
16	203.0	1.0	1.8	150.0	54.8	--	410.6	167.4
17	207.0	1.0	1.8	150.0	54.8	--	414.6	159.7
18	207.0	1.0	1.8	150.0	54.8	--	414.6	151.1
19	207.0	1.0	1.8	150.0	54.8	--	414.6	142.8
20	147.0	1.0	1.8	150.0	54.8	--	354.6	115.5
							8087.0	4712.1

* See Table VIII for Discounting and Escalation Factors.

TABLE VI

OPERATING COSTS OF THE ALTERNATE APPROACHES FOR SHIP SERVICE GENERATOR SETS
COST IN THOUSAND DOLLARS

	Approach		
	A	B	C
Total Unescalated and Undiscounted Operating Costs	4413.2	8460.0	8087.0
Total Escalated and Discounted Operating Costs	2567.0	4928.5	4712.2

NOTE: The escalation of operating costs was computed using 4 percent for the escalation rate. The discounting of operating costs was computed by the present value concept at an interest rate of 10 percent.

TABLE VII

TOTAL LIFE-CYCLE COST OF THE ALTERNATE APPROACHES FOR SHIP SERVICE GENERATOR SETS COST IN THOUSAND DOLLARS

	Approach		
	A	B	C
Total Acquisition Cost	1105.0	1136.0	1028.0
Total Escalated and Discounted Operating Cost	2567.0	4928.5	4712.1
Total Life-Cycle Cost	3672.0	6064.5	5740.1

TABLE VIII

DISCOUNTING AND ESCALATION TABLE

Year	*Escalation (4%)	**Discounting (10%)	Combined Escalation/Discount Factor $\left[(1 + r_1)^n \times \frac{1}{(1 + r_2)^n}\right]$
1	1.0400	.9091	.9455
2	1.0816	.8265	.8939
3	1.1248	.7513	.8451
4	1.1699	.6830	.7990
5	1.2167	.6209	.7554
6	1.2653	.5645	.7143
7	1.3159	.5132	.6753
8	1.3685	.4665	.6384
9	1.4233	.4241	.6036
10	1.4802	.3855	.5706
11	1.5395	.3505	.5396
12	1.6010	.3186	.5101
13	1.6650	.2897	.4824
14	1.7317	.2633	.4560
15	1.8009	.2394	.4311
16	1.8730	.2176	.4076
17	1.9479	.1978	.3853
18	2.0258	.1799	.3644
19	2.1068	.1635	.3445
20	2.1911	.1486	.3256
21	2.2788	.1351	.3079
22	2.3699	.1228	.2910
23	2.4647	.1117	.2753
24	2.5633	.1015	.2602
25	2.6658	.0923	.2461

* Factors derived from present value formula for escalation, present value = $(1 + r_1)^n$, where

r_1 = escalation rate (4%)
n = year (1 to 25)

** Factors derived from present value formula for discounting, present value = $\frac{1}{(1 + r_2)^n}$, where

r_2 = discount rate (10%)
n = year (1 to 25)

APPENDIX C

TIME VALUE OF MONEY

As explained in Managerial Economics, Decision Making and Forward Planning by Milton H. Spencer and Louis Siegelman, Money has a time value. Dollars at different points in time cannot be made directly comparable unless they are first expressed in terms of a common denominator. The common denominator which is used is the interest rate.

Thus, when money can be invested at 10 percent interest, a dollar today does not have the same value as a dollar next year, since a dollar today can be invested so that it is worth \$1.10 next year. Similarly, \$1.10 next year is not equivalent to \$1.10 in the following year, because \$1.10 next year can be invested at 10 percent so as to be worth \$1.10 plus 10 percent of that amount, or a total of \$1.21 in the following year.

It is clear that this compounding process can be extended as far into the future as we like. Further, by this process, one can equate a given sum of money at the present time with another sum of money at any future time. Thus, in line with the above example, the sum of \$1.00 today is, at 10 percent interest, equivalent to \$1.10 next year, or to \$1.21 in the following year, or to still greater amounts in later years.

The reverse of compounding is discounting. Whereas, in compounding one moves from the present into the future, in discounting one moves from the future back to the present. Thus, at 10 percent interest, how much is \$1.21 two years from now worth today? We know from the previous example that \$1.00 now is worth \$1.21 two years from today at 10 percent. Therefore, we may say that \$1.21 two years hence at 10 percent has a present value of \$1.00, or a present value factor of $1 \div 1.21 = .8264$. The formula for discounting is readily derived as present value factor = $\frac{1}{(1 + r_2)^n}$ where r_2 = discounting rate and n = years.

We are all aware of the effect escalation has on value of money. If \$1.00 escalates by 4 percent, one year hence \$1.04 has the same value as \$1.00 today. Two years from today at 4 percent escalation, we need \$1.0816, 1.04 + .04 (1.04), for the same value as \$1.00 today; therefore, the compound amount \$1.00 to be expended two years hence is \$1.0816 at 4 percent escalation. Thus, the accumulation factor at 4 percent escalation for year two is 1.0816, which is determined by the accumulation factor equation $(1 + r_1)^n$ where r_1 = rate of escalation and n = years. A check of the accumulation value factor when $r_1 = 4\%$ and $n = 2$ is as follows: $(1 + r_1)^n = (1 + .04)^2 = (1.04)^2 = 1.0816$.

Since we have had inflationary trends recently which decrease the value of money, escalation may be used. Also, we know or hope that money has a time value due to expected return on investment. Therefore, escalation and discounting are used in arriving at overall present worth of money to be expended at a future date. An example of escalating and discounting to find a combined factor is as follows, where:

r_1 = 4% = escalation rate

r_2 = 10% = discounting rate

n = 2 = year

$$\text{Combined factor} = (1 + r_1)^n \times \frac{1}{(1 + r_2)^n}$$

$$\text{Combined factor} = (1 + .04)^2 \times \frac{1}{(1 + .10)^2}$$

$$\text{Combined factor} = 1.0816 \times \frac{1}{1.21} = \underline{\underline{.8939}}$$

Therefore, the value of \$1.00 to be expended two years hence, escalated at 4% and discounted at 10%, is \$.8939.

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