AN APPROACH FOR DEVELOPING A PRELIMINARY COST ESTIMATING METHODOLOGY FOR USCG VESSELS

by

MARK JAMES GRAY

BaSC Mech. Eng., University of Waterloo
(1978)
MaSC Mech. Eng., University of Waterloo
(1980)

SUBMITTED TO THE DEPARTMENT OF
OCEAN ENGINEERING
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF

MASTER OF SCIENCE
IN
NAVAL ARCHITECTURE AND MARINE ENGINEERING

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June 1987

Signature of Author: ______________________
Department of Ocean Engineering
May 8, 1987

Certified by: ______________________
Henry S. Marcus
Associate Professor, Marine Systems
Thesis Supervisor

Accepted by: ______________________
A. Douglas Carmicheal
Chairman, Ocean Engineering Departmental Committee

AN APPROACH FOR DEVELOPING A PRELIMINARY COST ESTIMATING

METHODOLOGY FOR USCG VESSELS

by

MARK JAMES GRAY

Submitted to the Department of Ocean Engineering
on May 8, 1987 in partial fulfillment of the
requirements for the Degree of Master of Science in
Naval Architecture and Marine Engineering

ABSTRACT

A study was done on methods used to estimate new ship construction costs during the feasibility/preliminary design phase. Costs were functionally related to SWBS weight groups and design and fabrication complexities. Other factors affecting shipyard construction costs include inflation, production learning and scheduling.

Cost estimating relationships (CERs) are derived from historical data and are normalized to reflect technical cost trends in ship construction. The accuracy of the CERs is dependent upon the quality and range of the data. Cost risk or uncertainty can be quantified provided the probability distributions of the input data and CER regression coefficients are known.

Five cost models are examined and found to be quite similar in their approach. Differences can be attributed to the different needs of the organizations that support their use. The models are applicable to a wide range of ship types and displacements, depending upon the data available during their development. Cost estimates during the feasibility design phase are thought to be accurate to within 10-20% of actual costs.

In order for cost analysis to have a measurable impact during ship design, costing must be an integral part of the decision-making process. Before this can occur, management must have confidence in the costing team's ability to produce high quality estimates.

Thesis Supervisor: Dr. Henry S. Marcus

Title: Associate Professor of Marine Systems

ACKNOWLEDGEMENTS

I would like to express my appreciation to the many people who assisted me in this research endeavor.

Thanks to my thesis advisor, Professor Henry Marcus, not only for his guidance and direction, but also for allowing me the freedom to explore and learn on my own.

Special thanks to Dennis Clark, Mike Jeffers and Bob Jones of the Costing and Design Systems Office, Code 1204 at David Taylor Naval Ship Research and Development Center (DTNSRDC), for their support and invaluable assistance in the research and for sharing with me their philisophical understanding of cost engineering in particular, and life in general.

The assistance of Jim Herd, Tzee-Nan Lo and especially Ron Schnepper in the Ships Cost Analysis Division, NCA-2 at the Naval Center for Cost Analysis was greatly appreciated. Thanks also to Mike Hammes and Bob Simpson in the Cost Estimating & Analysis Division, SEA 017 at the Naval Sea Systems Command. These people gave freely of their time and effort during this study and supplied invaluable information.

Several individuals in the United States Coast Guard deserve special mention. Thanks to Lt John Tuttle, Office of Acquisition and Lt Shawn Smith, Office of Research & Development for their continuing interest in this work, and to Richard Rounsevelle of the Planning and Estimating Section in the Office of Engineering for his helpful suggestions.

To all the people who spent the time talking and explaining the seemingly infinite aspects of cost estimating to me, thank you all. I hope that I have managed to include all of the useful insights that were given to me.

I have saved my final note of appreciation and thanks for my wife Louise, who provided endless encouragement and love throughout this study.

This thesis work was funded by the Office of Research & Development of the United States Coast Guard.

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

Page

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

For years, ship design managers had to worry mainly about answering one question; "How will the system perform?" More recently, due to the imposition of budgetary constraints within government agencies, managers must also ask another question; "How much will it cost?"

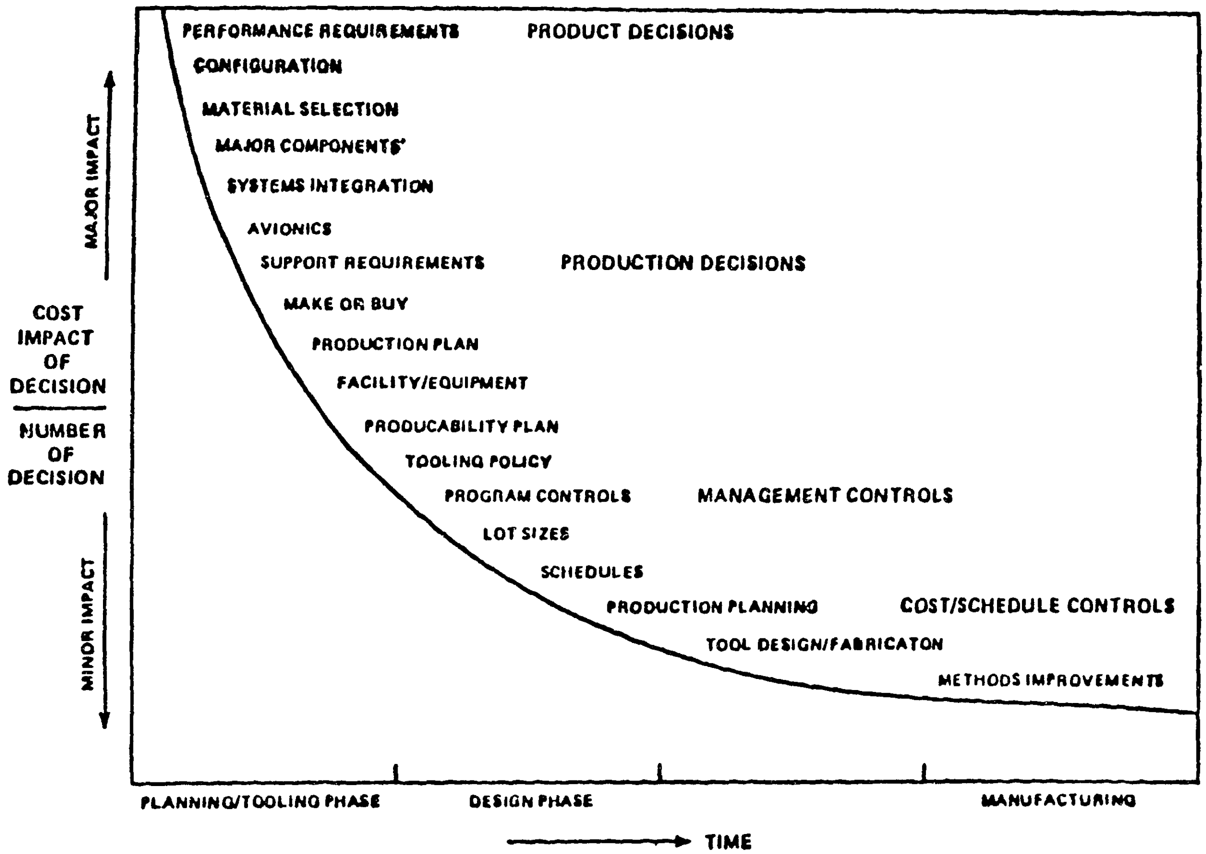
This increasing concern with system acquisition costs led to the implementation of design-to-cost (DTC) policies in the early 1970s (e.g., see Ref. 45). DTC required the early establishment of realistic cost goals and a continuing effort to maintain them throughout the design and production period. This type of design strategy has led to the expanded use of synthesis models for cost and performance trade-offs and has put more emphasis on early definition of the complete ship system.

Synthesis models (e.g., the US Navy's ASSET program) make it possible to quantify any particular capability or figure of merit, and assess the technical and cost impacts of its effect on the ship's systems. The figure of merit provides a measure of how well the ship accomplishes its mission (e.g., military effectiveness). The iterative nature of trade-off studies using synthesis models allows a design to evolve which maximizes (or minimizes for a cost figure of merit) the figure of merit based upon the ship's design and subject to technical, schedule and funding constraints.

The importance of establishing a credible cost estimating capability early in the design phase cannot be overlooked. Figure 1.1 gives a qualitative indication of the cost impact of decisions throughout a generic acquisition process. It is important to note the major impact of decisions in the planning (i.e., feasibility/conceptual) phase (e.g., see Ref. 3). The trend indicates that the maximum leverage for costs occurs during the early design phases. Therefore, the ability to perform a large number of performance/system versus cost trade-offs during this early design stage will greatly assist in minimizing cost uncertainty during later design phases.

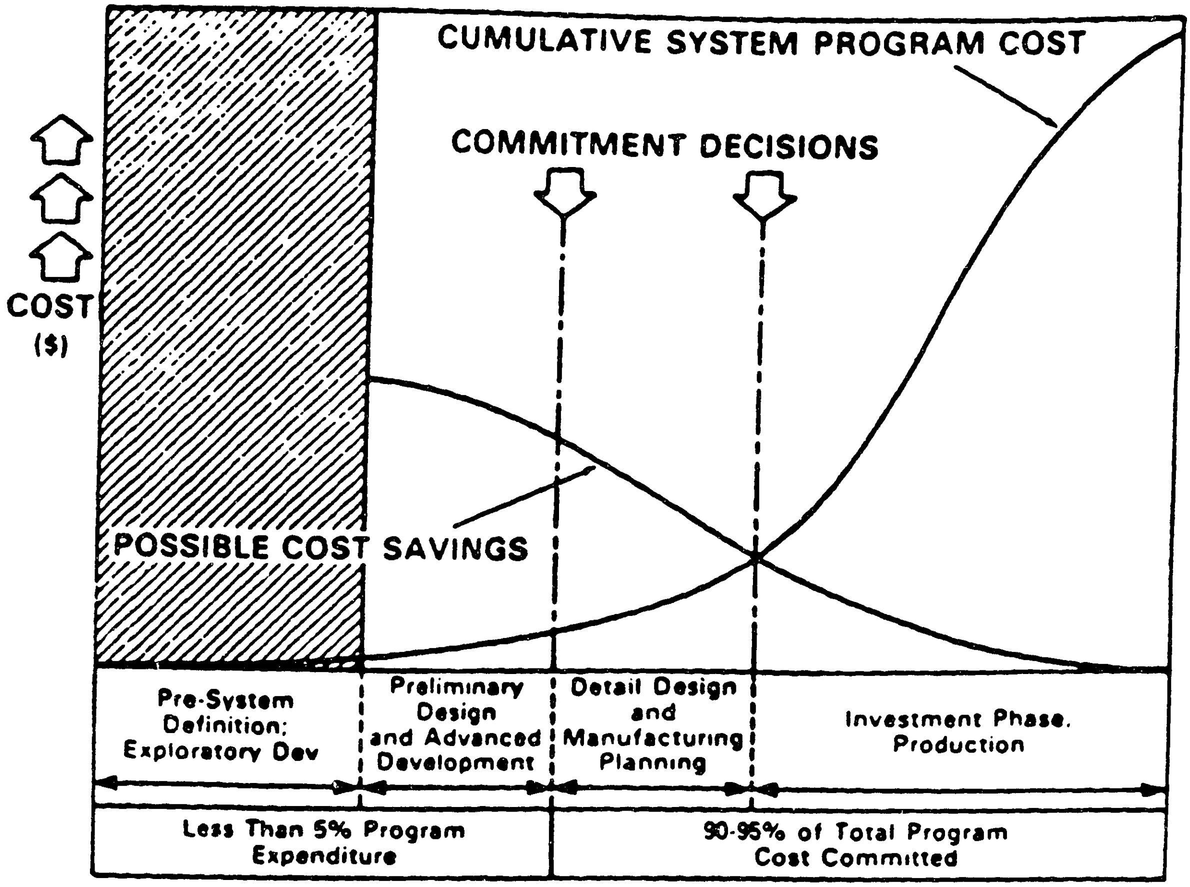
The advantages of incorporating performance/system versus cost trade-offs for the USN's DDG 51 is documented in Ref. 5. The approach was described as a closed loop feedback control process involving the review of the design for conformance to an established budget, and then making decisions to change the design in the areas where the budget constraints were exceeded.

Cost analysis during early design is in the enviable position of applying maximum effect for minimal cost (relative to the total program cost). The inverse effect for cost impact versus cumulative program cost is illustrated in Fig. 1.2. The relationship is particularly applicable to the introduction of advanced technologies into ship design. The greatest savings result from the introduction of innovations early in the development program. Attempts to incorporate innovation at later phases, when the design is committed to alternative technologies, can become prohibitively expensive.



Cost Impact of Decisions during a Design Process
(Ref. 60)

Figure 1.1



Cost Savings versus Cumulative Program Costs
(Ref. 15)

Figure 1.2

Having established that potential cost savings are a primary motivation for early ship design definition, it follows that the timely and credible estimation of ship costs during this early stage would help to: "reduce ship acquisition and life cycle operating costs; analyze cost drivers and technologies impact on cost drivers, and; improve the naval engineering awareness of cost early in the ship design process" (Ref. 26).

The purpose of this study is twofold; to document the techniques used to cost ships during these early design phases, and; to address the major areas involved with the establishment of cost estimating capabilities. Although these topics are listed sequentially, there is a high degree of interrelationship between costing techniques and the needs and resources of an organization that influence its costing requirements.

The first step in this study is to describe a frame of reference for the different levels of cost estimating quality that are used, the technical detail that is commensurate with each level, and where in the ship design process these different estimate qualities can be found.

Ship costing is a multi-faceted discipline, involving overlapping aspects of engineering, economics, business management, statistics and human resources. The aim of Chapter 2 is to provide a general understanding of the ship costing field and its terminology. The development of cost estimating relationships and their uncertainty, crucial to early stage estimating, is discussed in some detail.

A description of specific cost estimating techniques can be found in Chapter 3. The methodologies from five models used by various US Navy agencies and the US Coast Guard are included. The amount of information presented is dependent upon the documentation available in the open literature or volunteered.

A fairly qualitative comparison of the models was dictated by the proprietary nature of the material. Current ship cost estimating models typically relate ship weights to cost as a function of technology level.

The previous chapters have concentrated on the technical aspects of cost estimating. Chapter 4 examines the management and human resources factors that must be considered before the technical cost estimating capability can be integrated within the organizational operating environment. As with any corporate entity, a cost analysis group must receive support from all levels of management if it is to contribute effectively.

The final chapter presents the conclusions and recommendations of the study. Any discussion of costing must address the effects of the following areas on the credibility of the estimates received. These are: (1) the experience of the cost engineering group; (2) the development of appropriate cost-estimating algorithms, and ; (3) the range and applicability of the database.

The all-encompassing recommendation for implementing a cost estimating capability within any organization is that of maintaining a long-term commitment to its operation; primarily in the areas of personnel levels, training standards and data collection functions.

1.1 SHIP DESIGN PROCESS

There are three principal divisions in the NAVSEA (Naval Sea Systems Command) ship design process;

(1) exploratory design

(2) acquisition design

(3) service life design

Since this study deals with early stage new ship cost estimating, only the exploratory and acquisition design phases are of concern. The four acquisition phases are feasibility studies, preliminary design, contract design and detail design.

Fig. 1.3 indicates the order that the design process follows, starting from a statement of mission requirements from the customer (e.g., the Navy or Coast Guard) and ending with detail design. The dotted box in Fig. 1.3 encloses the feasibility design phase, which is the phase of primary interest for this study. Note the overlap with both exploratory studies and preliminary design.

Typically, these phases can be differentiated from each other by the increase in technical definition of the ship (i.e., a reduction in the technical uncertainty) as the design progresses from exploratory through to detail design. At any given stage in the ship's design, all of the ship systems will be defined to the same level of detail. Table 1.1 illustrates the increase in technical definition for a propulsion plant.

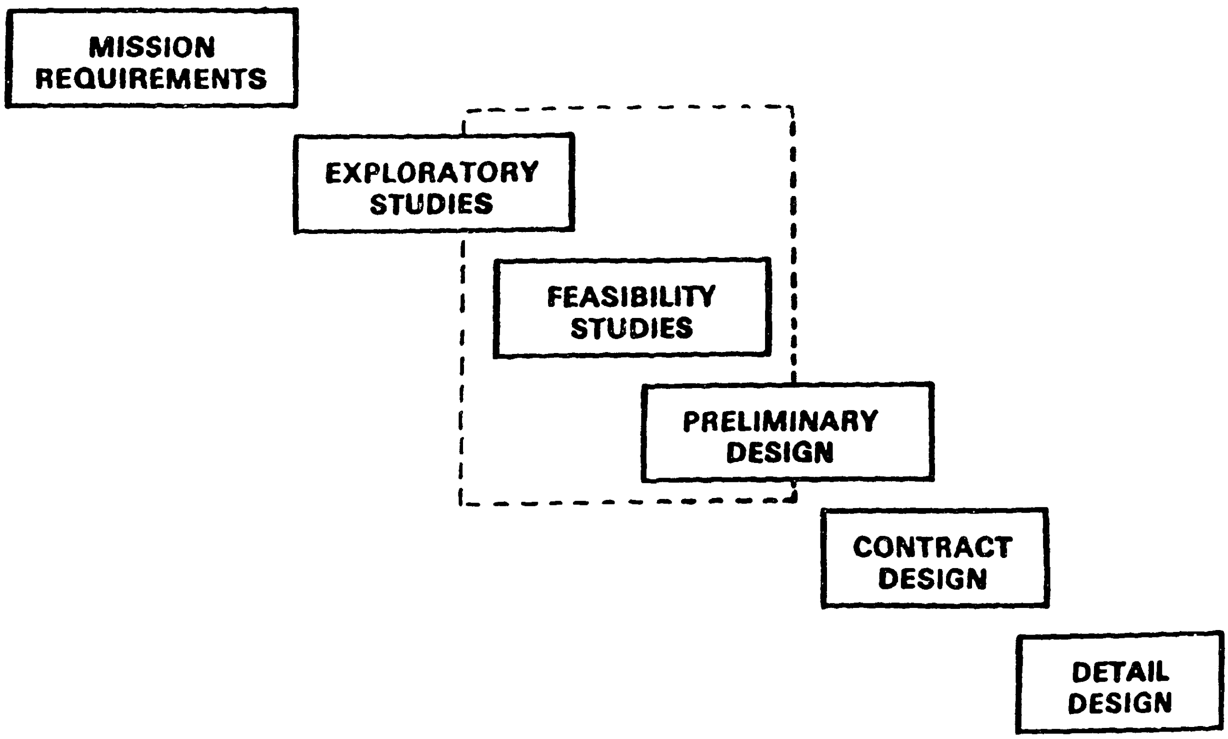
Level	Technical Definition
0	Whole Ship
1	Propulsion Plant
2	Propulsion Units
3	Gas Turbines
4	Engine Starter System
5	Engine Starter
.	.
.	.
.	.

Example of Increasing Level of Technical Definition
(Ref. 26)

Table 1.1

In an R&D environment, the technical definition can increase to a level commensurate with detail design and yet the ship will remain in the exploratory studies phase. Fig. 1.4 links the levels in Table 1.1 with cost model purpose for ship designs in the exploratory phase. For example, a high degree of technical definition is required for costing detailed technology assessments.

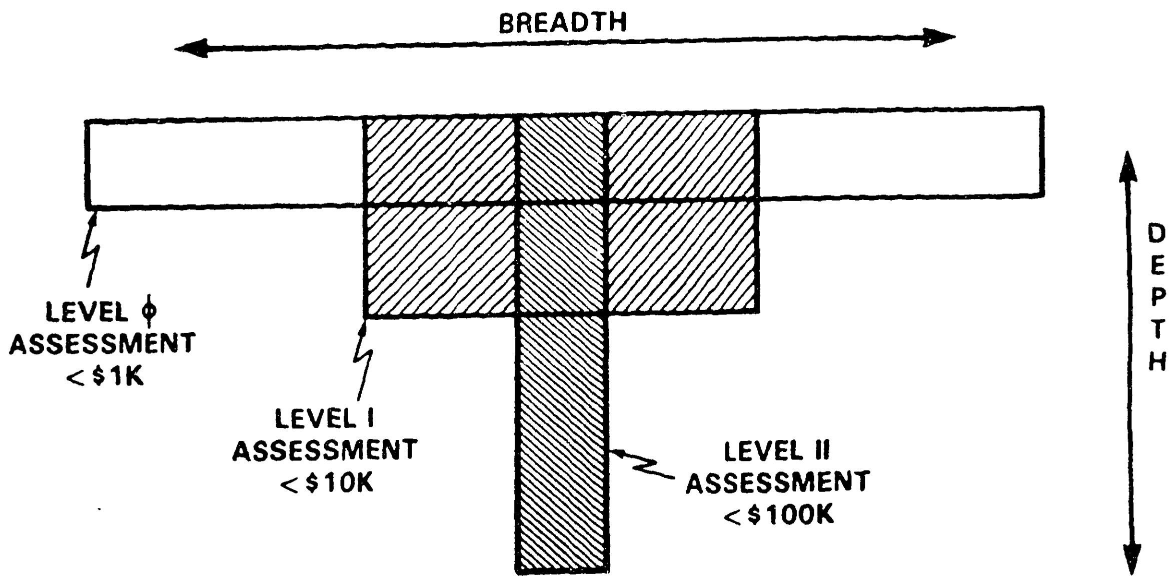
Fig. 1.4 also illustrates the relationships between the number of systems examined (breadth), the number of parts being added together for each system (depth), and the relative cost. If



The Ship Design Process
(Ref. 60)

Figure 1.3

MODEL LEVEL	SWBS LEVEL	COST MODEL PURPOSE
ϕ	WHOLE SHIP	EARLIEST-STAGE, CONCEPT DEVELOPMENT; PROGRAM COSTS, SCHEDULING EFFECTS
1	ONE-DIGIT (GROUP)	PROGRAM MANAGERS, RESOURCE APPLICATION AND APPORTIONING
2	TWO-DIGIT (SUB-GROUP)	↓
3	THREE-DIGIT (ELEMENT)	DESIGN ANALYSIS, TECHNOLOGY ASSESSMENT, INTEGRATION ANALYSIS, ALTERNATIVE SYSTEMS ANALYSIS
•	•	↓
•	•	
•	•	



Exploratory Cost Model Levels and Their Purpose
(Ref. 26)

Figure 1.4

the definition is at the whole ship level, only one system with one part needs to be considered and the cost analysis is inexpensive. As the number of systems increases (e.g., hull, propulsion, electrical, etc.) the breadth decreases, and as the parts that each system is broken down into increases the depth (and the cost of analysis) increases.

1.2 SWBS WEIGHT GROUPS

The Ship Work Breakdown Structure (SWBS) provides a common means of communicating the level of technical definition between the ship designer, shipyard and cost estimator. The major elements of the SWBS system that are of interest for ship costing are listed in Table 1.2. Examples of some of the items that make

SWBS Group	Description
100	Hull Structure
200	Propulsion Plant
300	Electric Plant
400	Command & Surveillance
500	Auxiliary Systems
600	Outfit & Furnishings
700	Armament
800	Design & Engineering Services
900	Construction Services

SWBS One-Digit Weight Groups

Table 1.2

Group	Description	Definition
1	Hull structure	Shell plating or planking; longitudinal and transverse framing; innerbottom plating; platforms and flats below lowermost continuous deck; fourth deck; third deck; second deck; main deck or hangar deck; forecastle deck (including platforms, flats, and decks between main and gallery deck); gallery deck; flight deck; landing platforms and special purpose decks above weather deck (includes catapult troughs); superstructures; foundations for main propelling machinery; foundations for auxiliaries and other equipment; structural bulkheads; trunks and enclosures; structural sponsors; armor; aircraft fuel saddle tank structure; structural costings, forgings, and equivalent weldments; sea chests; ballast and buoyancy units; doors and closures, special purpose; doors, hatches, manholes, and scuttles, nonballistic; doors hatches, manholes, and scuttles, ballistic; masts and king posts; compartment testing.
2	Propulsion	Boilers and energy converters; propulsion units; main condensers and air ejectors; shafting, bearings, and propellers; combustion air supply system; uptakes and smoke pipes; propulsion control equipment; main steam system; feedwater and condensate systems; circulating and cooling water system; fuel oil service system; lube oil system.
3	Electric plant	Electric power generation; power distribution switchboards; power distribution system (cable); lighting system - distribution and fixtures.
4	Communication and control	Navigational system and equipment; interior communications systems; armament control systems; countermeasure and ships' protective systems (except electronic); electronic systems including electronic countermeasures.
5	Auxiliary systems	Heating system; ventilation system; air-conditioning system; refrigerating spaces, plant and equipment; gas, HEAF, cargo piping, oxygen-nitrogen, aviation lube oil systems; plumbing installations; firemain, flushing, and sprinkler system; fire extinguishing systems; drainage, trimming, heeling, and ballast systems; freshwater system; scuppers and deck drains; fuel and diesel oil filling, venting, stowage, and transfer systems; tank heating systems; compressed-air systems; auxiliary steam, exhaust steam, and steam drains; buoyancy control system (flooding and venting - submarines); miscellaneous piping systems; distilling plant; steering gear system; rudder; winches, capstans, cranes, and anchor-handling system; elevators, moving stairways, and cargo handling equipment; operating gear for retractable elevating units; aircraft elevators; aircraft arresting gear barriers and barricades; catapults and jet blast deflectors, hydrofoils and lift systems.
6	Outfit and furnishing	Hull fittings; boats, boat stowage and handling; rigging and canvas; ladders and gratings, nonstructural bulkheads and nonstructual doors; painting; deck covering; hull insulation; storerooms, stowages, and lockers; equipment for utility spaces; equipment for workshops; equipment for galley, pantry, scullery, and commissary outfit; furnishings for living spaces; furnishings for office spaces, electronic, and radar; furnishings for medical and dental spaces.
7	Armament	Guns, mounts, and launching devices; ammunition-handling systems; ammunition stowage; special weapon stowage and handling.
8	Design and engineering services	Design and engineering services.
9	Construction service	Staging, scaffolding, and cribbing; launching; trials and docking; temporary utilities and services; material handling and removal; cleaning ship services.

SWBS Group Descriptions
(Ref. 54)

Figure 1.5

make up each group can be found in Fig. 1.5. The summation of one-digit groups 100 through 700 is equal to the weight of the whole ship less load items.

The SWBS classification system allows the ship to be specified at any of three levels; one-, two-, and three-digit. Each higher level indicates a higher degree of technical definition, as can be seen from the examples in Table 1.3. The three-digit SWBS level represents the highest level of definition. Fig. 1.4 shows the SWBS levels of technical definition as they apply to costing during the exploratory phase of ship design.

SWBS Level Breakdown	Technical Description
-	Whole Ship
1-Digit Weight	Hull Structure - Group 100 Electric Plant - Group 300
2-Digit Weight	Hull Decks - Group 130 Lighting Systems - Group 330
3-Digit Weight	Second Deck - Group 132 Lighting Fixtures - Group 332

Examples of Increasing SWBS Level of Technical Definition

Table 1.3

All of the ship costing techniques presented in this study use the SWBS weight groups as the means to classify weights.

1.3 ESTIMATE QUALITY

Estimate quality is related to a variety of factors, the majority of which are programmatic in nature (i.e., acquisition strategy plans). In this section, the estimate quality as related to technical definition only is discussed.

NAVSEA uses a cost estimate classification system which uses letters of the alphabet to designate estimate quality. In increasing level of design definition (i.e., decreasing level of uncertainty) these are ROM (Rough Order of Magnitude), Class F, D, C. Table 1.4 shows the SWBS level of technical definition appropriate for each estimate classification.

Estimate Classification	SWBS Technical Definition	NAVSEA Cost Phase
ROM	Less than Feasibility Study	Planning
F	Feasibility Study 1-Digit Weights	Planning/ Programming
D	Preliminary Design 2-/ 3- Digit Weights	Programming (maybe Budget)
C	End Preliminary Design 3-Digit Weights	Budget

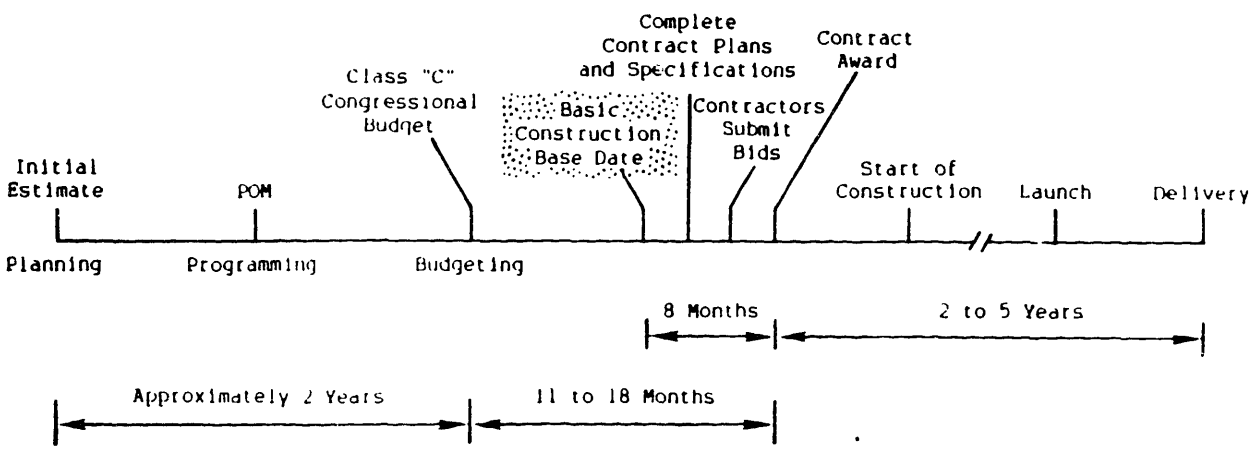
NAVSEA Ship Cost Estimate Classifications
(Ref. 16)

Table 1.4

This study is concerned with ship cost estimating in and around the feasibility phase, corresponding to a Class F estimate. The technical level of definition for this class of estimate is the one-digit SWBS group. Therefore the primary technical input to the estimator for this degree of quality will be an approximate weight for each of the 100-700 SWBS groups listed in Table 1.2 and Fig. 1.5.

The overlap that occurs between design phases means that one-digit SWBS weights are available in the latter stages of exploratory (i.e., conceptual) studies, all through feasibility studies, and on into the initial stages of preliminary design. Of course, one-digit SWBS weights can be calculated by simply adding up the weights of higher level components whenever they become available.

The NAVSEA cost phases referred to in Table 1.4 are divided into the planning, programming and budget phase. Class F estimates are generated in both the planning and programming phases. Fig. 1.6 shows how these phases fit into the "big picture" of ship acquisition. In Fig. 1.6, the initial estimate is a ROM estimate and the POM (Program Objective Memorandum) is issued to supply guidance to the various Navy agencies involved in the acquisition process.



Typical NAVSEA Ship Acquisition Time Line
(Ref. 16)

Figure 1.6

1.4 EARLY SHIP DEFINITION

In order to estimate acquisition costs realistically, the estimator requires a certain amount of information in several categories which relate to the ship's configuration, technical definition, and the design and fabricating specifications. Table 1.5 lists and describes these categories as they are addressed in this study. The inputs for each of the cost models discussed in Chapter 3 are classified according to the cost driver categories listed in Table 1.5.

Cost Driver	Description
Technology	technology available, state-of-the-art design influences
Ship Design	weights, margins, design standards, component selection
Manufacturing	fabrication techniques, degree of automation, learning
Programmatic	type of contract, procurement strategy
Economic	escalation, inflation & interest rates, discounting
Operations & Support	maintenance, personnel, fuel, spares

Common Cost Driver Classifications
(Ref. 19)

Table 1.5

As a means for providing the necessary information for each of the cost driver categories in Table 1.5, various synthesis models have been developed. Synthesis models are intended to provide a large number of feasible ship designs, quickly and consistently, in accordance with a set of design specifications. Detailed discussions of synthesis models for Coast Guard cutters and patrol boats can be found in Refs. 7 and 8, respectively. The US Navy introduced the CONFORM (surface ship continuing CONcept FORMulation) to provide consistent feasibility designs and cost estimates (e.g., see Ref. 46).

Fig. 1.7 illustrates the systems that influence the development of a feasible ship design. The design must operate within the constraints imposed by the R&D community, naval manpower levels, maintenance and supply capabilities, and manufacturing practises.

An indication of the minimum amount of information required to estimate the lead ship construction cost is given in Table 1.6. The GFM (Government Furnished Material) consists almost exclusively of those items of ordnance and electronics that comprise the combat system. Follow ship costs can be related to lead ship costs through the application of learning theory.

A similar list for O&S (Operating and Support) costs is given in Table 1.7. This list represents the information required by the USCG's CASHWHARS financial analysis program. Recent unpublished CG patrol boat feasibility studies have used the ASSET synthesis model as a front-end to the CASHWHARS program.

Ship Type
Hull material and Fabrication methods
Listing of major GFM items
Seven SWBS Group Weights
Propulsion Plant and SHP
Electrical Plant Capacity and Number
Crew Size
Special Equipments (e.g., active fin stabilizers, etc.)

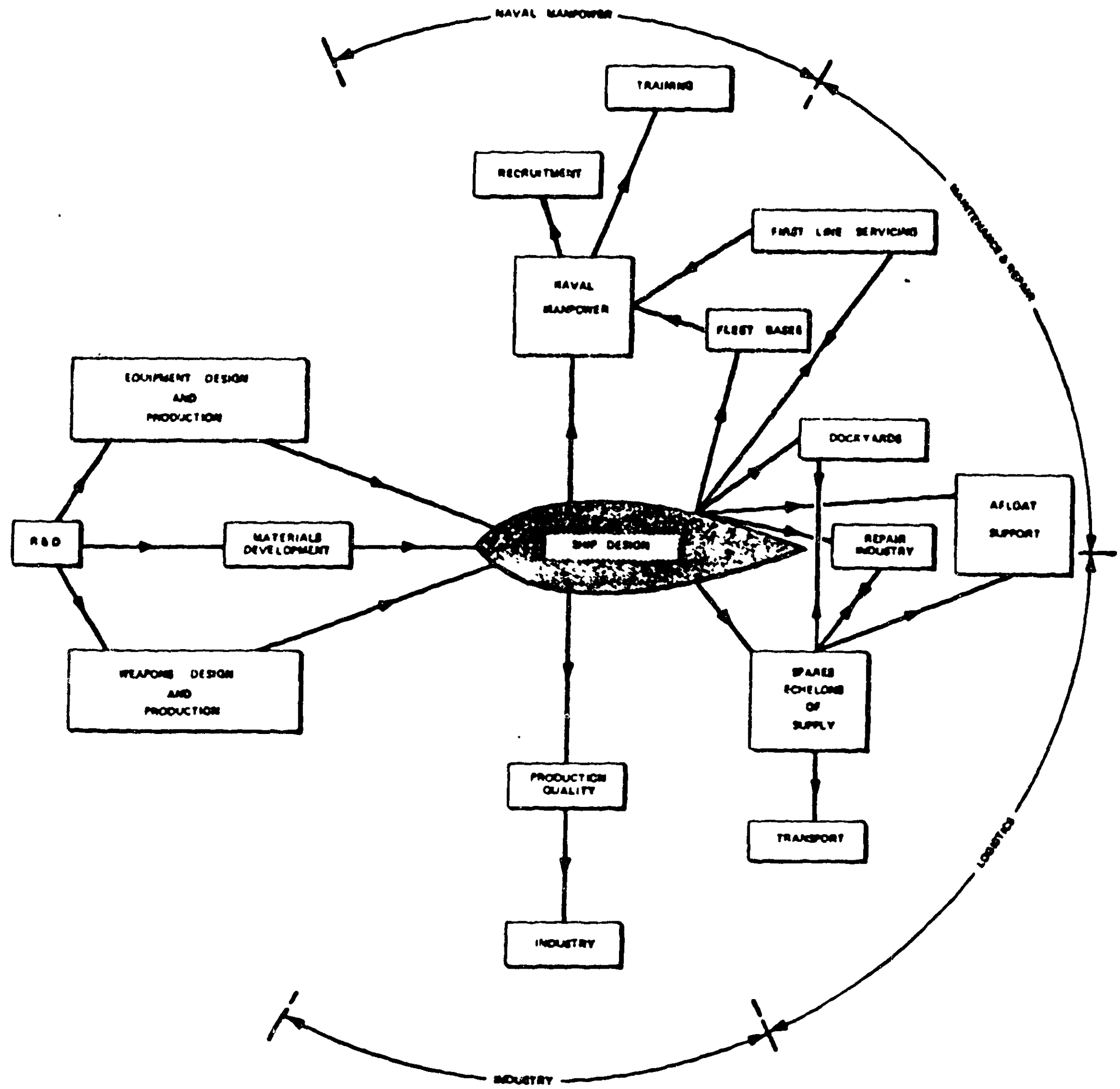
Minimum Lead Ship Construction Cost Data
(Ref. 6)

Table 1.6

Interest & Inflation Rates
Fuel Costs
Vessel Maintenance Schedules
Operating Hours
Mission Profile
Crewing
Vessel Life

Minimum O&S Cost Data
(Ref. 34)

Table 1.7



Systems Influence on Ship Design
(Ref. 47)

Figure 1.7

1.4.1 Effect of Design & Construction Standards

Kehoe et al (Ref. 49) looked at the effect of different NATO country design practices on the size and total ship investment cost of a typical antisubmarine warfare (ASW) frigate. The total investment cost included the basic shipbuilders cost, GFM, and other related costs (e.g., standard allowances for change orders, escalation, electronics and weapons cost growth and cost growth for future characteristics changes).

The seven major design practises listed below were examined;

(1) design & construction margins

(2) hull forms

(3) design displacement

(4) sustainability

(5) survivability

(6) in-service margins

(7) habitability

Sustainability and design margins were found to be the most contributing factors for increased ship size and cost.

Ship construction costs can also be expected to be significantly higher for different specification levels. For example, the use of military instead of commercial specifications will result in increased costs.

1.4.2 Incorporating New Technology

Typically, uncertain cost predictions are not the greatest hurdle to be overcome when considering the introduction of a new technology (Ref. 22). Far greater impact can be expected with political, national security, environmental, energy and societal influences. However, only the cost issue is addressed in this section.

When judging whether the use of a new material or technology to be incorporated into a ship design is cost effective, the cost analysis should be based on its LCC, including R&D, design, manufacture and O&S. The high degree of uncertainty expected with such an analysis must be quantifiable to allow for risk trade-off studies. Cost risk analysis is discussed in Chapter 2.

For shipyard applications, the decision to implement new technologies is primarily based on the economic benefits expected from predicted productivity and efficiency gains. Since the services and skills of the shipbuilder only account for about 20% of the total ship program cost, major gains in shipyard productivity from new technologies affect a relatively small amount of the total costs (Ref. 24).

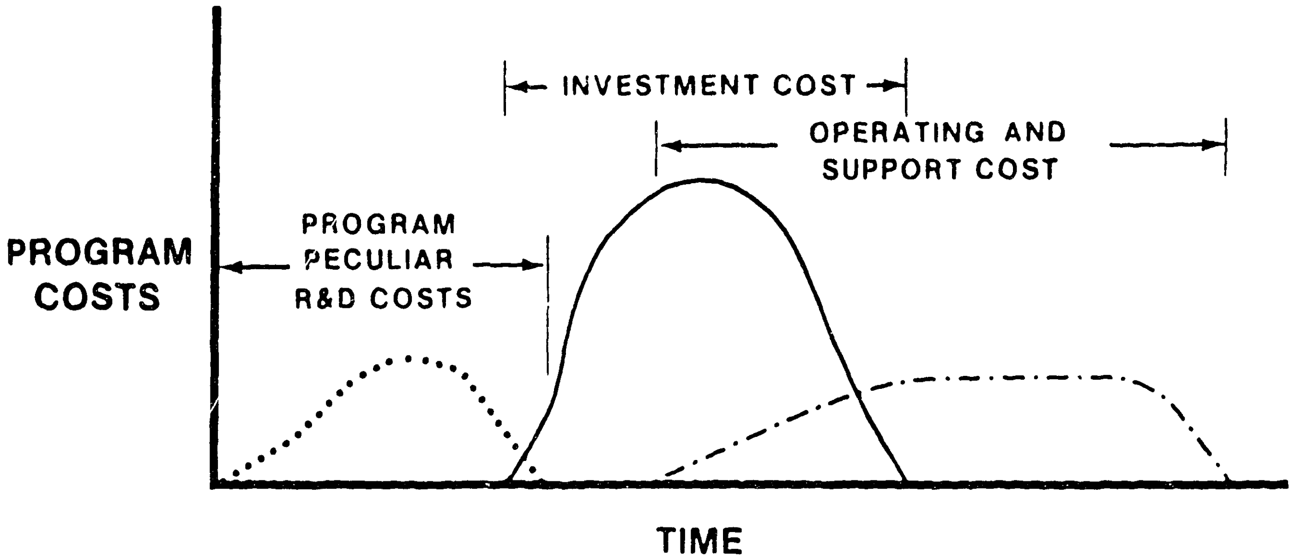
1.5 SHIP PROGRAM COSTS

Program costs are often referred to as the life cycle cost (LCC) for the particular system. LCCs are generally categorized into three areas: (1) research and development (R&D); (2) investment, and; operations and support (O&S). Fig. 1.8 illustrates a representative time line of LCC expenditures. Note that there is generally some degree of overlap between each cost category.

R&D costs are for the work associated with making high technology items or innovation design features available to the ship at key commitment points. There is often developmental work associated with combat system installations. R&D costs are not specifically addressed in this study.

Investment and O&S costs for conventional vessels are the major components of LCCs (Ref. 36). Ship investment costs include construction, government furnished material (GFM), outfitting, post delivery and other miscellaneous costs. The term investment costs is used interchangeably with acquisition costs.

Ship O&S costs include direct/indirect military personnel, direct/indirect ship operations and maintenance and direct ship



Representative Life Cycle Cost Time Line
(Ref. 60)

Figure 1.8

moderization costs. Table 1.8 presents the breakdown of development, acquisition and O&S LCCs for a 3600 ton Navy frigate. Based on a 30 year ship life, the O&S costs are

Category	Percentage Breakdown
Operating & Support (*)	
Indirect Support	2
Maintenance	10
Modernization	18
Operations	15
Personnel	12
	57
Acquisition	
Combat systems	17
Machinery	18
Hull	4
	39
Development	4

(*) based on a 30 year ship life

Navy Frigate Life Cycle Cost Breakdown
(Ref. 36)

Table 1.8

significantly greater. A lower percentage for acquisition costs can be expected if the combat capabililty of the vessel is reduced. The following percentage breakdown for the FFG-7 is: R&D - 1.6; Investment - 35.2, and; O&S - 63.2. The O&S costs for US Navy vessels are recorded by the VAMOSC (Visibility and Management of O&S Costs) program, a brief description of which can be found in Section 3.1.1.2.

There are a number of things that can be done during ship design to reduce the main elements of the O&S costs and thereby decrease the total LCC (e.g., see Ref. 36). However, these improvements generally result in a higher acquisition cost (Refs. 5 and 50).

Although, the importance of LCCs are not overlooked in the design process, acquisition costs tend to dominate the design decisions. There are three main reasons for the controlling influence of acquisition costs over LCCs (see Ref. 5): (1) there is a more immediate impact for the acquisition costs; (2) there is considerably less uncertainty associated with acquisition cost estimates, and; (3) there is greater flexibility in the future funding of O&S costs.

The emphasis on minimum procurement cost has been reflected in fixed displacement and hull length constraints or some other design criterion which constrains hull size and principal dimensions (e.g., see Refs. 47 and 48).

1.5.1 Reporting Ship Costs

Observed differences in ship costs. if explainable, can reflect differences in the subsystems of the ships as a function of technology changes, inflation, or productivity differences. If inflation and productivity are backed out of the data, the remaining differences should reflect the technology level and major characteristics of the ship subsystems, thus enabling analysts to establish specific cost trends in the data.

Variations in productivity are very much a function of stability in the shipyard's workload and its geographic location (Ref. 23). It is often difficult to remove the productivity shifts that account for different levels of shipyard efficiency (see section 3.1.2). However, the effects of inflation can be removed by expressing ship costs in so-called base year dollars. Other dollar terms used are then year dollars, referring to the dollar amount for a previous fiscal year (FY), and future year dollars for future costs.

Cost figures can be converted to any base year provided the required inflation rates are available. Fig. 1.9 shows the variation in inflation rates for several years. Note that inflation rates for Department of Defense (DoD) equipment is consistently higher than that for the general economy.

	US Economy	DoD - All Equipment	Aircraft
1975	9.3	9.8	10.6
1976	5.2	8.1	9.0
1977	5.8	10.2	13.2
1978	7.4	9.4	10.4
1979	8.5	8.1	11.4
1980	9.0	10.6	10.3
1981	9.4	10.9	11.0

Source: US Department of Commerce, Bureau of Economic Analysis

Inflation Rates
(Ref. 17)

Figure 1.9

For the calculation of total LCCs, O&S costs are generally discounted on a year by year basis using the net present value technique (e.g., see Refs. 1 and 34). If, for simplicity, the O&S costs are assumed equal to the same amount, A (base year $), each year throughout the vessel's life, then the net present value for the O&S costs, NPV (base year $), is given by the expression;

$$NPV = A\left((1+i)/(1+d) + \left((1+i)/(1+d) \right)^2 + \ldots + \left((1+i)/(1+d) \right)^L \right) \qquad (1.1)$$

where i = yearly escalation rate

d = yearly discount rate

L = ship life in years

The escalation rate is used to equate a given sum of money at the present time (i.e., base year) with another sum of money at any future time.

Discounting is the reverse of the compounding effect of inflation, in that the discount rate moves from the future back to the present. To explain in other terms, escalation is required to account for inflationary trends which decrease the value of present day money in the future, whereas discounting is used because of the time value of money from expected returns on investment. Obviously, the two effects are opposite. The discount rate is often taken as 10% (e.g., Refs. 1 and 34).

CHAPTER 2

OVERVIEW OF SHIP COST ESTIMATING

Cost estimating is concerned with all aspects of production and economics that influence the development, construction and operation (including retirement) of a ship. Within the construction portion of any government agency's shipbuilding budget, there are three primary elements of cost:

(1) costs incurred for management of the acquisition program

(2) costs incurred for the procurement of GFM

(3) shipyard costs for construction of vessels

The costs associated with the management of the ship acquisition are programmatic in nature. These include the effects of inflation, profit and other economic factors plus change orders and various cost contingency margins. Programmatic costs significantly impact on the total program costs. For instance, a one dollar change in production costs translates to about a two dollar change in total program costs after programmatic effects are included (e.g., see Ref. 5).

This chapter deals with the traditional methods of estimating the costs involved with GFM purchases and shipyard construction services, referred to as basic construction costs (BCC). Direct labor and material BCCs make up only 25% of the funds that must be appropriated for each new ship (Ref. 23). Table 2.1 lists the various methodologies generally used to come up with cost estimates in this area.

Delphi

Analogy

Engineering

Cost Estimating Relationships (CER)

Parametric

Cost Estimating Methodologies

Table 2.1

The Delphi technique can be described as the solicitation of expert opinion. As such, Delphi estimates rely upon the experience of individuals and often vary widely from one to another. Therefore, the best approach for this method is an iterative one, working towards a consensus among the persons involved. The Delphi method is frequently used to extrapolate outside of the range of existing cost data.

Analogy relies on the comparison of new with existing systems to determine costs. This technique requires historical data on similar existing systems for it to be feasible. Analogy estimates are the most economical to produce of all the methods listed in Table 2.1.

The engineering method is referred to as bottoms-up estimating and is the "accepted" method of obtaining reliable estimates (e.g., budget quality). This technique is characterized by separate material and labor costing on a component by component basis, typically using some form of work breakdown structure (e.g., the SWBS groups for Navy ships). Depending upon the technical definition available, component can range from highly aggregated (e.g., whole ship) to very detailed (3-digit SWBS). Bottoms-up estimating is generally the most time consuming and costly of all the methodologies for the same level of detail. The NAVSEA Code 017 model described in Chapter 3 uses the traditional engineering approach for cost estimating.

The previous method can be described as using cost-to-cost relationships, whereby costs are estimated from elements of cost such as labor hours. Parametric and CERs use cost-to-noncost estimating, which involves the use of inputs such as performance (e.g., SHP), weight, etc. to arrive at a system cost. Parametric and CERs are derived using multi-variable and single variable regression techniques, respectively, on existing data. Therefore, these methodologies represent averaged system cost trends and are called top-down estimates. Parametric and CERs are the most economical techniques to use as they give quick answers to what if questions, provided these changes can be properly reflected in the noncost variable(s).

CERs can only be used to predict costs if the new ships have systems similar to those in past ships. The NCA, USCG and ASSET models found in Chapter 3 use CERs to calculate basic construction costs. Increased system definition can be expressed as a separate CER whenever there is sufficient cost data at that level to define a unique trend. The more design features that can be accounted for by using different trends, the more flexibility there is in the analysis.

Parametric models generally serve as a cross check for detailed estimates (i.e., using the engineering method). They have proven useful for evaluating future technology assessments, and can influence long term priorities. The RCA PRICE model is a well-known parametric model.

Cost-to-noncost relationships are typically incorporated into computerized models. This leads to quick turn around time for estimates as well as consistency of the results (e.g., see Ref. 6). Consistency is an important factor given the high motivation to accept low estimates as a means to win approval against a competing system. Low estimates can result from unreal performance requirements, difficulty in guestimating unknown variables or predicting technology impacts, and/or over-optimism (e.g., underestimating manhours).

Although the factors that contribute to a low estimate can be important, the general estimating philosophy has always been one of conservatism (Ref. 51), which serves to minimize the effects of unknowns that always arise as ship design (technical) definition improves. For advanced naval vehicles, where the database is thin, there is a natural tendency to estimate unknowns conservatively, resulting in higher estimated costs and risks. (Ref. 46). As the concept nears an acquisition commitment, the high cost estimates may eliminate an otherwise feasible alternative from competition. In a recent SWATH design, hull structure estimates reflected a tremendous difference in cost per pound compared to conventional monohulls, even though the material and fabrication specifications were identical (e.g., see Ref. 46).

2.1 ESTIMATING BASIC CONSTRUCTION COSTS

2.1.1 General

Basic construction is defined as the contract award price for ship construction, including all production labor, overhead, and material costs plus an amount for cost of money (COM) and profit. Note the use of the word price in this definition. In contracting, price indicates dollar amounts inclusive of fee or profit. If the fee or profit is excluded, the dollars amounts are referred to as costs.

An estimate of BCC is developed by utilizing estimates for the two major parameters of ship construction costs, material costs and labor hours. Direct labor costs are calculated using separate manufacturing or engineering rates or an appropriate aggregate rate; overhead is estimated as a percentage of the direct labor costs.

Overhead costs represent that portion of fixed and variable costs allocated to the production of each ship but not directly related to its construction. Examples of fixed overhead include rent, insurance, depreciation of buildings and equipment, and the cost of money. Variable overhead costs change with the activity level in the shipyard and include taxes, employee benefits, communication and travel costs, and production related expenses.

During the feasibility phase of the ship design process, basic construction material and direct labor costs are estimated using two primary approaches:

(1) wherever ship definition permits, vendor quotes are solicited for the equipment involved;

(2) wherever ship definition is not sufficient to support a vendor quote, material and labor costs are estimated by a CER.

CERs reflect historical ship cost data, either in the form of return costs or cost proposals/pricing exercises for similar ships. Labor hour CERs are based on a review of CPRs (contractor performance reports) , historical return costs, proposals, previous estimates and shipyard experience.

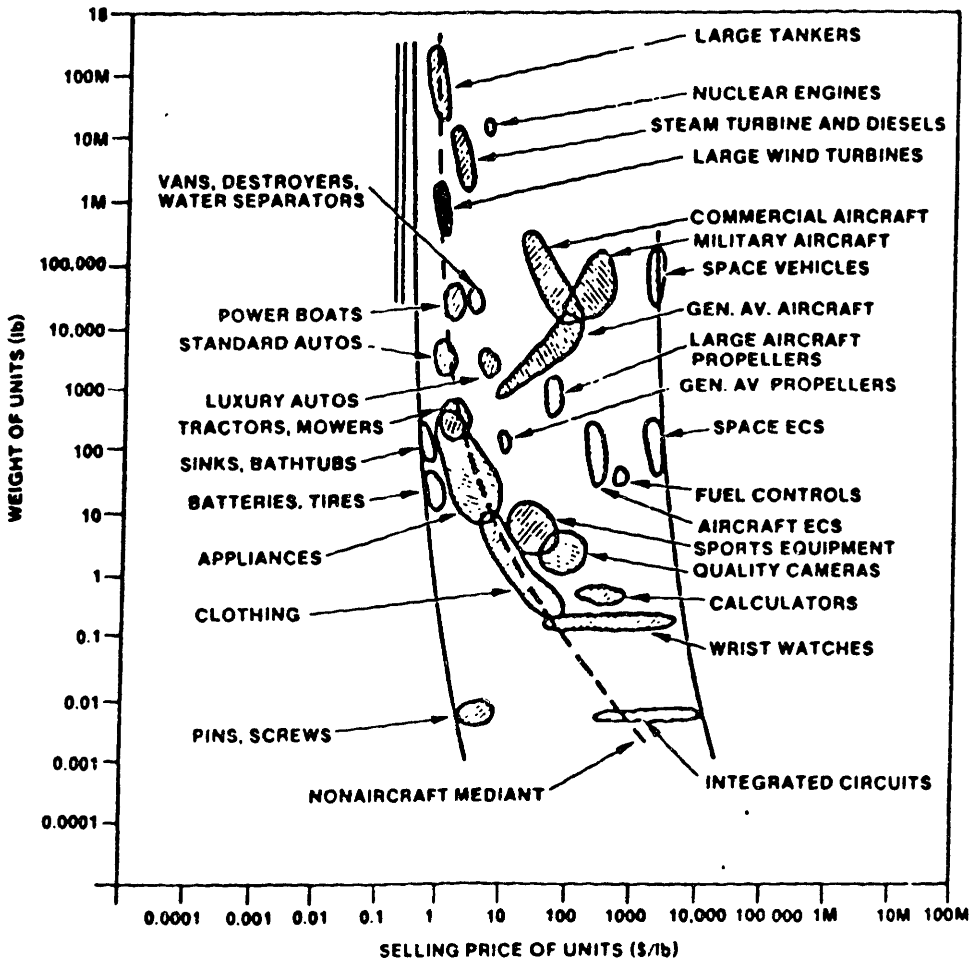
CERs relate non-cost design parameters to costs. Typically, in new ship cost estimating, costs, C ($), are functionally related to SWBS weights (see Table 1.2), so that;

$$C = f\ (\text{weight}) \tag{2.1}$$

where f( ) represents some functional relationship. Fig. 2.1 shows weight based cost estimates in terms of dollars per pound for a wide range of products. The cost per pound for similar products will vary depending upon their differences in complexity.

Other variables besides weight may correlate better with costs, depending upon the application. For example, propulsion systems often use shaft horsepower (SHP) as an independent variable for estimating costs.

Material estimates for hull structure include a scaling



Weight Based Unit Production Prices
(Ref. 19)

Figure 2.1

factor which accounts for the impact of scrap, cut-outs, cut-offs, mill tolerance, weld rod and transportation. Typical factors add an additional 15% to weight based quotes.

Ships can have the same weight in a functional area (e.g., hull structure) and yet have different costs. Cost variations of this type are due to differences in materials, fabricating, level of technology, plus a variety of other factors. Early in the design process, these factors can be incorporated into CERs to explain general cost trends. However, as design and technical definition increases throughout the design process, the top-down approach inherent in the use of CERs becomes less tenable.

Design definition supports the solicitation of vendor quotes for most of the high value components within the functional areas. Whenever actual equipment costs and weights are obtained from quotes they can be incorporated into the cost estimates for ship construction costs. This is done by reducing the appropriate weight groups by the equipment weights available, recalculating the weight group costs using the appropriate cost estimating relationships (CERs), and then adding the equipment costs to these updated values. This method of shopping list additions will tend to increase the accuracy of any cost estimates since the data is obtained directly from the manufacturer.

The use of actual equipment data is especially helpful for determining accurate electronics and armament hardware costs. The principal reason for this is that their costs depend mainly upon their performance and sophistication, which are not as easily quantified as weight, space, or any other physical or technical characteristic. As a result, it is difficult to develop a functional relationship such as Eqn. (2.1) to explain historical cost trends in electronics and armament.

For Navy acquisition programs, the effects of software development on costs is becoming more important (especially for combat systems) . In 1980, the DoD spent nearly $3 billion dollars on software costs. However, projected amounts for 1990 are in excess of $32 billion dollars (e.g., see Ref. 17).

There are several models in use for estimating the design and support costs associated with software development. The names of some of the more well-known models are Jensen, COCOMO (COnstructive COst MOdel), SLIM, and PRICE-S. Information on these models can be found in Refs. 17, 18 and 19.

2.1.2 Should Cost versus Actual Cost

When dealing with GFM quotes, it is important to understand the distinction between should costs and actual costs. Should costs are based on time-and-motion studies of various tradesmen working under controlled conditions. Controlled conditions generally mean that all tools and materials are available and easily accessible throughout the work and that there are few interruptions.

Manufacturers generally supply should cost information for major items and ancillary hardware costs. Care must be exercised with these vendor quotes, since there is an understandable tendency for over-optimism and bias on the part of vendors, resulting in low cost estimates for the particular item(s).

In contrast, under actual working conditions, tools and materials must be shuttled between the workplace and supply depot(s) and there are continual disruptions due to a variety of reasons. The result of these differences is that actual costs can be expected to exceed should costs by 15 to 20 percent (Ref. 2).

The effects of modular construction and other producibility considerations on this difference have yet to be adequately investigated. However, it would seem logical that any producibility improvement would reduce the difference between the two.

Should cost can have different interpretations than described above for vendor quotes. The US Navy may initiate a should cost study of a sole-source contractor's facilities to identify inefficiences in the operation and determine what a reasonable cost to the government would be if these were eliminated. The results of the study form the basis for the government's position during contract negotiations.

Finally, a should cost study can also refer to an independent review of a proposed program budget estimate by a team of analysts. Their purpose is to establish a range of costs that can be expected for the program.

2.1.3 Learning Rate

Shipbuilding, as well as many other industries, experiences a learning or improvement process when multiple units are being constructed in orderly phased sequence. The historical data accumulated by industry verify that learning takes place (Ref. 43). These empirical data provide the basis for what is referred to as learning curve theory.

The theory is that each time the total quantity of ships built doubles, the manhours, material, or basic construction cost of the ships is reduced by a constant percentage of the previous manhours, material, or basic construction cost.

For a given learning rate, the cost of the N^{th} ship, C_N ($), can be calculated from the following relationship;

$$C_N = C_1 \; N^{(\log R \; / \; \log 2)} \qquad (2.2)$$

where C_1 = lead ship cost ($)

R = the fractional learning rate (%/100)

Eqn. (2.2) is referred to as the unit learning or Boeing curve relationship. Since each point on a learning curve represents a theoretical individual unit cost as a percentage of the lead ship production cost, the area under this curve up to a given quantity equals the total production cost for that amount.

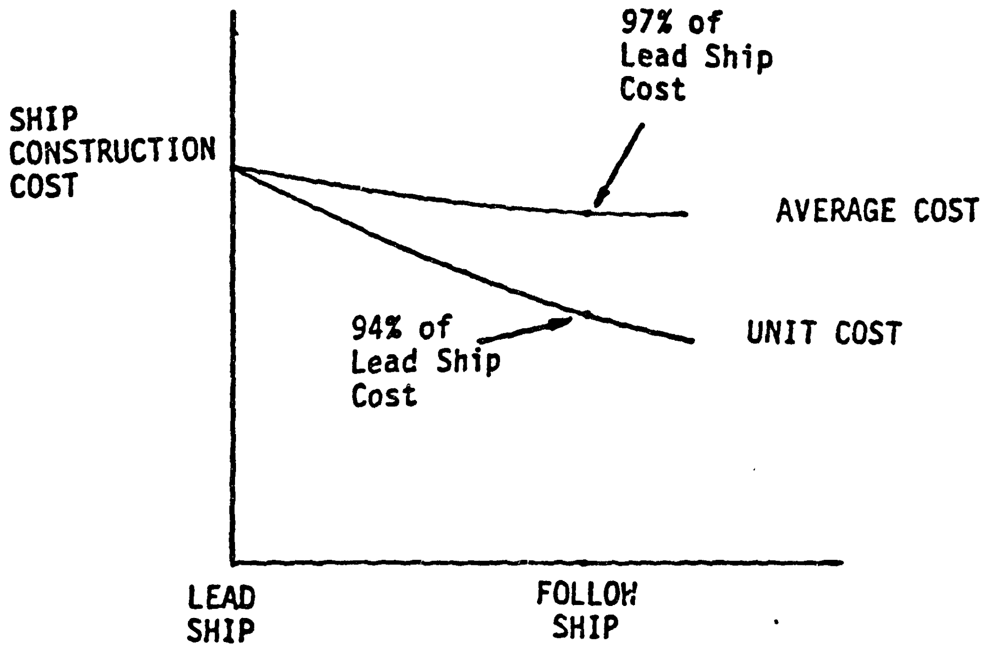
Estimators have a choice of working with unit or cumulative average curves. The difference in these two approaches can be explained using the following example. If the eighth ship manhours were 90 percent of the fourth ship manhours, then the learning would be expressed as a 90% unit learning curve. On the other hand, if the average manhours of all eight ships were 90 percent of the average manhours of the first four ships, then the learning would be expressed as a 90% cumulative average learning curve.

Fig. 2.2 illustrates that a unit learning rate of 94% is equivalent to a cumulative learning rate of 97% . Provided they are used correctly, the choice of unit versus cumulative rates for follow ship calculations does not affect the total ship acquisition cost. Unit learning rates of about 90% have been noted for Navy destroyers and frigates (e.g., see Refs. 25 and 30).

The amount of learning that occurs on any production schedule depends on a variety of factors, including system complexity (i.e., skill level required), manufacturing technology, construction time and time between starts.

Low skill level jobs exhibiting minimal learning have learning rates close to unity, that is, there is little or no reduction in labor with subsequent performance of the task. Conversely, systems requiring highly skilled tradesmen can show significant learning effects, so that there is a sharp reduction of labor between the lead and follow ship.

The more highly automated the fabrication process is, the less learning that takes place between the first and last ships (e.g., see Ref. 20). Innovations like robotics and zone outfitting result in lower production costs from increases in shipyard efficiency and consistency of application, not from learning effects.

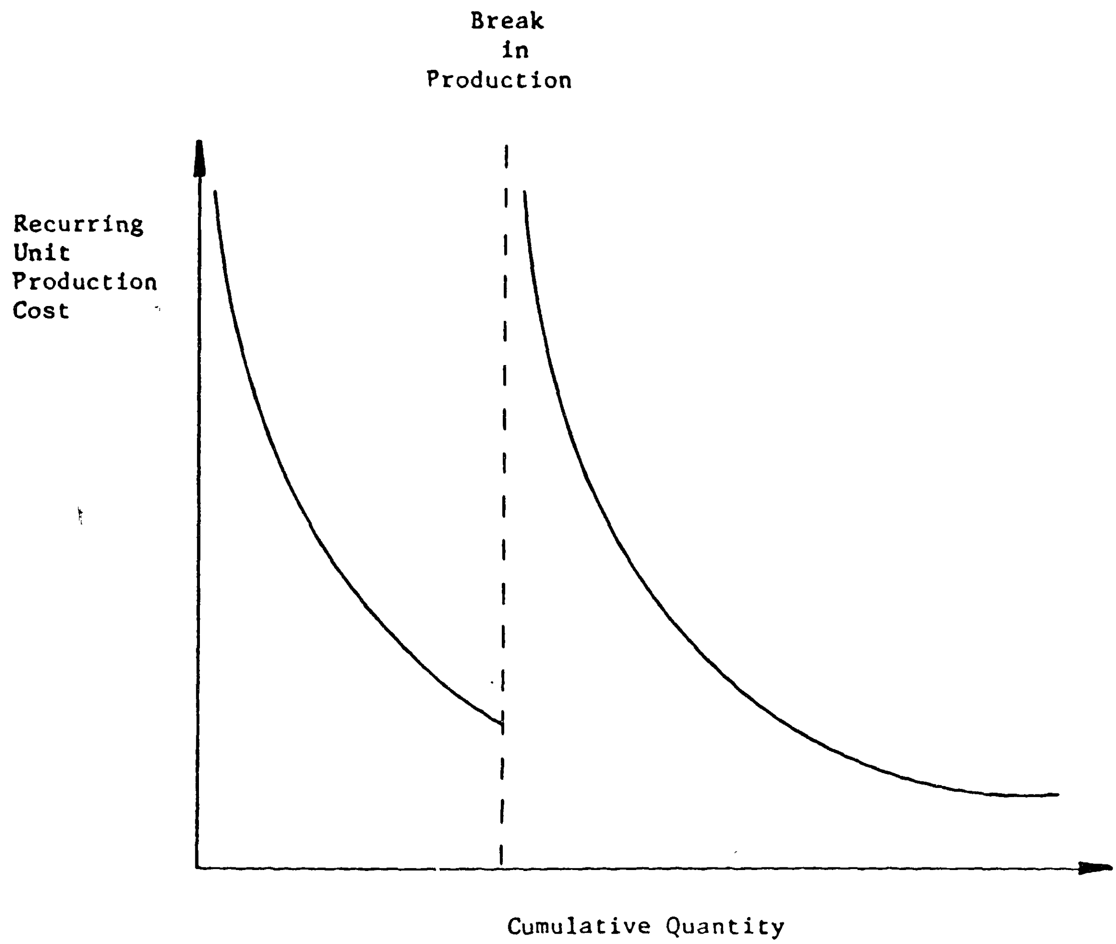


Unit and Cumulative Learning Curves
(Ref. 1)

Figure 2.2

Learning theory is defined for production in an orderly phased sequence. BIW (Bath Iron Works) reached a high point in their production learning during a time period in which a number of Navy destroyers were built in a relatively short time frame (Ref. 23).

When production occurs in multiple lots, too slowly, or with too great a time gap between construction starts, follow ship costs do not follow Eqn. (2.2). Fig. 2.3 illustrates that for a lapse in production, the shipyard experiences a jump in costs upon resumption of building.



Disruption of the Learning Curve
(Ref. 17)

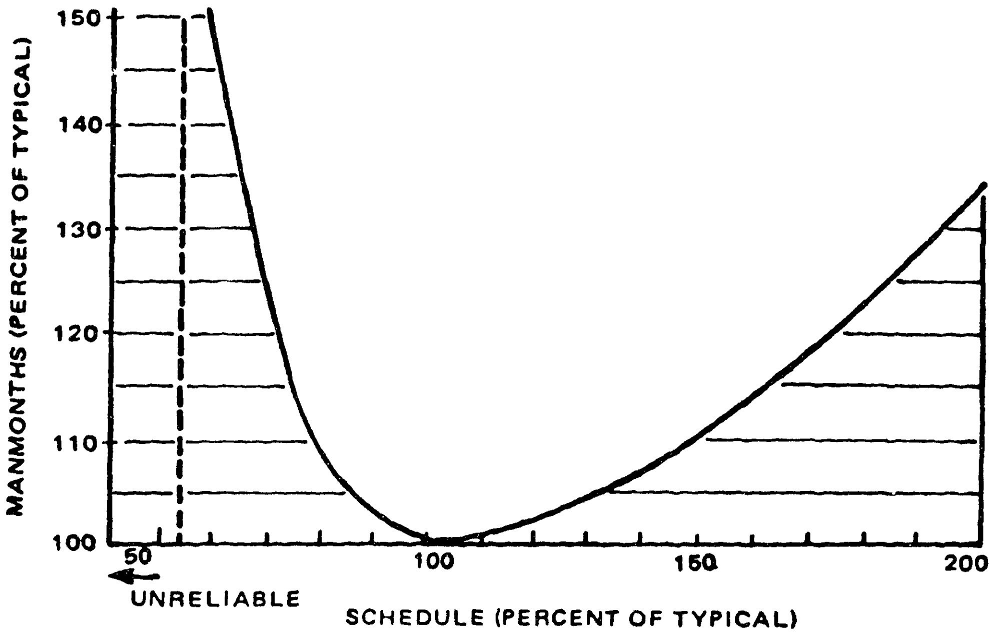
Figure 2.3

2.1.4 Scheduling

The construction costs for a ship or group of ships is highly dependent upon the procurement strategy chosen for construction. This strategy indicates the number of vessels, the length of each construction period, the time between construction starts and the number of lots that the vessels are to be built in. From this partial listing, it can be seen that production learning and scheduling effects are interrelated.

Pre-outfitting, modular and zone construction, increased use of automation and other fabrication improvements are resulting in shorter construction times. The effect of these changes is the reduction of production manhours, thereby reducing costs. However, current indications are that the production savings are being offset by increased engineering and support efforts (Ref. 16). An overall drop in total construction costs can be expected as these advanced techniques become more fully integrated into the fabrication process. The impact of producibility gains is further reduced because shipyard costs only affect a relatively small amount of the total program budget (Ref. 24).

Fig. 2.4 illustrates that an optimum project schedule results in the lowest production costs, while compression of the schedule (i.e., overtime, more shifts) results in significant increases in costs. Although stretching out of the schedule also results in increased costs due to inflation and reduced learning



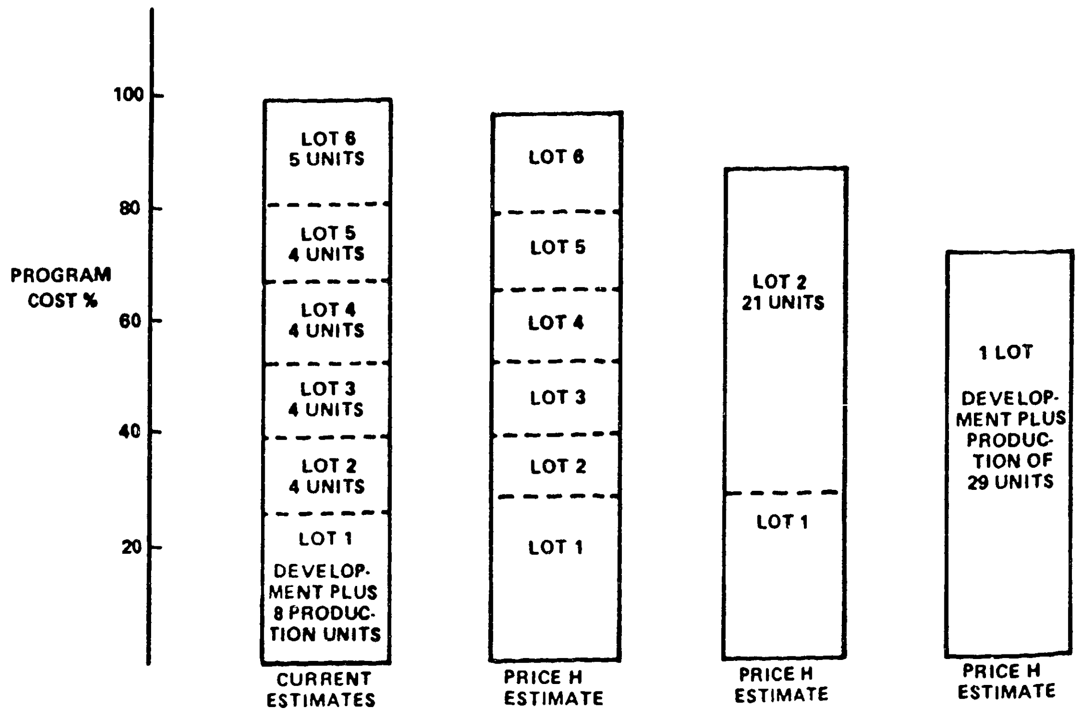
Schedule Length versus Optimum Program Cost
(Ref. 61)

Figure 2.4

effects, these are generally less severe in magnitude. There is also an optimum phasing of design and construction schedules, when construction starts immediately after design is complete. Overlapping of these schedules will result in increased costs, as shown in Fig. 3.15.

Variations in expenditures and government funding patterns can significantly affect program costs. Fig. 2.5 compares multiple and single lot production costs using the RCA PRICE cost model (see section 3.1.5).

In the feasibility design phase, there exists a great deal of uncertainty regarding production scheduling. Lowest costs can be expected for an "optimum" construction period combined with a single lot procurement strategy.



Program Cost Comparisons
(Ref. 26)

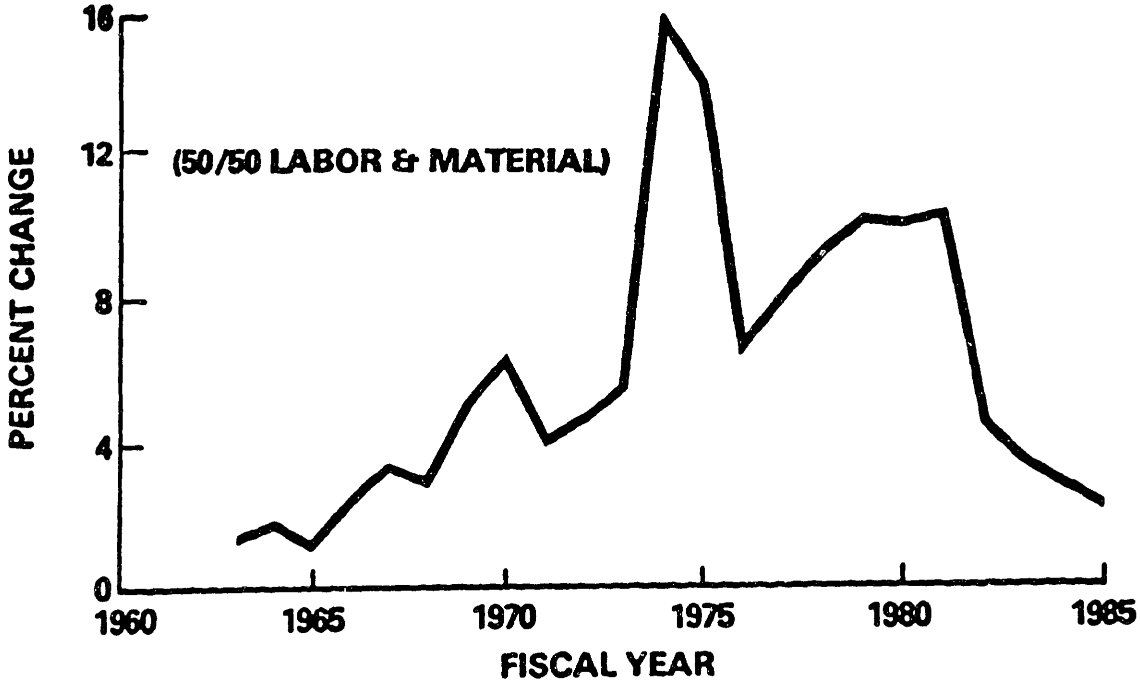
Figure 2.5

2.1.5 Inflation and Escalation

The rate of change in economic conditions, such as inflation, can affect cost estimates more substantially than the technical aspects of a cost model (Ref. 23). Inflation is defined as the price increase of a product over time, or alternatively, the decrease of the amount of product a fixed amount of money will buy relative to some base year.

It is important to realize that when looking at price or wage inflation, each product price or industry wage rate is determined by a unique set of cost and market factors (e.g., regional labor rate differences), and their inflation rates will consequently differ from case to case. Using forecasted prices that are not truly representative of a specific product can lead to serious miscalculations of future cost estimates. For example, if an estimate of the average annual inflation is low by 3% per year for a system to be manufactured seven years from now, the result is a cost overrun of 23 percent.

The visible measures of inflation are the various price indices that are often quoted. These indices range from highly aggregate indicators such as the wholesale price index (WPI) down to disaggregate producer price indices (PPI) for specific commodities. At higher levels of aggregation (e.g., the WPI), there is less fluctuation in the indices than would be found at the disaggregate levels. Fig. 2.6 shows the percent yearly variation in the BLS (Bureau of Labor Statistics) composite index used by the US Navy for estimating contract escalation. The



BLS Shipbuilding Composite Index
(Ref. 62)

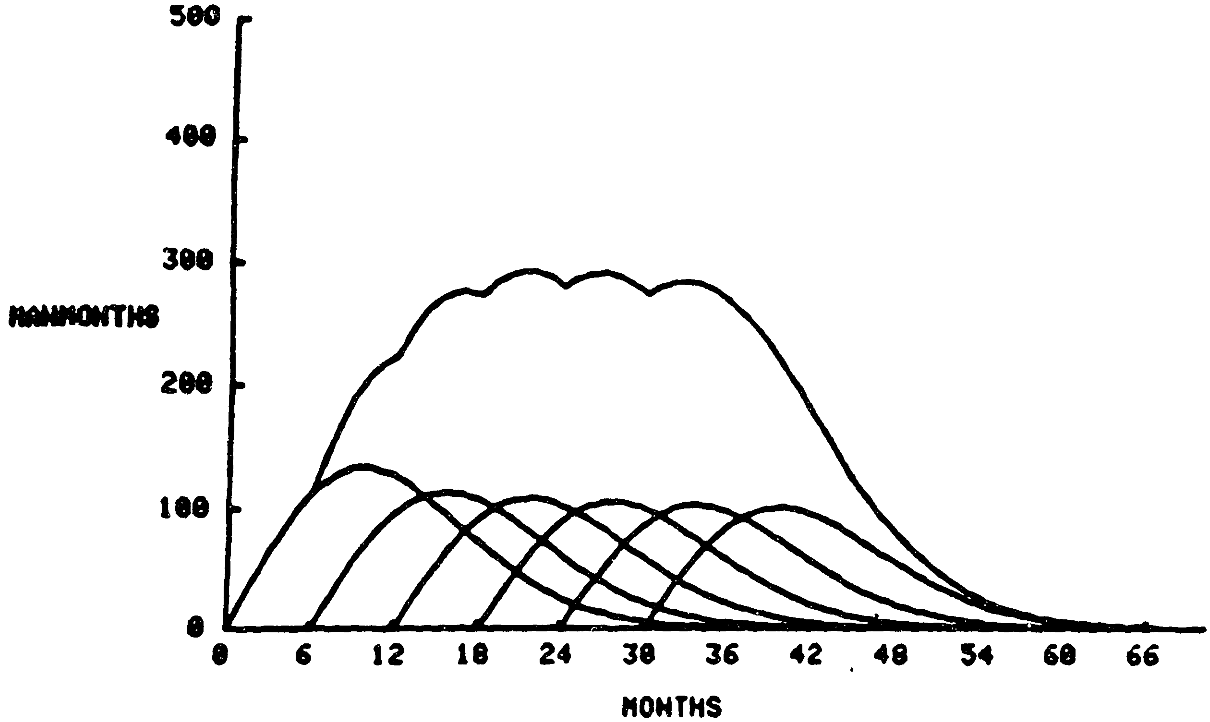
Figure 2.6

fluctuations can be caused by a number of factors, including technology, inventory, competition, and the overall effect of inflation on the economy.

Escalation accounts for the change in cost expected between contract award and ship delivery due to inflation. Currently, the USN has extended the escalation coverage out to 8 months past the delivery date. Outyear pricing defines general estimating procedures and inflation factors for developing ship costs estimates with base dates in the future. The failure to identify the differences among relative escalation rates for important labor, material and energy cost inputs can lead to serious errors in forecasting program costs.

Escalation amounts are computed based on a specified building period and an assumed manhour profile (e.g., see Ref. 53). Figure 2.7 shows a cumulative manpower curve for 6 ships representative of a 36 month award to delivery period assuming a 6 month interval between construction starts. Total labor amounts for this example are in the vicinity of 91,000 manmonths.

The use of more aggregate material price and earning indexes can lead to errors in material and labor cost escalation estimates. To provide a best estimate of a project's future cost escalation, a composite of the project's labor, material and energy inputs should be constructed to the greatest degree of detail practicable.



Cumulative Manpower Curves
(Ref. 62)

Figure 2.7

Historically, naval shipbuilding material and equipment costs inflate at different rates than materials for domestic applications, as mentioned in Section 1.5.1. Because of this, the government calculates its own escalation rates: the 50/50 labor and material composite index illustrated in Fig. 2.6 is an example. Table 2.2 indicates the PPIs and weightings that are used to calculate a whole ship BLS material index.

PPI	Description	Weighting
10-1	Iron and Steel	.45
11-4	General Purpose Machinery	.40
11-7	Electrical Machinery and Equipment	.15

BLS Material Index Breakdown

Table 2.2

NAVSEA also develops escalation indices for the SWBS weight groups. Table 2.3 shows the weightings that are used to develop a single ship weighted average for a non-combatant surface ship.

SWBS Group	Description	Weighting
100	Hull Structure	.092
200	Propulsion Plant	.118
300	Electric Plant	.093
400	Command & Surveillance	.015
500	Auxiliary Systems	.281
600	Outfit & Furnishings	.354
700	Armament	.005
800	Integration/Engineering	.026
900	Assembly & Support Services	.016

SWBS Group Escalation Weighting Factors

Table 2.3

The importance of accurately predicting inflation and its effect on escalation during the construction process cannot be overlooked. The cost growth from unexpected inflation (if not accounted for) may result in decreased production rates and program stretchouts. More drastic measures may entail the reduction in units procured or even cancellation of the program. In any event, these actions lead to higher per unit costs, deployment shortfalls and reduced capabilities.

2.1.5.1 Calculating ROM Escalation

The methodology and information contained in this section for estimating ROM (Rough Order of Magnitude) escalation for outyear (i.e., non-budget year) pricing is taken from a NAVSEA 017 Memorandum dated 3 April 1986. The escalation percentages that are multiplied against the cost of the ship are given in Table 2.4. These percentages are based on the number of months between an assumed contract award in the last quarter of the fiscal year and post delivery, 8 months after the delivery date. The cost for each ship is the sum of 100% of direct labor, 95% of overhead and 100% of material dollars and cost of money (see Section 3.1.1).

Other assumptions used in the determination of the ROM escalation factors include: base date is 8 months prior to the award date; start of construction 12 months after the award date; 50/50 labor/material composite (e.g., see Fig. 2.6); specified ship construction expenditure curves (e.g, see Fig. 2.7), and; escalation for energy and fringe benefits growth. For ships awarded after FY 90, the factors for FY 90 are to used.

FY Award Date	Post Delivery - Award Date (months) 24	36	48	60	72	84	96
88/07 (*)	6.4	8.0	9.4	10.8	12.1	13.5	14.8
89/07	5.5	6.8	8.0	9.3	10.6	11.9	13.2
90/07	4.6	5.8	7.0	8.3	9.6	10.9	12.2

(*) year/month

ROM Percentage Escalation Factors

Table 2.4

The following example is given for a FY 88 ship;

(1)	Base date	87/11
(2)	Award date	88/07
(3)	Start of construction	89/07
(4)	Post delivery date	92/06
(5)	Target cost (000's)	$250,000
(6)	Delivery - Award date	48
(7)	Escalation = (5) x escalation factor = $250 M x 9.4% = $24 M	

The escalation for the FY 88 $250 M ship is $24 M.

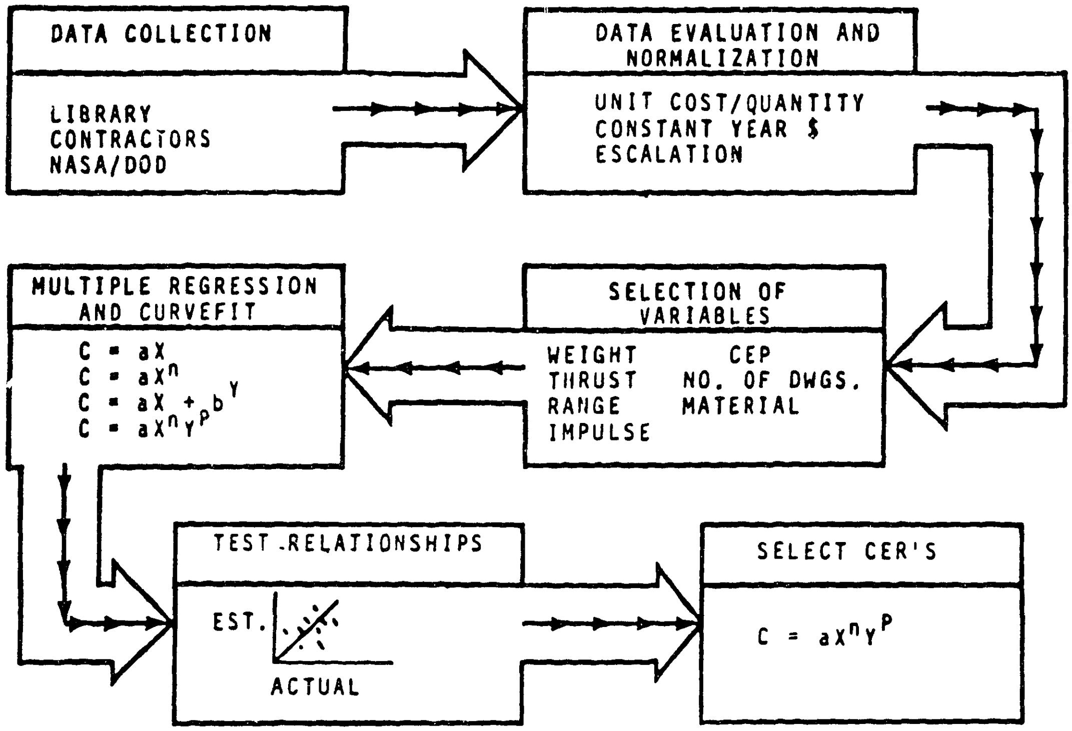
Changes in the base date of 8 months prior to award are adjusted by 0.4% for each month. For changes in the start of construction from 12 months after award are adjusted by 0.1% for each month. For the following example of a FY 89 ship;

```
(1)  Base date                                  88/06
(2)  Award date                                 88/11
(3)  Start of construction                      90/01
(4)  Post delivery date                         93/10
(5)  Target cost (000's)                     $271,000
(6)  Delivery - Award date                        60
(7)  Adjustment for Base date
      88/11 to 88/06, change of -3 months
                               -3 x .4% = -1.2%
(8)  Adjustment for Start of construction
      88/11 to 90/01, change of +2 months
                               +2 x .1% = +0.2%
(9)  Escalation = (5) x (escalation + adjustments)
                = $271 M x (9.3 -1.2 + 0.2)
                = $23 M
```

The escalation for the FY 89 $271 M ship is $23 M.

2.2 CER DEVELOPMENT

This section describes a methodology for calculating cost estimating relationships (CERs) from given cost data. Fig. 2.8 illustrates the six steps involved in the procedure. Data collection is the first step. Data is obtained from historical data, cost returns and ship operational information. Often the sources that have the data do not want to give it up, so that it must be paid for in some manner (e.g., a contract to assemble the relevant data). In addition, the data gathered is not always in the form that it is needed for CER development. For example, most shipyards do not group costs according to SWBS weight group for their internal accounting procedures. Therefore, a significant



CER Development Methodology
(Ref. 63)

Figure 2.8

portion of the development work and expenses can be involved in data collection (Ref. 23).

The second step of the process is primarily concerned with normalizing the data. The most widely used normalization is converting the costs to a common base year $. Previous mention has been made for removing producibility effects from the data as well (e.g., see Refs. 9 and 23).

Once the data is in a usable format, the factors in the ship design, construction and operation which may be thought to have an effect on costs must be determined. Variables are also chosen based upon their easy availability within the design community. It was found that SWBS weight groups and SHP for propulsion are the factors used most in ship costing.

Having selected the independent variables to relate to costs, the analyst must decide on one or more rational relationships with which to statistically curvefit the data. A rational CER means not just an equation that "fits" the data, but one which has some basis in engineering. For the cost models reviewed in Chapter 3, three types of CERs are used;

(1) linear (e.g., NAVSEA Code 017 and NCA)

$$\text{Cost} = A + Bx \tag{2.3}$$

(2) log - log (e.g., USCG)

$$\log \text{Cost} = A + B \log x \tag{2.4}$$

(3) log - linear (e.g., ASSET)

$$\text{Cost} = A\, x^{B} \tag{2.5}$$

where A and B are unique constants to be determined for each equation from regression analysis and x is the design, construction or operational cost variable or element chosen. These equations do not include the RCA PRICE model, which uses a proprietary multiple-variable regression relationship to relate cost to non-cost variables (i.e., parametric analysis).

Although any data can be curvefit, it remains to test the curves for "goodness of fit" and other significance tests. For instance, the variable giving the least variance (i.e., least cost uncertainty) when compared to the data may be selected as the cost element used in the CER (e.g., see Section 2.2.1). Experience can also prove to be invaluable in the selection process.

As a result of these tests and rationalizations, a particular CER is selected as the most appropriate for the situation. It is important to realize that the CER represents an historical trend to costs and therefore it is strictly applicable only within the range for which the data exists. This means that these algorithms should be used to predict costs of newer ships having systems similar to those found in past ships.

2.2.1 Reliability of CERs

There are two areas in which errors in CER development can be found: measurement and stochastic errors. Measurement error is not addressed in this study. This section discusses some of the methods available for determining the probabilistic error (i.e., goodness of fit) for CERs. Confidence in any derived CER is highly dependent upon the quality and quantity of cost data available and on whether the derived CER can accurately reflect observable cost trends. However, if large departures are made from the database designs, errors will increase in magnitude.

Generally, for any statistical curvefit, the more data available, the better the fit, provided the variable chosen exhibits an explainable trend. Smaller subsystems are found to be more specifically related to weight, volume, power or other design variables than are more general groups (Ref. 23). For example, relationships for whole ship cost to ship displacement can be expected to have a higher variance than those found for individual SWBS group weight costs. Because of this, whole ship costs are usually estimated as a summation of SWBS group costs.

Although it would be desirable to reduce the estimating error for every SWBS group CER, typically, only a small portion of the system elements account for the majority of investment dollars. Table 2.5 shows the SWBS weight group and subgroup (see Section 3.1.2) cost percentages of the shipyard construction costs. These construction costs include all direct labor and material costs except for armament (SWBS 700) and communications and control (SWBS 400), which are for installation only.

SWBS Subgroup	Group	Percentages Subgroup	Group
1A		11.67	
B		2.33	
C		2.33	
D		2.17	
	1		18.33
2A		14.50	
B		2.67	
C		1.67	
D		3.33	
	2		22.33
3A		3.50	
B		7.67	
	3		11.17
4A		2.67	
B		4.67	
	4		7.00
5A		7.33	
B		12.00	
C		1.00	
D		1.33	
	5		21.33
6A		1.33	
B		3.00	
C		7.33	
D		2.17	
E		2.33	
	6		16.00
7		3.67	
	7		3.67
		100.00	100.00

Percentage of Basic Construction Cost
(Ref. 23)

Table 2.5

The sum of the top ten of the subgroups in Table 2.5 account for 75% of the total shipyard construction costs (Ref. 23). Therefore, for maximum reduction of errors, the majority of CER development effort should be directed at minimizing the uncertainty of the high cost driver categories.

The main SWBS group cost drivers found in Table 2.5 are propulsion, auxiliary equipment and hull. The ANVCE study found that the relative importance of each of these three groups was a function of the particular ship design. For example, the complex lift system in hydrofoils made the auxiliaries group the dominant cost element, while for advanced monohulls the propulsion group was the highest percentage cost (Ref. 54).

Cost driver impacts are particularly useful for trade-off studies and are often expressed as marginal cost factors. They are usually generated using synthesis programs which are interfaced with cost model CERs. The factors are typically expressed in terms of dollars per ton. Examples of marginal cost analyses can be found in Refs. 5, 13, 35 and 42.

In order to evaluate the "goodness of fit" of the CERs developed for the ANVCE study (see Appendix E), the average percentage of deviation of the estimated versus actual cost values were calculated for each SWBS group. The percentage

Cost Group	Percentage of Deviation from Data Base		
	Average	Upper Limit	Lower Limit
1. Hull structure	8.2	30.0	-14.3
2. Propulsion	6.4	26.0	-15.0
3. Electric plant	11.1	28.7	-19.4
4. Communication and control	13.0	37.9	-24.5
5. Auxiliary systems	9.5	39.0	-22.6
6. Outfit and furnishings	14.1	43.0	-23.1
7. Armament	21.2	83.5	-27.3
8. Design and engineering services	10.9	36.4	-22.0
9. Construction services	14.4	54.3	-30.5
Average Total Dev.	12.1	42.1	-22.1

Percentage Deviation for SWBS Group CERs
(Ref. 54)

Table 2.6

Ship Class	Deviation from Data Base (%)	Ship Class	Deviation from Data Base (%)
PF 109	5.8	PGH 1	6.2
SWATH DE	6.3	PGH 2*	-37.4
SWATH MCM	3.0	PCH 1*	8.5
DLGN 25	-5.1	PHM 1*	-26.8
DLGN 35	-5.8	AGEH 1	22.3
DLGN 36	-4.2	DBH	5.5
DLGN 38	-0.1	ARCTIC SEV	32.2
CPIC	13.9	JEFF A*	-28.1
PG 92 (P)	-15.5	JEFF B*	-30.6
PG 92 (T)	8.7	2KSES (B)	-15.3
PGG 1 (P)	6.5	2KSES (R)	- 9.3
PGG 1 (T)	2.9		

* Ship sample with actual returned costs in data base.

Percentage Deviation for Total Ship Construction Costs
(Ref. 54)

Table 2.7

deviation for one point can be written as;

$$PD = | C_{estimated} - C_{actual} | / C_{actual} \times 100\% \qquad (2.6)$$

where PD = the percentage deviation of a single data point

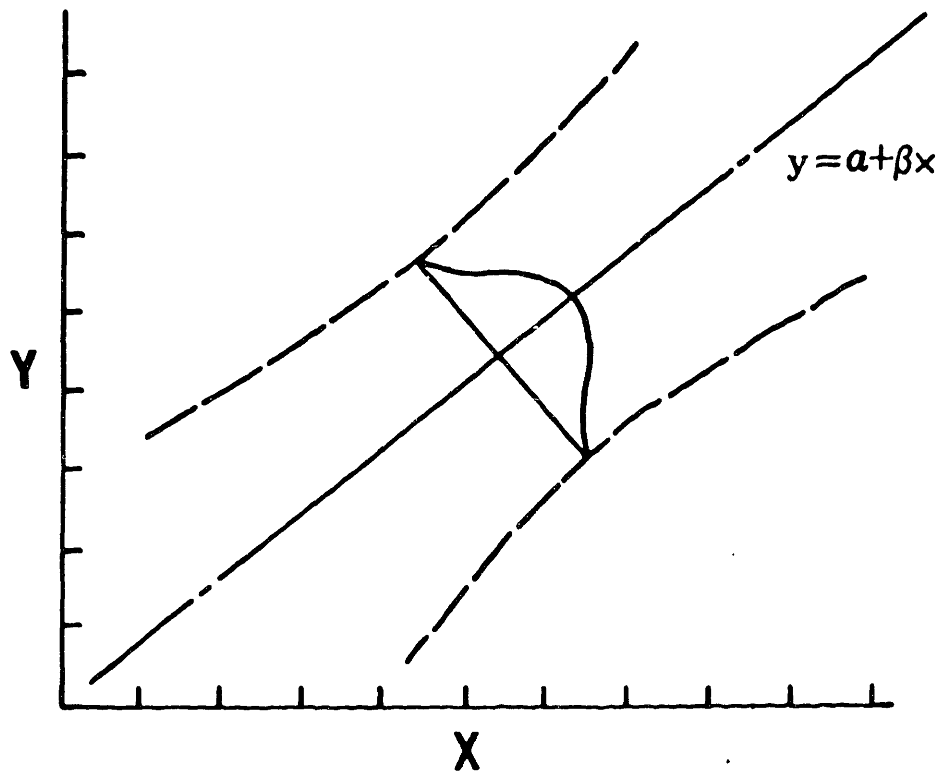
$C_{estimated}$ = the cost calculated from the appropriate SWBS CER

C_{actual} = the corresponding cost data point

The absolute value signs ensure that the over- and under-estimates are weighted evenly. Table 2.6 shows the average percentage deviations for the SWBS group CERs from the ANVCE study. Armament (SWBS 700) shows the greatest uncertainty. Although there are wide deviations within any one cost group, the average for each group is much less. This further illustrates that the CERs represent overall trends and are not intended to be representative of any one ship design.

Deviations of estimated total ship construction costs (i.e., total labor plus material) from actual costs for the ANVCE database are shown in Table 2.7. The large under-estimates are due to the addition of change orders and other unforeseen production costs in the return cost data which are not accounted for in the SWBS group CERs. It is important to remember that the deviations shown in Tables 2.6 and 2.7 indicate how well the CERs can reproduce the database, not how successfully the CERs will predict the costs of ships not in the database.

Variance is often used as a measure of uncertainty for CERs. Fig. 2.9 illustrates that the calculated variance can define a



Confidence Interval about a Regression Line
(Ref. 55)

Figure 2.9

probability distribution about the CER regression line which allows certain statistical tests to be carried out for goodness of fit (e.g., see Refs. 19, 28 and 56). Most analysts assume a Gaussian or normal distribution (see Section 2.3.2.1.2) with zero mean about the line and constant variance throughout the data range. Ref. 28 discusses the implications of non-constant variance on cost risk analysis.

2.3 RISK ANALYSIS

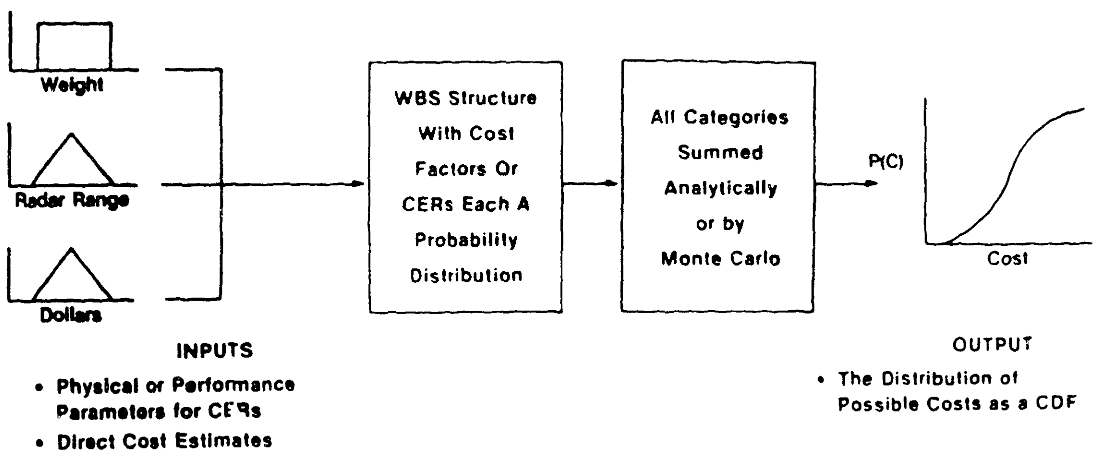
2.3.1 General

Uncertainty in the ship design process has typically been described in qualitative terms, for example, as low, medium or high risk. The sum of these uncertainties is usually accounted for by incorporating various construction margins (Ref. 28). Risk analysis attempts to quantify the uncertainties that are inherent in any predictive method in such a way that the user can select the level and type of risk to be accepted and provide a means of identifying the individual contribution of various elements to the overall risk.

In simple terms, risk (uncertainty) can be divided into three categories: cost, schedule or technical. Included in these categories are the effects of new technologies, inflation, schedule changes, shipyard productivity, plus others. In this section, some of the techniques that have evolved to estimate the cost risks in shipbuilding will be examined.

An important area in terms of cost risk that is not addressed is the uncertainty associated with the cost analyst. The experience of the estimator will go a long way to reducing the uncertainty in the system cost. Experience is particularly important in areas where costs associated with technical changes must be extrapolated from existing data.

The general cost risk methodology is indicated in Fig. 2.10. In the first step, input estimates are expressed in terms of a probabilistic distribution, as opposed to a traditional deterministic (i.e., point) value. These inputs include the cost



The General Cost Risk Analysis Approach
(Ref. 32)

Figure 2.10

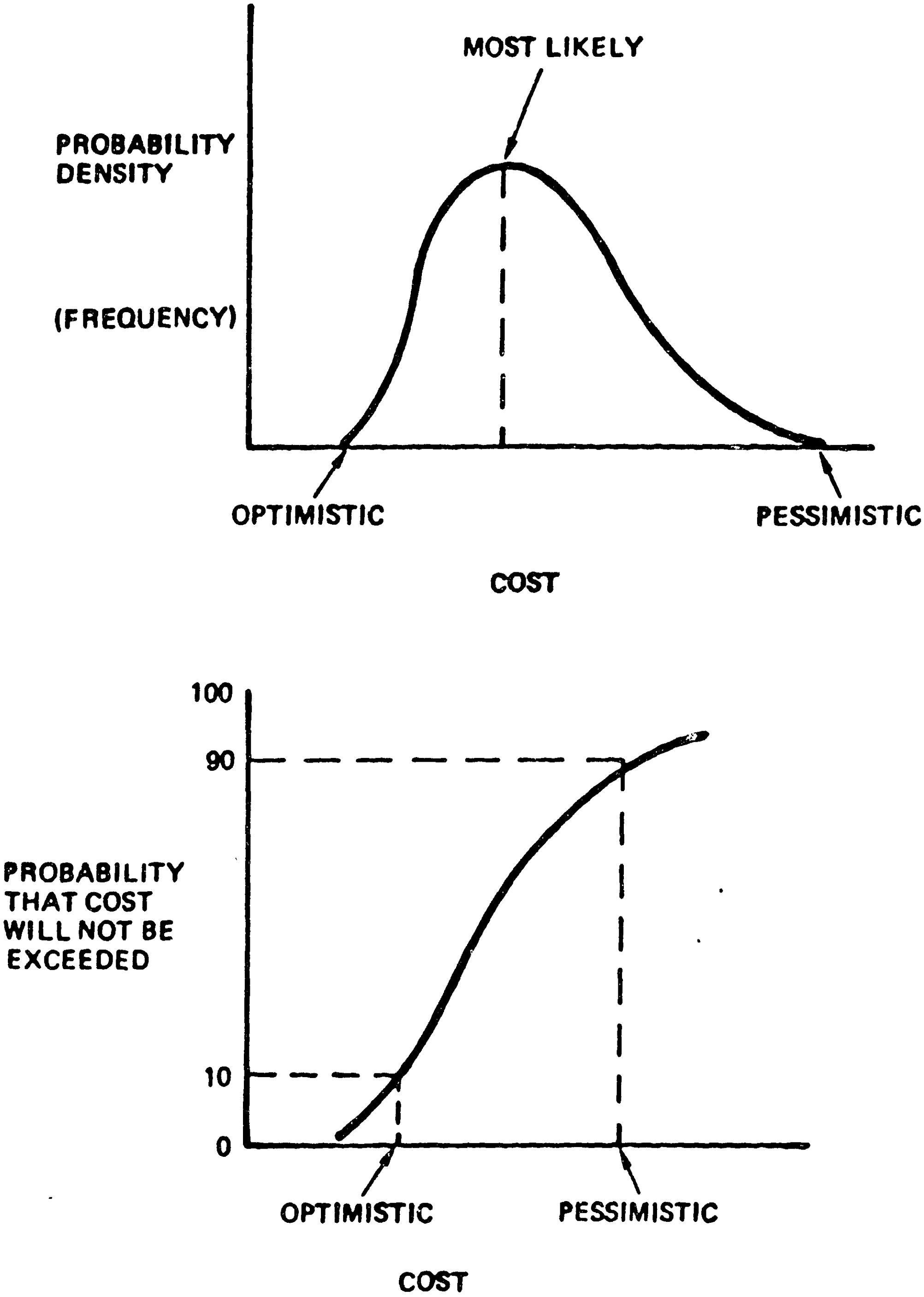
of GFM, performance characteristics, weight, and other technical definitions required in most cost estimating methodologies. For example, a cost analyst may know something about the lowest bound, most likely value, and upper bound of an input or perhaps the mean and variance of its distribution.

The second step in a general risk analysis is to transform the non-cost input variables to separate subsystem cost probability distribution functions (PDF) using the CERs developed. The PDF shows the probability of occurrence of a given costs estimate. It is important to note that since the CERs are based on regression analysis, they introduce an additional uncertainty into the process.

The final step is the summation of the separate subsystem PDFs, using either analytical or simulation (i.e., Monte Carlo) methods, to obtain the total PDF for the ship. However, the most useful presentation of cost uncertainty indicates the probability of exceeding a given sum (generally the most likely estimate). This is the type of distribution shown in Fig. 2.11 as the final output of the risk analysis process; it is referred to as the cumulative probability distribution (CDF) and is the result of integrating the area under the PDF.

Fig. 2.15 and Eqns. (2.11-12) illustrate the relationship between the PDF (p(x) or frequency) and the CDF (P(x)). The optimistic and pessimistic values are the best estimates of the lower and upper bounds, respectively, for the cost of the system. Note the characteristic S-shape of the CDF.

The effect of defining systems more fully and therefore



Uncertainty Measures Using Probability Density
and Cumulative Density Functions
(Ref. 19)

Figure 2.11

obtaining a more accurate cost estimate would be seen by the reduction in the width of costs under the S curve. It is interesting to note that, according to Eqn. (2.12), the probability of any point estimate being correct is zero. Only a system with zero uncertainty would reduce to a single point estimate.

In this study, risk is defined as the uncertainty measure of a ship costing estimate. Although there are several measures of uncertainty to be found in the literature (e.g., see Ref. 18), the variance (see Eqn. 2.14) is probably the most familiar. The variance is often used with the mean to define a coefficient of variance (COV), which is simply the square root of the variance divided by the mean value.

Since the COV increases in relation to uncertainty, larger COV values should be expected during conceptual and preliminary design, and smaller values for contract design. Ref. 29 treats the uncertainty of weight using this concept, and suggests the existence of constant COVs for classes of items (i.e., hull, propulsion, etc.).

Both material and labor contribute to the uncertainty of any estimate. However, the uncertainties associated with labor costs are usually much more significant. Individual labor costs tend to be positively skewed (i.e., skewed right in Fig. 2.14), since there is a physical limit on the minimum time to accomplish a given task. At the total job level, the summation of these tasks produces a close approximation to the normal distribution (Ref. 29).

Cost interval estimates are often used to express uncertainty in a point estimate: for example, $X + or - 10%, where X is the most likely estimate value. However, such a statement can be misleading without a proper statistical frame of reference. For a randomly distributed variable, the level of confidence or variance associated with the estimate will provide the appropriate frame.

The level of confidence, or confidence interval, gives the probability of the variable actually falling within the specified limits (i.e., $X + or - 10%) at any given time and is typically expressed as a percentage. For a normal distribution, Table 2.8 shows the variation of confidence levels with number of standard deviations (square root of the variance) about the mean (also the most likely value for a Gaussian distribution due to symmetry).

Confidence Interval (%)	Number of Standard Deviations about the Mean
38.30	0.5
68.26	1.0
86.64	1.5
95.44	2.0
99.74	3.0

Relationship between Confidence Interval and Standard Deviations for a Gaussian Distribution

Table 2.8

It is obvious from Table 2.8 that the greater the range for the estimate, expressed as standard deviations about the mean, the higher the confidence that the estimate will be within the specified range. The relationship further illustrates that a cost interval estimate must be associated with a confidence interval or measure of the standard deviation as related to a particular probability distribution.

The previous discussion points out the major assumptions used in risk analysis. These are as follows;

(1) a system is made up of a set of elements or subsystems;

(2) total system cost is the sum of the element costs;

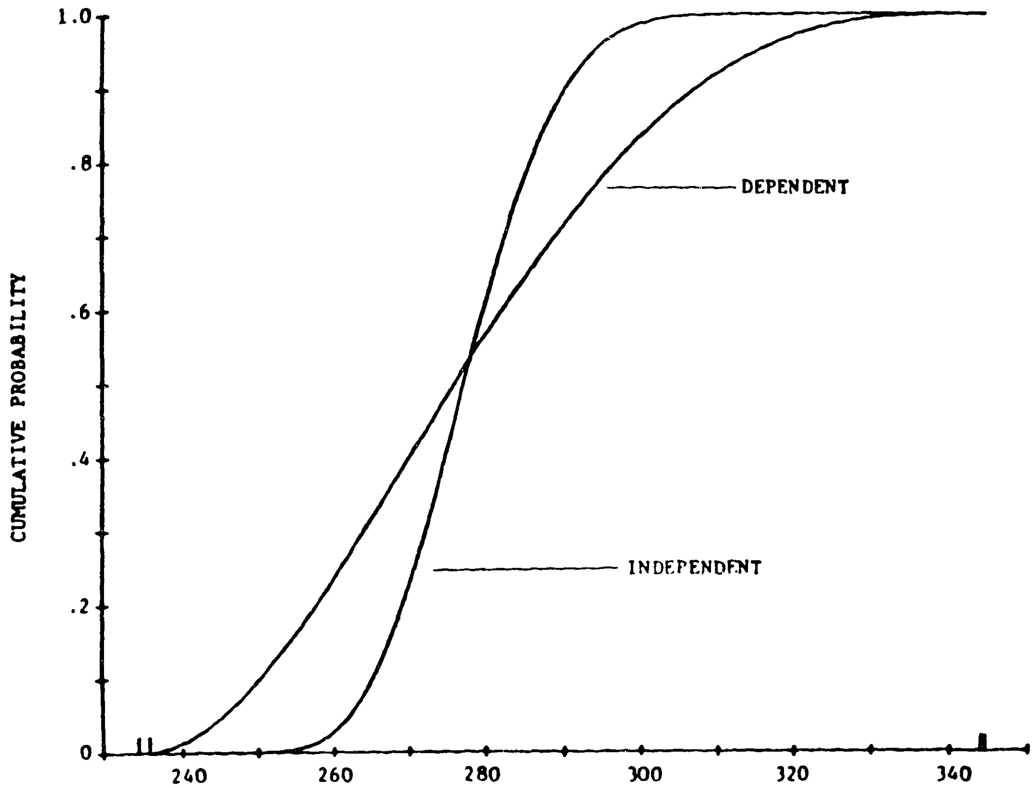
(3) there is a cost estimating relationship (CER) for each element;

(4) the inputs to the CER are treated as random variables, and;

(5) the element costs are stochastically (i.e., statistically) independent

The last assumption has been used in several analyses (e.g., see Refs. 19 and 28). However, the influence of dependency among the input variables can have a significant effect on the total system CDF and subsequent cost risk analysis (e.g., see Refs. 31 and 32).

The variation in the CDF for independent versus dependent input variables is shown in Fig. 2.12. The obvious effect is a reduction in the cost uncertainty for independent inputs versus dependent ones. Therefore, the assumption of independent inputs



Cumulative Density Functions for Dependent and Independent Input Variables
(Ref. 33)

Figure 2.12

results in an overly optimistic prediction of uncertainty when dependency does indeed exist.

The cost estimating methods discussed in this study use SWBS weight groups as major input parameters. As any ship synthesis program will show, there is a high degree of dependency among ship weights, performance characteristics, and other technical inputs.

2.3.2 Analytical Methods

2.3.2.1 Cost Element PDFs

In the context of this study, a cost element can refer to a sub-system cost (i.e., SWBS weight group cost, GFM, etc.), a non-cost input for a CER (i.e., weight, SHP, etc.), or the regression constants in a CER.

Analytical methods provide analysts with a certain measure of cost expectations and dispersion in certainty by fitting probability distribution functions with well-known and understood properties to the cost elements.

In reality, the actual shape of the PDF is unknown. However, it is possible to identify some logical characteristics (e.g., see Ref. 31). These include;

(1) it should have fixed, positive upper and lower bounds;

(2) it should not necessarily be symmetric;

(3) it should be unimodal, and;

(4) it should be computationally simple.

There are several PDFs that satisfy these requirements, including (in decreasing order of complexity), Beta, Gaussian, triangular and uniform distributions. The Gaussian or normal distribution can be generated as a limiting form of the beta distribution (Ref. 33).

Table 2.9 indicates the variation of skewness and kurtosis among these four distributions. Skewness is a measure of symmetry about the mean and can be calculated using the expression;

$$\text{skew} = (\text{mean} - \text{mode}) / \text{standard deviation} \tag{2.7}$$

where the standard deviation is the square root of the variance (e.g., see Eqn. 2.14). Kurtosis provides a measure of the peakedness of the distribution (i.e., a comparison of the spread of observations under the curve), with high values indicating less spread.

Distribution	Skewness	Kurtosis
Beta	any value	> 1.8
Gaussian	0	3
Triangular	-.565 to .565	2.4
Uniform	0	1.8

Comparison of PDF Characteristics

Table 2.9

The use of any distribution requires that a minimum amount of information for each cost element be provided to the analyst. This information can be obtained by the Delphi method (i.e., expert opinion) and is generally in the form of the most likely value (mode), lowest bound and upper bound.

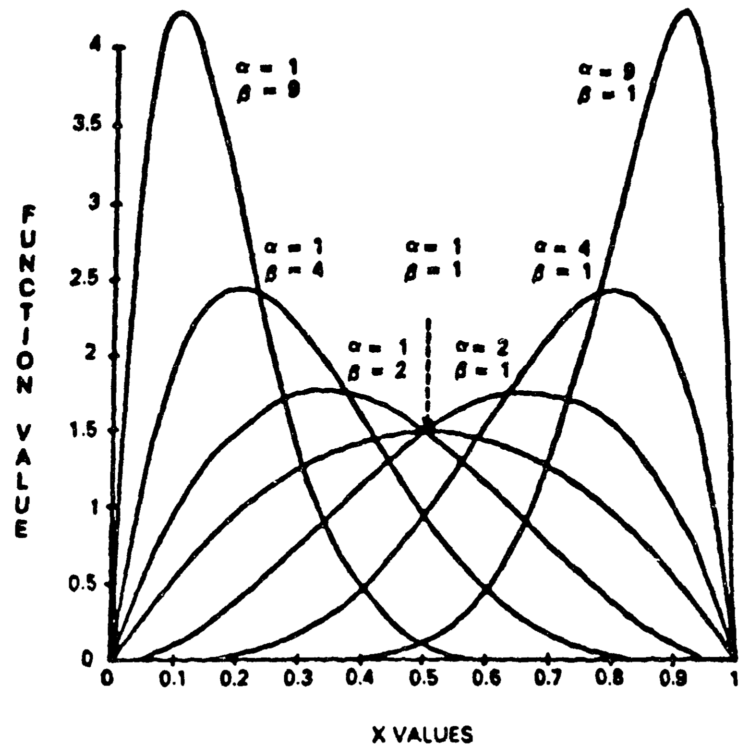
In some cases the user may not wish to set absolute lower and upper limits. In such an instance, the cost analyst may be supplied with a low estimate and an associated probability of underrun, the mode, a high estimate and the probability of overrun.

The preceding cost element data will completely specify any of the four PDFs. If it is only possible to assign upper and lower bounds to the element, the uniform distribution is used.

2.3.2.1.1 Beta PDFs

A range of normalized beta PDFs are shown in Fig. 2.13. As indicated by Eqn. (2.8), the parameters alpha and beta are required to uniquely determine the shape of the normalized function. For the beta distributions to be unimodal, both alpha and beta must be greater than zero (Ref. 33). Eqns. (2.9-10) show how these parameters are related to the mean and variance. The random variable X, on the interval 0 to 1 can be rescaled and shifted to the cost element range of "a" (low value) to "b" (high value), using the transformation "a + (b-a)X".

The beta distribution is well suited to costing analysis because it can assume many shapes with varying kurtosis (peakedness) and skewness. These properties allow the analyst to model any amount of variance (dispersion) and skewness. This variety lends itself to the procedure of graph selection, in which the analyst selects a graph from a family of distributions which best characterizes the cost element uncertainty. Fig. 2.14 is an example of such a series of plots, showing differences in variance and skewness.



where

$$f(x) = \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)*\Gamma(\beta)} x^{\alpha-1}(1-x)^{\beta-1} \tag{2.8}$$

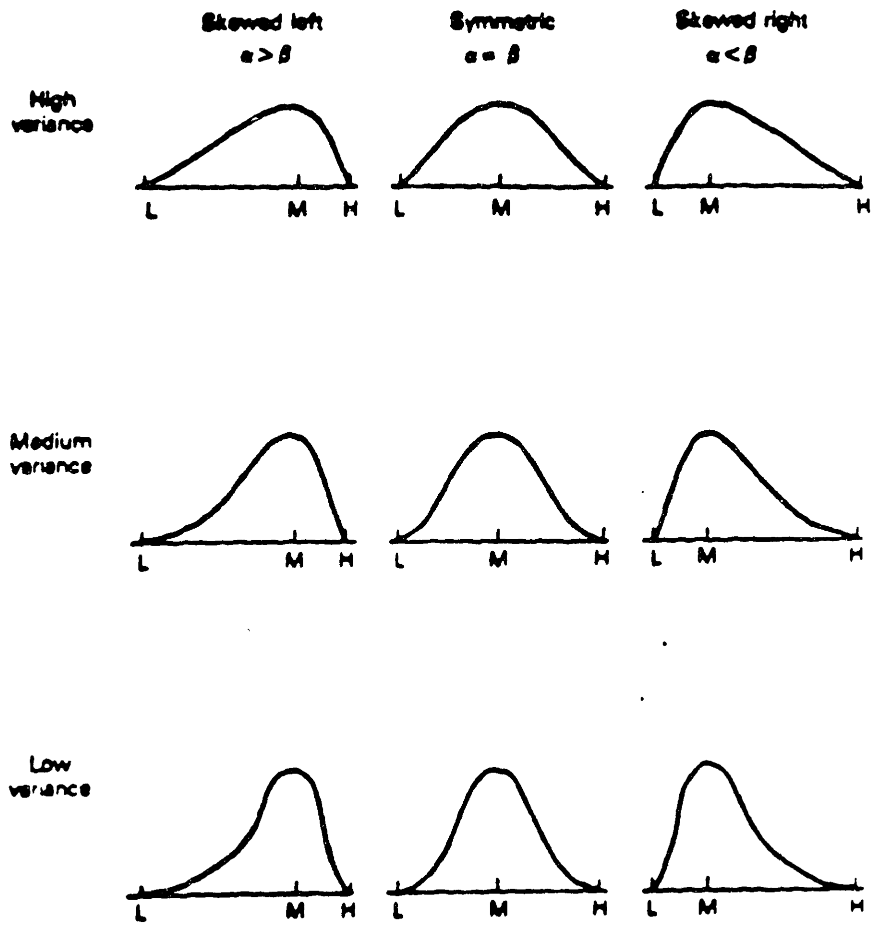
having mean μ and variance σ^2

$$\mu = \frac{\alpha}{\alpha+\beta} \tag{2.9}$$

$$\sigma^2 = \frac{\alpha\beta}{(\alpha+\beta)^2(\alpha+\beta+1)} \tag{2.10}$$

The Normalized Beta Probability Density Function
(Ref. 33)

Figure 2.13



Shape Variations using Beta PDFs
(Ref. 33)

Figure 2.14

2.3.2.1.2 Gaussian PDFs

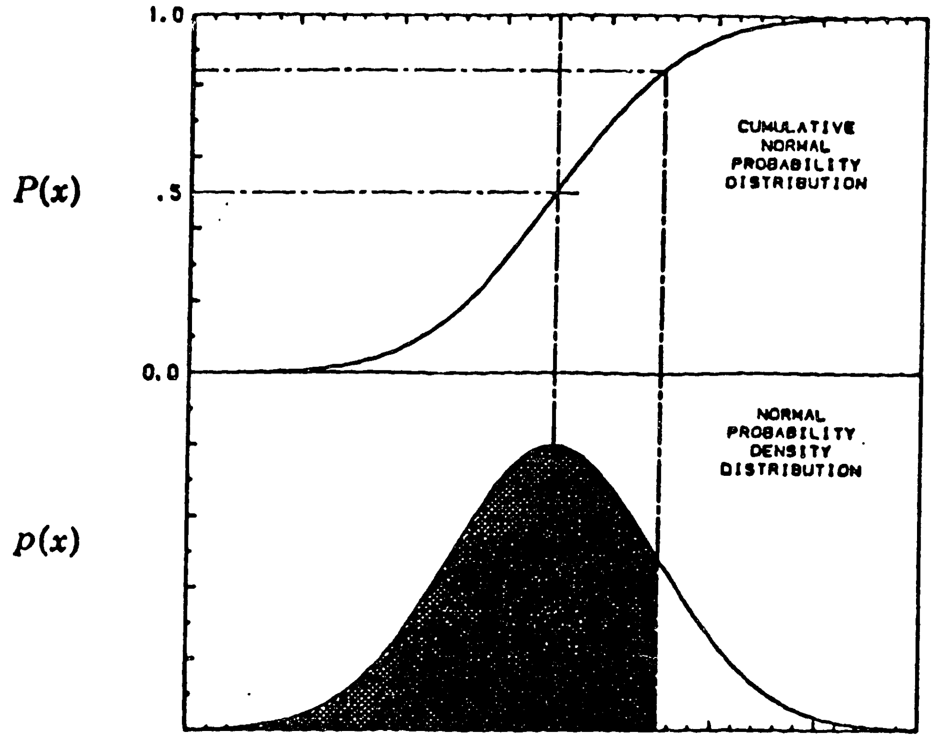
The form of the Gaussian (or normal) probability distribution function is shown in Fig. 2.15 and by Eqn. (2.11). Whereas the beta PDF requires four parameters to define its shape and range (i.e., alpha, beta, high and low values), the Gaussian PDF only needs a mean and variance (see Eqns. 2.13-14).

The symmetric shape of the Gaussian curve is generally applicable to the distribution of a large number of independent elements and is not particularly applicable to single cost elements. Also, the distribution has no finite endpoints. These characteristics limit its use in cost risk analysis.

2.3.2.1.3 Triangular PDFs

The triangular distribution is very popular due to its simplicity and wide range of applicability (e.g., see Ref. 33). Its shape can be determined with only knowledge of the lower, most likely, and high estimates. Fig. 2.16 indicates the possible shape of a triangular distribution for three different modes (most likely values), m. The location of the mode in the range between the lower estimate, a, and the high estimate, b, determines the degree of skewness for the cost element.

The analytic form for this PDF is shown in Eqn. (2.15), and the resulting mean and variance for a triangular distribution can be calculated using Eqns. (2.16-17), respectively. The integration of this PDF gives CDFs in good agreement with more complex analytical functions (Ref. 33).



where

$$p(x) = \frac{1}{\sqrt{2\pi\sigma_x^2}} e^{-[(x-\mu_x)^2/(2\sigma_x^2)]} \quad (2.11)$$

$$P(x) = \int_{-\infty}^{x} p(\xi)d\xi \quad (2.12)$$

and μ_x is the mean value of x and σ_x^2 the variance of x.

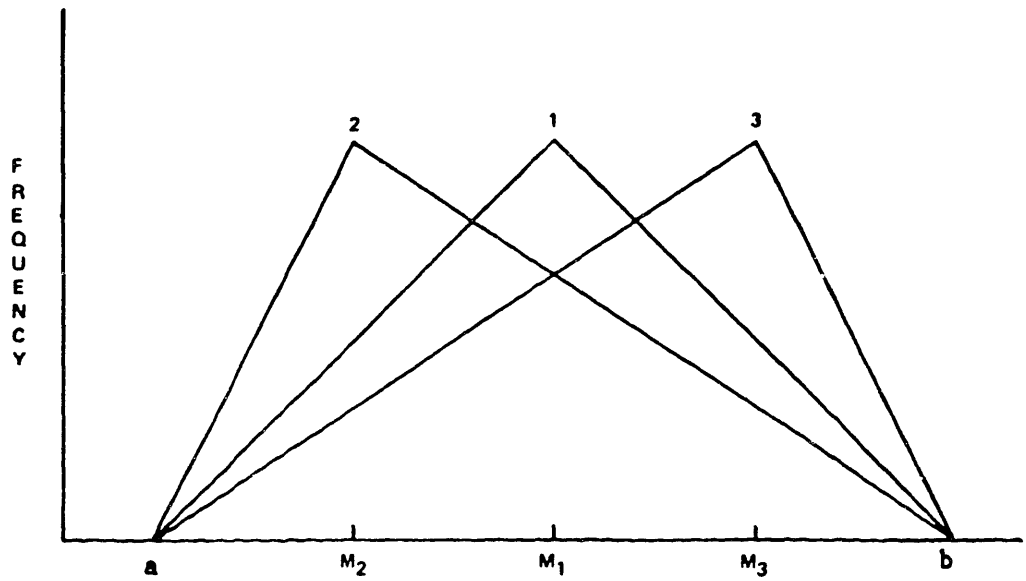
$$\mu_x = \frac{1}{N}\sum_{i=1}^{N} x_i \quad (2.13)$$

$$\sigma_x^2 = \frac{1}{N}\sum_{i=1}^{N} (x_i - \mu_x)^2 \quad (2.14)$$

where range of index i from 1 to N is over all members of class

The Gaussian Probability Density Function

Figure 2.15



where

$$f(x) = \begin{cases} \dfrac{2(x - a)}{(m - a)\ (b - a)} \ ; & a \leq x \leq m \\ \dfrac{2(b - x)}{(b - m)\ (b - a)} \ ; & m \leq x \leq b \end{cases} \tag{2.15}$$

having mean μ and variance σ^2

$$\mu = \frac{a + m + b}{3} \tag{2.16}$$

$$\sigma^2 = \frac{a(a - m) + b\ (b - a) + m(m - b)}{18} \tag{2.17}$$

The Triangular Probability Density Function

Figure 2.16

2.3.2.1.4 Uniform PDFs

For situations when only the lower and upper bounds of a cost element are known, the uniform distribution can be used. For a lower estimate equal to "a" and an upper value equal to "b", the probability density function, mean and variance of this simplest of PDFs are as follows;

$$f(x) = 1 / (b - a) \tag{2.18}$$

$$\text{mean} = (a + b) / 2 \tag{2.19}$$

$$\text{variance} = (a - b)^2 / 12 \tag{2.20}$$

2.3.2.2 Method of Moments

The method of moments provides the capability of analyzing the risk (uncertainty) inherent in the summation of independent and dependent cost elements that are input directly or estimated using polynomial CERs. In this study, the following additive polynomial relationship will be discussed;

$$\text{Cost} = C_1 + C_2 + C_3 + \ldots + C_N \tag{2.21}$$

where the C_Ns represent the independent or dependent subsystem costs. The values of C are estimated from CERs of the form:

$$C = X_1 + X_2 X_3^P + \text{error term} \tag{2.22}$$

where the X_is are cost elements or regression constants and P is a constant. The error term is generally unknown and is typically ignored in subsequent calculations. For costs that are input directly, $C = X_1$.

Using the moment of methods, the estimation of the total system cost PDF involves four basic steps:

(1) calculate individual sets of moments for each C_N in Eqn. (2.21);

(2) add the N sets of moments together;

(3) fit a PDF with moments equal to the sums calculated in (2);

(4) numerically integrate the PDF to obtain the CDF.

In the first step, additive moments, A_is, for each CER (i.e., Eqn. 2.22) are calculated. Eqn. (2.23) shows that the expressions used to calculate the additive moments require knowledge of the Taylor series representation of the CER, the first origin moment (the mean value), and three central moments (moments about the mean). Ref. 32 indicates that these four moments will provide sufficient information to determine the PDF asymmetry and shape and yet allow easy computations.

The Taylor series in Eqn. (2.23) is expanded about the mean, u_i, of each input variable, X_i. Expansion to higher order derivatives is straightforward and would probably be more accurate. The first additive moment does not include the Taylor series and is merely the value of the CER calculated using the mean values for all X_is. Subsequent moments require the sum of the CER partials, each evaluated at its i^{th} mean value.

For directly inputted costs, the value of the partials would be equal to one and the additive moments would be equal to the mean cost, variance (i.e., A_1 and A_2) and a combination of the central moments.

If the values of C_N can be assumed independent, then the second step in the method of moments is the addition of the N sets of A moments (i.e., the A_k moment of the sum is equal to the sum of the individual A_k moments) (Ref. 33).

For complete linear dependence, the A moments must be transformed into D moments, which have the same additive properties as the A moments (Ref. 33). Therefore, the D_k moment of the sum is equal to the sum of the individual D_k moments. The relationship between the moments is given by Eqn. (2.24).

Once the total system cost moments have been calculated, then a PDF can be fit using the values calculated. The actual total system cost moments will fall between the independent and dependent values obtained using Eqns. (2.23-24), respectively. Several methods have been used for fitting a given distribution. Refs. 28 and 33 outline the methodology involved in fitting the moments to a Beta distribution.

If an independent Gaussian distribution is assumed for the elements, only the first two additive moments (mean and variance) need to be calculated (Ref. 29). For dependent variables, the mean and standard deviation are summed for the total system cost. Since the square of a standard deviation summation is greater than a variance summation (for the same values), the risk associated with dependent variables is greater than for independent ones. This is illustrated in Fig. 2.12.

$$A_1 = C(u_1, u_2, \ldots u_n)$$

$$A_2 = \Sigma \left(\frac{\partial C(X)}{\partial X_i} \right)^2 u_{i_{(2)}}$$

$$A_3 = \Sigma \left(\frac{\partial C(X)}{\partial X_i} \right)^3 u_{i_{(3)}} \qquad (2.23)$$

$$A_4 = \Sigma \left(\frac{\partial C(X)}{\partial X_i} \right)^4 (u_{i_{(4)}} - 3u_{i_{(2)}}^{\ 2})$$

where the partials are evaluated at u_i, and $u_{i_{(k)}}$ is the kth central moment of X_i.

$$D_1 = C(u_1, u_2, \ldots u_n)$$

$$D_2^2 = \Sigma \left(\frac{\partial C(X)}{\partial X_i} \right)^2 u_{i_{(2)}}$$

$$D_3^3 = \Sigma \left(\frac{\partial C(X)}{\partial X_i} \right)^3 u_{i_{(3)}} \qquad (2.24)$$

$$D_4^4 = \Sigma \left(\frac{\partial C(X)}{\partial X_i} \right)^4 u_{i_{(4)}}$$

where D_k = dependent additive moment

A_k = independent additive moment

Additive Moments for the Method of Moment Calculations

Figure 2.17

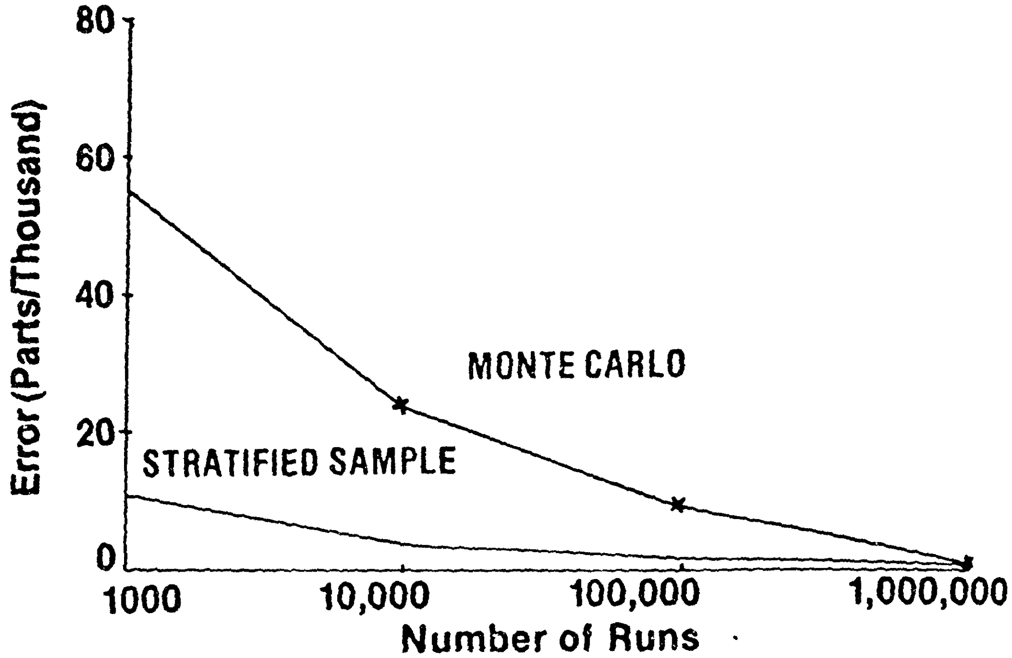
2.3.3 Monte Carlo Methods

Monte Carlo or computer simulation methods are techniques in which the value generated for a cost element or CER regression constant is determined by selecting random numbers subject to a defined probability law. If the generated random number falls within the limits of a pre-determined probability range, then a particular value for the variable is chosen.

Because the method simulates a random sampling of the variables involved, several computer runs must be made to ensure that the full range of values for each variable is obtained. In this respect, the Monte Carlo method is iterative, since the exact number of calculations is not known beforehand.

Several numerical techniques have been developed to make simulations more efficient and less time consuming. Two techniques that are discussed include Stratified Sampling and Slice (see Ref. 32). They differ from so-called straightforward Monte Carlo random sampling methods by the number and size distribution of intervals along the probability range.

Figure 2.18 shows the decrease in error for the Stratified Sampling as compared to simple Monte Carlo. The error is estimated from the differences between the simulation values of the additive moments and those obtained from exact calculations. The convergent nature of the simulations is obvious from the reduction in errors associated with number of runs. Also, the greater efficiency and accuracy of Stratified Sampling over simple Monte Carlo is easily seen.



Decrease in Variance Error with Increasing Run Size
for Monte Carlo Methods
(Ref. 32)

Figure 2.18

CHAPTER 3

DESCRIPTION OF SPECIFIC SHIP COST MODELS

There is certainly no shortage of cost models in use at this time. There are probably a dozen or so official cost models in use by the US Navy alone, not to mention a myriad of private models kept within the agencies to independently check the "official" estimates. In addition, the majority of companies involved in the ship or shipbuilding industry possess their own cost models.

It is important to understand that these cost models serve different functions for different organizations. For example, the cost models at NAVSEA Code 017 are intended to provide budetary estimates for ship construction. The models in use at the Naval Center for Cost Analysis are used by OPNAV to provide independent checks on new ship construction bids that are received. Cost models are used by NAVSEA design teams to perform cost trade-off analyses.

Contractor cost models are used to submit contract bids for new ship construction. Also, there are government agencies that are interested in the development of cost models. For instance, the development of ASSET and RCA PRICE cost models at DTNSRDC for future Navy applications.

The intent of this chapter is to provide a representative cross-section of conceptual/preliminary cost models in use at this time. The first part of the chapter is a description of five cost models which are applicable for this type of early stage cost estimating. These include NAVSEA Code 017, Naval Center for Cost Analysis (NCA), ASSET, USCG and RCA PRICE.

All the models require an estimation of SWBS weights in order that costs can be determined. Technology differences are accounted for using a variety of methods. As well as a description of the models and their use, the necessary input parameters for each model are listed.

Due to the proprietary nature of cost models and their databases, the comparison of these models is primarily a qualitative one. Perhaps further studies could focus on a more quantitative study involving specific vessel costing comparisons.

Typically, point estimates during conceptual design are in the plus or minus 15-25% range. After preliminary design, the range may be reduced to 5-15%. However, due to the large number of assumptions inherent in any cost estimate, it would appear that any "reasonable" cost estimate can be rationalized.

3.1 ACQUISITION & LIFE-CYCLE COST ESTIMATING

3.1.1 NAVSEA CODE 017

3.1.1.1 General

Code SEA 017 refers to the Office of Cost Estimating and Analysis of the Naval Sea Systems Command (NAVSEA). This office is charged with the responsibility for preparing the Navy's official ship cost estimates for planning and programming purposes and for the annual Department of Defense (DoD) shipbuilding budget (e.g., see Ref. 16). These responsibilities encompass ship cost estimating and analysis at the initial design feasibility study phase through production award. SEA 017 also serves as advisor to NAVSEA on the historic, current, and emerging trends in all elements of cost estimating and cost analysis.

Generally, SEA 017 estimates are used in the preparation of the shipbuilding procurement account, Shipbuilding and Conversion, Navy Appropriation (SCN). An SCN procurement item that has been authorized by Congress must be full funded or the work must cease. This full funded policy ensures that monies are available for all reasonable and expected costs through the ship construction and post-delivery period. Ship cost estimates prepared under this policy are said to be "end costed".

Since every official NAVSEA ship cost estimate is to be treated as a potential budget candidate, certain requirements have been established to ensure the estimate is treated in its proper context. These are as follows:

1. a written OPNAV (Operations, NAVY) cost and feasibility request must be in hand

2. formal technical design inputs (e.g., SWBS weight groups) must be available

3. an approved acquisition strategy and shipbuilding schedule must be available

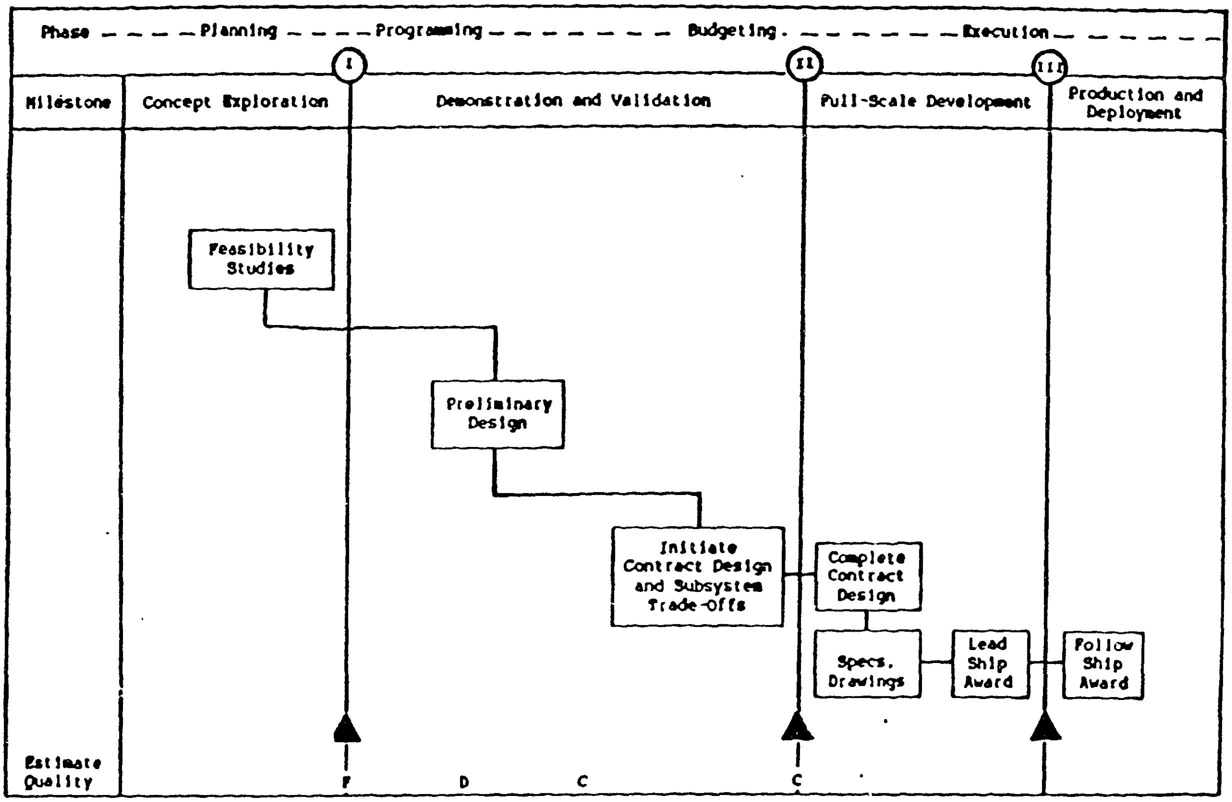
4. a cognizant Program Manager must be involved

It becomes obvious that ship cost estimating within the NAVSEA community operates within a controlled environment.

There are four principal divisions in the acquisition design process: feasibility studies, preliminary design, contract design and detail design. The first three new ship design phases and their relationship to the key Navy acquisition milestones and to the quality of SEA 017 cost estimates are shown in Figure 3.1.

The detail design phase is the responsibility of the shipbuilder or design agent. As the design proceeds through the various phases, the quality of the cost estimates increases proportionately with the range and depth of the technical inputs.

In this study, the cost estimating methodology used for calculating a Class F estimate is outlined. This class of estimates is considered to be of feasibility design "ball park" quality. The method is essentially the same used to calculate Class D and C estimates. However, whereas a Class F estimate is calculated from the light ship weight estimate at the one-digit level of SWBS, Class D and C estimates use two-/three-digit breakdown. The Class C estimate is considered budget-quality and is based on technical definition available at the completion of the Preliminary Design.



Acquisition Review Milestones, Technical Definition
and Cost Estimate Quality
(Ref. 16)

Figure 3.1

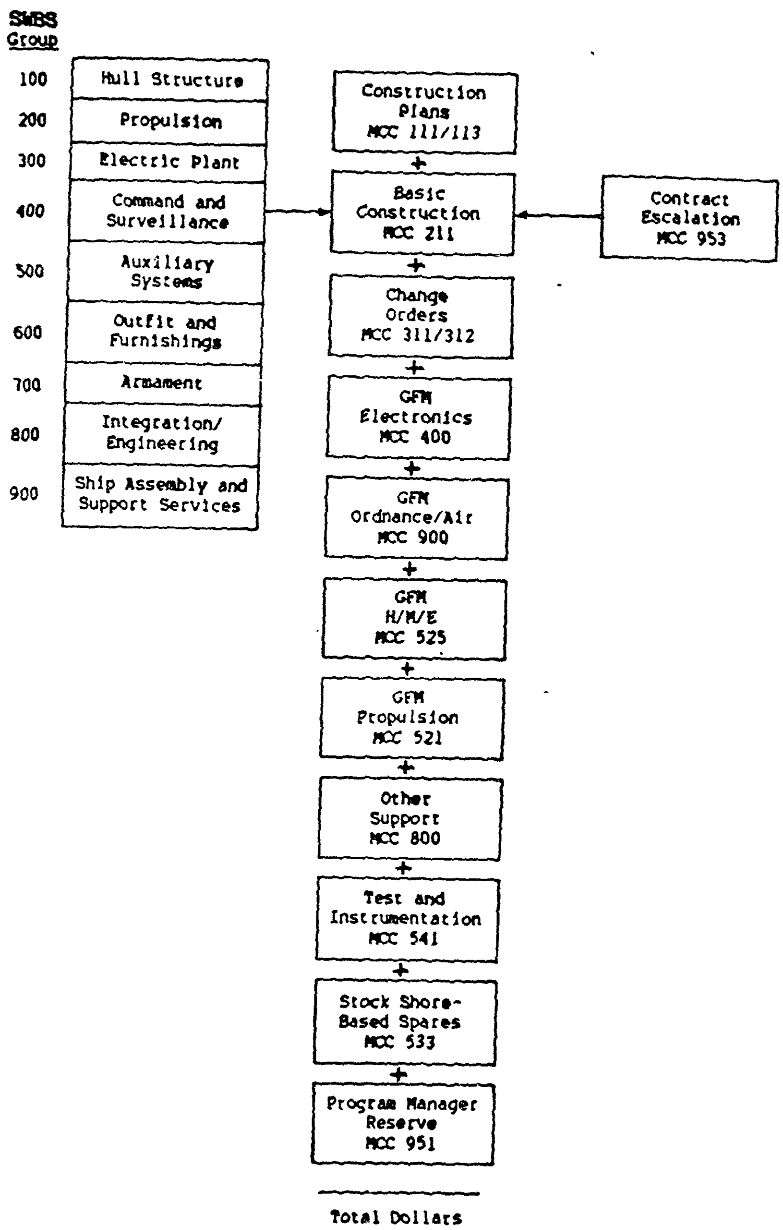
3.1.1.2 Cost Estimating Relationships

The cost estimating methodology outlined in this section is based upon the information available in Ref. 16 and an input/output printout from the Unit Price Analysis (UPA) cost model. The UPA model was designed to address the cost elements discussed in this section.

Cost estimating relationships used within SEA 017 for feasibility and preliminary design phases, are calculated from selected manhour and material costs divided by the weight of the seven major SWBS groups. These factors are updated annually based on historical data as well as return costs on previously awarded shipbuilding contracts and the past year's bid data on new awards. In addition, all GFM lists are reviewed and adjusted as required.

As previously mentioned, ship cost estimates generated by SEA 017 are said to be "end costed". The cost categories that constitute a total end cost estimate are shown in Figure 3.2. The major category codes (MCCs) conform to the cost collection/accounting and budgetary systems of NAVSEA.

The categories of an end cost estimate can be separated into three groupings; shipbuilder portion, government furnished material (GFM), and miscellaneous G&A (general & administrative). The sum of the basic construction, construction plans, contract escalation and change order cost categories constitute the portion of monies that are paid to the shipbuilder/design agent. The GFM portion is made up of government supplied electronics, ordnance/air, H,M&E (hull, mechanical & electrical), and propulsion. The remainder of the program costs are associated



Categories of a Total End Cost Estimate
(Ref. 16)

Figure 3.2

with a variety of G&A costs.

The basic construction cost (MCC 211) is the central element of the NAVSEA ship cost estimating process. Basic construction is defined as the original contract award price for ship construction. It includes all allowable labor, overhead and material costs plus an amount for cost of money (COM) and profit.

Labor manhours, MH (hrs), and material costs, MC ($M), cost factors are developed for each of the SWBS weight groups 100-700, such that;

$$MH_i = KL_i \; W_i \tag{3.1}$$

where W_i = appropriate SWBS weight group (LT)

KL_i = appropriate manhour cost factor (hrs/LT)

$$MC_i = KM_i \; W_i \tag{3.2}$$

where KM_i = appropriate material cost factor ($M/LT)

Estimates of labor manhours and material costs for SWBS groups 800 and 900 are typically estimated as a percentage of the sum of manhours and material dollars for groups 100 through 700, such that;

$$\begin{aligned} MH_8 &= FL_8 \; (MH_1 + MH_2 + \ldots + MH_7) \\ MH_9 &= FL_9 \; (MH_1 + MH_2 + \ldots + MH_7) \\ MC_8 &= FM_8 \; (MC_1 + MC_2 + \ldots + MC_7) \\ MC_9 &= FM_9 \; (MC_1 + MC_2 + \ldots + MC_7) \end{aligned} \tag{3.3}$$

where FL_i = appropriate labor fraction (%/100)

FM_i = appropriate material cost fraction (%/100)

Representative values for these variables are; FL_8 and FL_9 = 0.25-0.35, and; FM_8 and FM_9 = 0.01-0.10. Labor manhours can also be estimated using manloading profiles based on previous programs.

The design and builder's (D&B) margin is costed and included as part of basic construction on the assumption that the margin will be "used up" during the development of the design and in construction of the ship as awarded. The costing of the margin is done by applying the D&B margin percentage to the total manhours and material dollars for groups 100 to 900;

$$MH_{D\&B} = F_{D\&B} \ (MH_1 + \ldots + MH_9)$$

$$MC_{D\&B} = F_{D\&B} \ (MC_1 + \ldots + MC_9) \qquad (3.4)$$

where $F_{D\&B}$ = D&B fraction (%/100)

The D&B margin is generally on the order of 12%.

For calculating labor costs, separate labor rates are employed for manufacturing and engineering operations. Manufacturing rates are applied to labor associated with SWBS weight groups 100-700, 900 and the D&B margin. The engineering rate is applied to the labor required for SWBS group 800 work. For any given labor rate, the labor cost, LC ($M), is given by the simple expression;

$$LC_i = MH_i \ \$/HR \tag{3.5}$$

where $/HR = appropriate labor rate (dollars per hour)

Overhead costs, OV ($M) are calculated as a percentage of the labor costs associated with each of the SWBS groups 100-900, such that;

$$OV_i = F_{ovhd} \ LC_i \tag{3.6}$$

where F_{ovhd} = labor overhead fraction (%/100)

The cost of construction for each SWBS weight group plus margin, C ($M), is simply the addition of material cost and direct and overhead labor costs, so that;

$$C_i = MC_i + LC_i + OV_i \tag{3.7}$$

The cost for each SWBS group can be summed to arrive at an intermediate ship construction cost, C_{CC} ($M), where;

$$C_{CC} = C_1 + C_2 + \ldots C_9 + C_{D\&B} \tag{3.8}$$

The cost of money (COM) is intended to compensate contractors for the cost of providing capital for facility investments. Government standards specify the fraction of facility costs that contractors can treat as capital invested in the marketplace. The rate of return allowed on these investment costs is referred to as the imputed interest rate.

The amount used for the COM is calculated by multiplying the sum of the estimated direct labor costs by an appropriate factor.

This factor is computed by multiplying the shipbuilder's net book value of assets times the imputed interest rate and divided by a labor cost allocation base. The base is set equal to the direct labor dollars expended in the shipyard for a particular year. The equation for the COM is as follows;

$$COM = F_{com} \; (LC_1 + \ldots LC_9 + LC_{D\&B}) \qquad (3.9)$$

where F_{com} = the COM factor (%/100)

$$= \frac{\text{(net book value)(imputed interest rate)}}{\text{(allocation base)}}$$

Cost of money is also referred to as facilities cost of money which can be abbreviated to FCM.

Profit is the final element in the estimation of the basic construction cost. Profit, C_{profit} ($M), is calculated as a percentage of the sum of all SWBS group plus margin costs. It can be expressed as;

$$C_{profit} = F_P \, C_{CC} \qquad (3.10)$$

where F_P = profit fraction (%/100)

and C_{CC} is the construction cost estimated in Eqn. (3.8)

After the profit dollars are calculated, the construction costs, cost of money and profit are summed to arrive at a complete basic construction price, P_{BC} ($M), where;

$$P_{BC} = C_{CC} + C_{profit} + COM \qquad (3.11)$$

It is important that all elements making up the basic construction price be adjusted to a common dollar base date.

Shipbuilding contracts are generally costed to a given near-term base date. The contracts include an escalation clause to reimburse the shipbuilder for inflation occurring in the shipbuilding industry over the life of the contract (as measured from the base date in the contract). The dollar requirement that is estimated , C_{esc} (\$M), reflects a specified building period and an assumed labor outlay profile (e.g., see Fig. **).

Several of the end cost categories are typically calculated as a percentage of the basic construction price (i.e., Eqn. 92). Construction plans , change orders and PM (program manager) reserve categories are all examples of this type of methodology.

Construction plans refer to the nonrecurring costs related to the development of detailed construction drawings and other associated engineering tasks by the shipbuilder or design agent. Associated tasks include related engineering calculations, computer programs, contractor responsible technical manuals, damage control books, ships selected records, and mock-ups. The lead ship normally carries the majority of the costs for this category.

Historical data is reviewed to determine what percentage the construction plan costs were of the basic construction price on similar new designs. Percentages developed in this manner are then adjusted by judgement factors, such as ship complexity, to obtain the cost of construction plans, C_{CP} (\$M), where;

$$C_{CP} = F_{Cfactor}\, F_{constr}\, P_{BC} \tag{3.12}$$

where $F_{Cfactor}$ = a complexity factor (typically > 1)

F_{constr} = construction plan fraction (%/100)

A typical value for F_{constr} is 0.12. The final estimate is expressed in terms of material, labor, and overhead costs, COM and profit.

The change order category is simply an allowance of money to fund necessary changes after the shipbuilding contract is awarded. Some of the reasons for these changes are:

- To include state-of-the-art improvements that come about during construction
- To correct "fit-up" problems that surface due to incorrect drawings
- To correct differences between contract drawings and ship specifications
- To incorporate safety items that become evident during construction
- To incorporate improvements that are generated by the operational forces afloat
- To have the shipbuilder repair or modify GFM (government furnished material)
- To change the contract ship delivery point or the contract date of delivery

For the lead ship, change order costs , C_{cord} ($M), are estimated by the following expression;

$$C_{cord} = 0.10\ P_{BC} \tag{3.13}$$

For follow ships, change order costs are given by;

$$C_{cord} = 0.05\ P_{BC} \tag{3.14}$$

The 10 and 5% figures reflect new NAVSEA guidelines to reduce programmatic costs. Historically, the cost of change orders for the lead and follow ships has been taken as 12 and 8%, respectively, of the basic construction price (e.g., see the ASSET cost model description).

Although the change order dollar amount is estimated in base year dollars, it is not inflated over the life of the contract. Therefore, it represents a total amount to be spent throughout the construction period.

Government furnished material (GFM), including both hardware and software, is provided by the Navy to shipbuilders for installation aboard ships during the construction period. The Navy chooses to supply these selected equipments for any number of reasons, including standardization, safety, security, cost savings and convenience. The GFM categories can be a significant portion of the ship cost. The estimator must ensure that these costs are not duplicated in the basic construction category.

GFM costs, C_{GFM} ($M), are categorized (see Fig. 3.2) into electronics, ordnance/air, H,M&E (Hull, Mechanical and Electrical) and propulsion. Electronic items include electronics production components, training support equipment, test and engineering services, and repair parts associated with installation.

The ordnance/air items include fire and missile control systems, search radars, missile launching systems, gun systems, training support equipment, test and integration services, landing aids, and selected catapult components.

H,M&E items consist of H,M&E equipments, small boats, special vehicles, environmental protection equipment, training support equipment, H,M&E engineering services, and repair parts associated with installation of H,M&E equipment. Some "unofficial" estimates have calculated the cost of this category as 2% of the basic construction price.

Propulsion GFM usually involves nuclear propulsion systems. Components for conventionally powered ships are generally the responsibility of the shipbuilder and are therefore included in the estimate for the basic construction price.

Cost estimates for each of the GFM categories are prepared using appropriate GFM "shopping lists". These lists are reviewed for ship design compatibility and base year pricing. Historical data on similar purchases are used for comparison purposes.

The shopping list approach for GFM cost estimation is broken into the following cost elements:

- major hardware, defined as the primary units that make it possible for the total system to meet the mission requirement;

- ancillary equipment, required to logistically support the major hardware such as special-purpose test equipment, special tools, gauges and jigs;

- technical data/documentation, for developing and documenting the complete data package associated with installation, integration, operation, and maintenance of the hardware or system;

- spares, required to ensure the operational readiness of an equipment or system until the normal Navy supply system assumes support;

- system engineering, engineering support required to ensure the integration of the various components that make up a major hardware item;

- technical engineering services, contractor/vendor and government engineering services required to support efforts to attain system operational readiness;

- other costs, including nonrecurring production start-up, training, software, test and evaluation, and changes.

Due to the diverse nature of GFM equipments, there is no standard procedure for estimating GFM costs. Delphi (e.g., vendor quotes), analogy, CERs, or engineering methodologies are used wherever they are deemed appropriate and produce the best results. Whatever method is used, material, labor, overhead, COM, and profit estimates are obtained for each GFM category.

The remaining end cost categories comprise a number of miscellaneous G&A cost elements (programmatic in nature). These include the categories of other support, test and instrumentation, stock shore-based spares and program manager reserve.

The other support category involves a variety of G&A functions, including but not limited to equipment transportation costs, travel in support of ship acquisition, contract engineering services, commissioning ceremonies, and in-house engineering services.

Other support costs, C_{other} ($M), are estimated from previous ship acquisition programs, are supplied by the ship acquisition managers, or can be estimated as a percentage of the basic construction price, so that;

$$C_{other} = F_{sup} P_{BC} \tag{3.15}$$

where F_{sup} = other support factor (%/100)

A typical value for F_{sup} is 0.08.

The test and instrumentation category includes the cost of testing and instrumentation (T&I) related to routine or special trials leading to qualifying a ship for active service. The majority of these costs will be borne by the lead ship.

Estimates for test and instrumentation costs, $C_{T\&I}$ ($M), are obtained by analogy/comparison with previous programs. The ship acquisition program managers can provide necessary information on the number of trials and special tests that are required. Past costs can be adjusted to reflect the current requirements. The costs must also be inflated to the proper time period, remembering that most of the T&I effort is conducted before ship delivery and acceptance by the Navy.

The stock shore-based spares category includes procurement of back-up spares for stock ashore or aboard tender/repair ships. The stock spares funded in this category are limited to first-of-its-kind installations on the lead ship. Examples include propellers, anchor chains, anchors, turbine generators, diesel and gas turbine engines, and selected shafting.

Items included in the stock spares cost, C_{spares} ($M), are supplied by the program manager. In most cases, the estimator will already have priced the equipment from shopping lists assembled for estimating the basic construction costs or H,M&E

GFM. If this is not the case, marine vendor quotes can be obtained for the item.

The Program Manager (PM) reserve category provides a source of funds to the project manager for unforeseen future problems or actions. This cost reserve is made up of the following elements:

- general cost reserve, for general risks in the estimating and acquisition process, equal to 1% of end cost (less contract escalation);

- lead ship cost reserve, for cost uncertainties associated with introduction of the first ship of a new class, equal to 3% of end cost (less contract escalation);

- follow ship cost reserve, for uncertainties associated with follow-on construction, equal to 2 and 1% of end cost (less contract escalation) for complex and non-complex ships, respectively;

- cost reserve for less than budget quality (i.e., Class D and F), equal to 1% of end cost (less contract escalation)

Complex ships are defined as combatants, unique ships and craft, and other ships with significantly complex GFM systems.

The appropriate percentages to be applied to estimate the dollar amount for PM growth can be found in Table 3.1.

Program Type	Budget Quality	Less Than Budget Quality
Lead Ship - New/Modified Repeat	4%	5%
Follow Ship - Complex	3%	4%
- Not Complex	2%	3%

Percentages to Calculate
Program Manager Cost Reserve
(Ref. 16)

Table 3.1

The PM cost reserve, C_{PM} (\$M), is then estimated using the following expression;

$$C_{PM} = F_{PM}(P_{BC} + C_{CP} + C_{cord} + C_{GFM} + C_{T\&I} + C_{spares} + C_{other}) \qquad (3.16)$$

where F_{PM} = program manager reserve cost fraction (%/100) (from Table 3.1)

The total end costed price for a lead ship, P_{total} (\$M), is estimated by summing the individual cost categories in Fig. 3.2;

$$P_{total} = C_{CP} + P_{BC} + C_{esc} + C_{cord} + C_{GFM} + C_{other} + C_{T\&I} + C_{spares} + C_{PM} \qquad (3.17)$$

When multiple ships are awarded for construction, learning benefits and reduced costs are anticipated. The degree of learning is highly dependent upon the acquisition plan. Another important aspect of pricing follow ships is the exclusion of non-recurring costs, which are borne by the lead ship only. The majority of non-recurring costs occur in the stock shore-based spares, test and instrumentation and construction plans end cost categories.

If learning will take place, appropriate learning rates must be applied to both manhour and material dollar estimates (Eqns. 3.1-3.2). These reductions are reflected in a reduced basic construction price, P_{BC} (Eqn. 3.11).

Historical bid data indicates that shipbuilders prefer cumulative learning curves, and so these are generally applied. Values for the learning rates are estimated from historical return cost data. A typical labor learning rate from an "unofficial" estimate, applicable to both direct labor and overhead, was 92%.

Additional cost reductions for follow ship construction are realized on change order costs, C_{cord} (Eqn. 3.14), and program manager reserves, C_{PM} (Table 3.1). Escalation costs , C_{esc}, will change as a result of reduced manhour requirements and varying construction periods.

Provided that learning rates have been properly applied, all non-recurring costs have been eliminated, and related costs have been adjusted, the total end costed price of a follow ship, P_{total} ($M), can be estimated by summing the following categories;

$$P_{total} = P_{BC} + C_{esc} + C_{cord} + C_{GFM} + C_{other} + C_{PM} \tag{3.18}$$

To assist Navy cost estimators involved in ship cost estimating, POMs (program objective memorandum) are issued to provide guidance on a range of cost issues. Some of the topics addressed include labor rates, shipyard profit, material/labor shipbuilding indices, cost of money (COM), overhead, outyear pricing, ROM (rough order of magnitude) estimates, and escalation. For example, the following percentage values are suggested for the following variables;

F_P = 10% (see Eqn. 3.10)

F_{com} = 5.588% (see Eqn. 3.9).

Life cycle cost estimates are not required for budgetary purposes. However, life cycle costing enhances the decision making process, especially during the early planning (concept formulation) phase of the acquisition cycle (see Fig. 3.1). For example, design trade-off studies conducted during this period can be evaluated on a total cost basis as well as on a performance/technical basis.

NAVSEA cost estimators use ship data from the VAMOSC (Visibility and Management of Operating and Support Costs) program to assist in the preparation of the O&S portion of life-cycle costs. The VAMOSC program presents O&S data for Navy ships which were in active commissioned status throughout the particular reporting year. The cost data are of a quality that the CNO (Chief of Naval Operations) has approved the acceptability of VAMOSC data for decision-making usage.

Operating and support costs are presented in two separate sections for 121 cost elements. The first section displays average costs for each of 21 combatant ship types (e.g., CG, CV, DDG, FF, FFG, etc). The second section gives total O&S data for six classifications of ships, including warships, amphibious warfare, patrol combatants, mine warfare, mobile logistics, and support. The format by which these costs are listed and an explanation of all the cost elements is found in Ref. 21.

The 121 data elements are grouped into the five major cost categories defined below:

Direct Unit Costs - identifies the direct cost associated with the operation and support of an individual ship

Direct Intermediate Maintenance - cost of material and labor expended by a tender, repair ship, or equivalent ashore or afloat Intermediate Maintenance Activity (IMA) in the repair and alteration of other vessels

Direct Depot Maintenance - cost associated with depot level maintenance performed for the ship by public or private facilities

Direct Recurring Investment - cost of Appropriations Purchase Account (APA) and Navy Stock Account (NSA) repairable repair parts consumed by or procured for the ship

Indirect Operating and Support - cost of those services and items (non-investment) that are required by the ship after commissioning and launching which are necessary to continue operations but do not result in an expense against Fleet Operations and Maintenance, Navy (O&MN) appropriations

Table 3.2 indicates the five major categories and the sub-categories that are summed in order to calculate the major category amounts. Successive sub-categories in Table 3.2 are indicated by further indentation.

Direct Unit Costs		
	Personel	
		Manpower
		TAD
	Material	
		Ship POL
		Repair Parts
		Supplies
		Training Expendable Stores
	Purchased Services	
		Printing and Reproduction
		ADP rental - contract services
		Rent and Utilities
		Communications
		Other
Direct Intermediate Maintenance		
	Afloat Maintenance Labor	
		Labor Manhours
	Ashore Maintenance Labor	
		Labor Manhours
	Material	
		Afloat Repair Parts
		Ashore Repair Parts
Direct Depot Maintenance		
	Scheduled Ship Overhaul	
		Regular Overhaul
		Public Shipyard
		Private Shipyard
		Ship Repair Facility
		Selected Restricted Avail.

VAMOSC-Ships Cost Categories
(Ref. 21)

Table 3.2

Direct Depot Maintenance (continued)

- Non-Scheduled Ship Repair
  - Restricted Availability
    - Public Shipyard
    - Private Shipyard
    - Ship Repair Facility
  - Technical Availability
- Fleet Moderization
  - Overhead
    - Public Shipyard
    - Ship Repair Facility
  - Labor
  - Funded Material
  - Special Program Material
  - Other
  - Outfitting and Spares
- Other Depot
  - Naval Air Rework Facility
  - Field Change Installation
  - Rework
  - Design Services Allocation

Direct Recurring Investment

- Exchanges
  - Organizational Exchanges
  - Depot Exchanges
- Organizational Issues

Indirect Operating and Support

- Training
- Publications
- Engineering and Technical Services
- Ammunition Handling

VAMOSC-Ships Cost Categories
(Ref. 21)

Table 3.2 (continued)

3.1.1.3 Input Information

The following input information is required by NAVSEA Code 017's Unit Price Analysis (UPA) computer cost model for the estimation of Navy ship acquisition costs. The inputs listed in Table 3.3 below are considered to be representative of the minimum amount of design definition necessary to describe the ship. The parameters below are grouped into the common cost driver classifications outlined in Table 1.5.

TECHNOLOGY

Ship type (e.g., destroyer, SWATH, etc.)
Hull & Superstructure material
Propulsion plant type
Electrical plant type

SHIP DESIGN

Hull structure weight (SWBS group 100)
Propulsion plant weight (SWBS group 200)
Electric plant weight (SWBS group 300)
Command & Surveillance systems weight (SWBS group 400)
Auxiliary systems weight (SWBS group 500)
Outfit & Furnishing weight (SWBS group 600)
Armament weight (SWBS group 700)
Design & Builders margin

PAYLOAD DESIGN

Cost of payload GFE
(includes armament and weapons portion of com. & surv.)

NAVSEA Code 017 Ship Acquisition Cost Parameters

Table 3.3

MANUFACTURING

Learning rate (labor & material)
Labor rate
(manufacturing & engineering)

PROGRAMMATIC

Cost of Money fraction
Profit fraction
Overhead fraction

ECONOMICS

Base year $
Base year for BLS data
BLS material indices

NAVSEA Code 017 Ship Acquisition Cost Parameters

Table 3.3 (continued)

Output from the NAVSEA model gives cost information for lead and follow ships. The following additional information in Table 3.4 is used to escalate/discount the costs throughout the construction period to a common year dollar value.

<u>Inputted Costs</u>

Lead ship end cost
Follow ship end costs

<u>PROGRAMMATIC</u>

Contract award date
Start of Construction
Manpower profile (length of construction)
Time between ships
Number of ships required

<u>ECONOMICS</u>

Base year $
Inflation rates

NAVSEA Code 017 Fleet Escalation/Discounted Cost Parameters

Table 3.4

3.1.1.4 Output Information

The NAVSEA new ship costing estimating program gives a cost breakdown of lead and follow ship material, labor, overhead and total acquisition (i.e., end) costs. There are two classes of cost information: one is a one digit SWBS group summary, and the next is the so-called P-8 estimating format. Table 3.5 indicates the SWBS group summary information available.

Cost Category	Cost Variable (Eqn #) Lead Ship	Follow Ship
<u>Construction</u>		
Material Cost		
SWBS Group 100-700	MC_i (3.2)	same(*)
800-900	MC_i (3.3)	same
D&B Margin	$MC_{D\&B}$ (3.4)	same
Labor Manhours		
SWBS Group 100-700	MH_i (3.1)	same
800-900	MH_i (3.3)	same
D&B Margin	$MH_{D\&B}$ (3.4)	same

(*) must include effects of learning, if applicable

NAVSEA Code 017 SWBS Output Summary

Table 3.5

Cost Category	Cost Variable (Eqn #)	
	Lead Ship	Follow Ship
Labor Costs		
SWBS Group 100-900	LC_i (3.5)	same
Overhead		
SWBS Group 100-900	OV_i (3.6)	same
Material + Labor + Overhead		
SWBS Group 100-900	C_i (3.7)	same
Total Construction	C_{CC} (3.8)	same
Cost of Money	COM (3.9)	same
Profit	C_{profit} (3.10)	same
Construction Price	P_{BC} (3.11)	same

NAVSEA Code 017 SWBS Output Summary

Table 3.5 (continued)

Cost Category	Cost Variable (Eqn #)	
	Lead Ship	Follow Ship
Add-on		
Construction Plans	C_{CP} (3.12)	NA (**)
Change orders	C_{cord} (3.13)	C_{cord} (3.14)
GFM	C_{GFM}	same
Other support	C_{other} (3.15)	same
Spares	C_{spares}	NA
Program Manager reserve	C_{PM} (3.16)	same
Test & Instrumentation	$C_{T\&I}$	NA
Escalation	C_{esc}	same
End Costed (sailaway)	P_{total} (3.17)	same (3.18)

(**) Not Applicable

NAVSEA Code 017 SWBS Output Summary

Table 3.5 (continued)

For budget purposes, acquisition costs are documented using the so-called P-8 format. The P-8 format gives an acquisition cost breakdown using the and cost categories outlined in Fig. 3.2. A partial listing of the categories used to output ship costs is given below.

MCC	Category
100	Plan costs
200	Basic construction costs
300	Change orders
400	Electronics (GFM)
500	H,M&E (GFM)
800	Other costs
900	Ordnance (GFM)
951	Program manager growth
953	Escalation

NAVSEA Code 017 P-8 Output Summary

Table 3.6

3.1.2 NCA

3.1.2.1 General

NCA (Naval Center for Cost Analysis) was established to guide, direct and strengthen cost analysis within the Department of the Navy and to ensure the preparation of credible estimates of resources required to develop, procure and operate military systems.

Ship cost estimates are the responsibility of the personnel in NCA-2. Their primary costing activity is to provide an independent cost analysis of each major ship acquisition program submitted to, or considered by the Secretary of the Navy or the CNO. In other words, NCA-2 develops an independent cost check of NAVSEA Code 017 estimates.

Due to the requirement for an independent cost check and limited personnel resources, NCA-2 contracted the naval architecture firm of Gibbs & Cox to develop a method for estimating the basic construction cost of near-term future frigates, destroyers and cruisers of the USN. Table 3.7 indicates the six ship classes used in the database. All the ships were built at Bath Iron Works (BIW).

To account for variations in design definition, two models were developed: a one-digit cost model that utilizes weight data available at the SWBS one-digit level and a two-digit cost model that uses SWBS three-digit level weight data. These two levels of detail allow costs to be estimated from technical information available at the NAVSEA planning phase up to the budget phase (i.e., including Class F and D estimates as shown in Fig. 3.1).

Gibbs & Cox states that the goal of the models is to provide feasibility level estimates for near-future (i.e., 1980's) vessels. The scope of the estimates is limited to shipyard costs only (material and direct labor portion of the basic construction cost) and does not include the cost of GFM for the command and surveillance and armament systems (i.e., SWBS groups 400 and 700, respectively). However, the shipyard's material and labor costs for GFM installation are included in the models.

Ship Class	DD 931	DDG 2	CG 16	CG 26	FFG 4	FFG 7
Number Built	14	23	9	9	6	8(*)
Year Comm.	55-59	60-64	62-64	64-67	66-67	77-80
BIW Delivery Date	11/55	8/60	7/62	11/64	4/67	11/77
Full Disp.(LT)	3960	4500	7800	7900	3426	3605
LP (ft)	407	420	510	524	414	408

* as of 1980

NCA Cost Model Ship Database
(Ref. 23)

Table 3.7

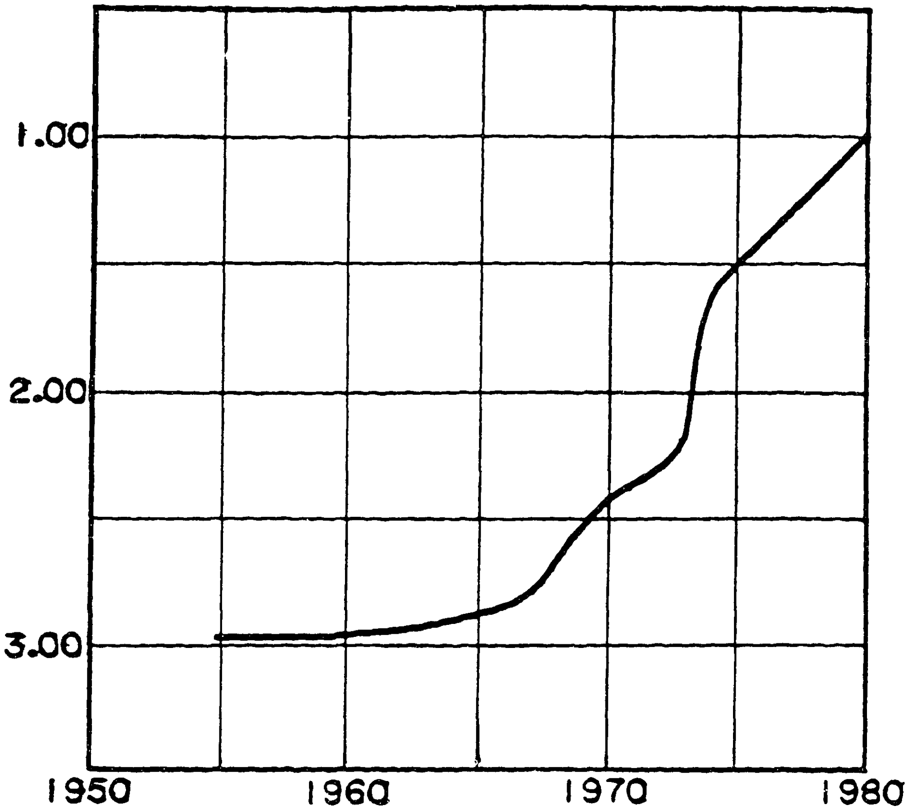
3.1.2.2 Cost Estimating Relationships

The cost estimating methodology outlined in this section is based upon the information available in Ref. 23. CERs were only developed for shipyard material costs and labor manhours. Additional costs, such as GFM, overhead, training, spares, and Navy program support are not included. However, these additional costs would be available to NCA through the same channels as for NAVSEA, and so NCA would be equally able to estimate each of the end cost categories shown in Fig. 3.2.

Various weight groupings (e.g., SWBS groups) were identified by Gibbs & Cox as the primary cost drivers for the development of the cost estimating relationships. Other significant cost drivers include shaft horsepower (SHP), installed generating capacity in kilowatts (KW), type of propulsion plant, and cubic number (CN). These variables are related to material costs and labor manhours for each cost group through simple cost algorithms.

These algorithms were developed using a linear least squares regression technique. The linear fit was used because of the small number of sample points and the uncertainty of future technological direction.

The costs of all the relevant groups are added to provide the basic shipyard costs associated with a lead ship. Material costs and labor manhours are presented in three formats: (1) tabular lists of costs and labor manhours at the time of the ship's delivery; (2) graphs of material costs (adjusted for inflation) and labor manhours (adjusted for BIW shipyard productivity) plotted against a relevant parameter, and; (3) mathematical equations calculated from the graphs in (2).



FFG-7 __________ 1.32
FFG-4 __________ 2.75
CG-26 __________ 2.90
CG-16 __________ 2.92
DDG-2 __________ 2.95
DD931 __________ 2.97

Shipbuilding Inflation Factors for 1980
(Ref. 23)

Figure 3.3

BIW return cost data and material costs, MC ($), were adjusted for inflation from the delivery date (see Table 3.7) to a 1980 standard using the following relation:

$$MC_{1980} = MC_{Delivery\ Date}\ Inflation\ Factor \qquad (3.19)$$

where the Inflation Factor, shown in Fig. 3.3, was based upon the steel vessel index from the Statistical Quarterly (e.g., see Ref. 24).

BIW total labor manhours were adjusted to 1980 standards by use of the productivity curve shown in Fig. 3.4 and the following simple expression:

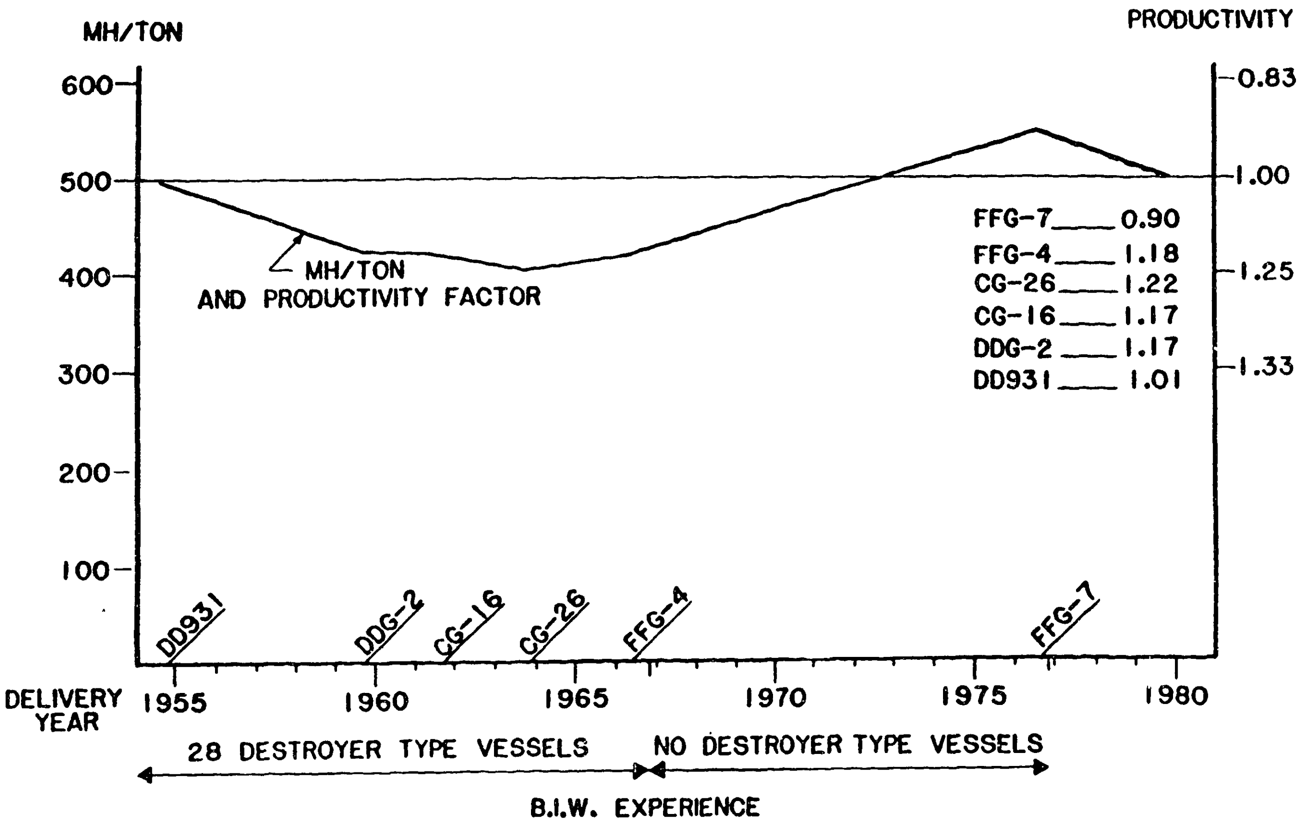
$$MH_{1980} = MH_{Delivery\ Date}\ Productivity\ Factor \qquad (3.20)$$

Variations in the Productivity Factor were due to the effects of workload and management practises over the building period of interest.

3.1.2.2.1 One-Digit Model

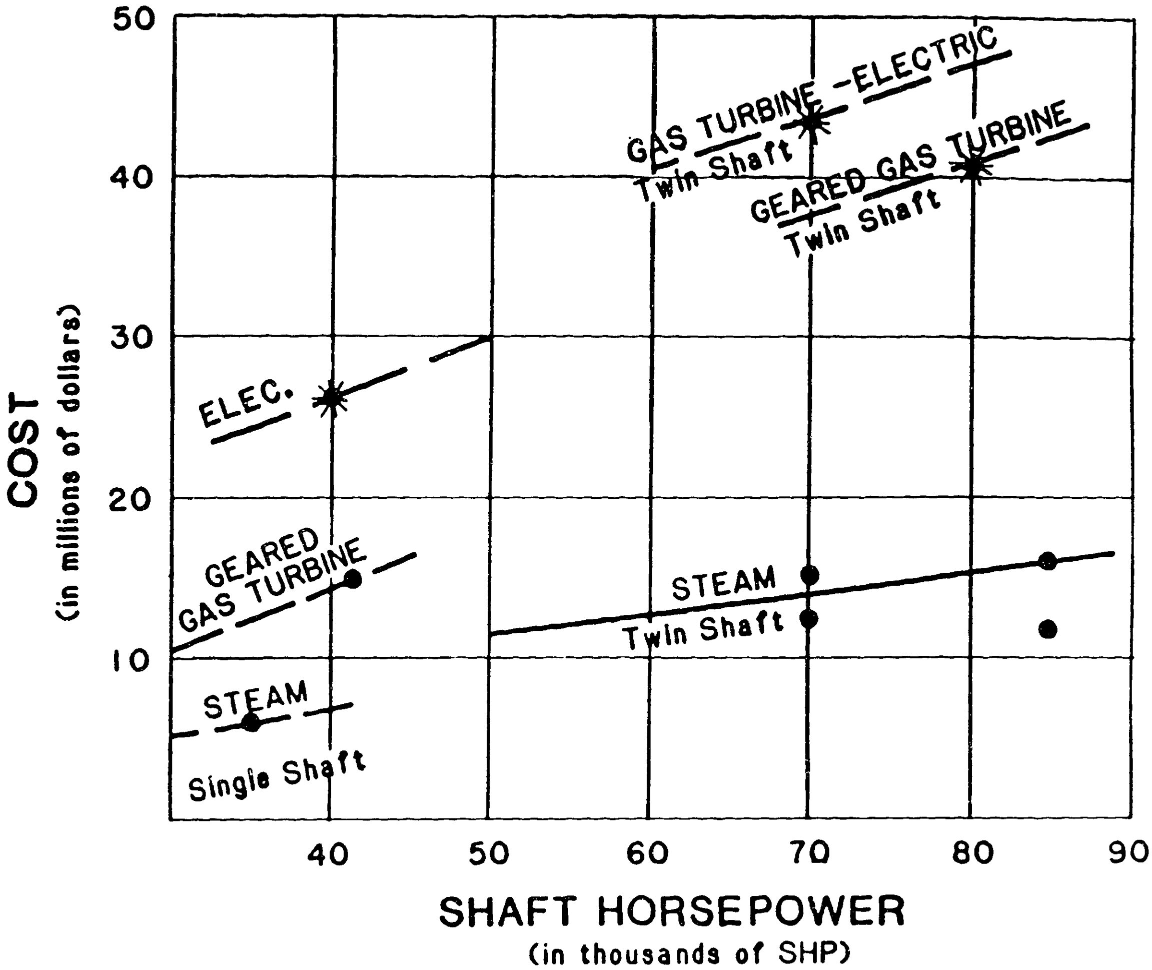
The one-digit level cost model relates one-digit SWBS weight group estimates, cubic number, KW, and SHP of a ship to material cost and labor manhours graphically or through simple linear equations.

Fig. 3.5 shows a representative plot of material cost versus SHP (shaft horsepower) for SWBS 200 - Propulsion. Actual data points were obtained from the ships in Table 3.7 and are indicated as filled-in circles. Starred (*) points were derived by BIW estimators based on return costs of similar systems. The solid line in Fig. 3.5 indicates the calculated algorithm for the actual data points. The dashed lines are projected algorithms for



BIW Total Ship Labor Factors for 1980
(Ref. 23)

Figure 3.4



One-Digit Propulsion Systems Material Cost
(Ref. 23)

Figure 3.5

actual or derived data points.

Cost algorithms were developed from the plots for material cost, MC ($), and labor manhours, MH, for each of the nine SWBS groups (e.g., see Fig. *.*) according to the following equation:

$$MH_i \text{ or } MC_i = Slope_i \; CD_i + Intercept_i \qquad (3.21)$$

where CD_i = particular SWBS group cost driver

Eqn. 3.21 shows the functional form of the estimating relationships and is not meant to imply identical slopes and intercepts for material cost and labor manhours. Table 3.8 indicates the cost drivers for material and labor for each of the SWBS groups. There are several SWBS groups where more than one independent variable is satisfactory for the generation of the cost algorithms.

The cost and labor figures used in the model for design and engineering services (SWBS group 800) are applicable to USN ships built after 1970. They include costs from the following areas:

Program Manager's Office
Integrated Logistics Support
Reliability, Maintainability, and Availability
Data Management
Producibility Management
Test and Evaluation
Integration Engineering
Configuration Management

The figures used for the lead ship should be reduced to 50% for the first follow ship and to 20-25% for succeeding ships of the same class.

Construction services were found to be proportional to the length of time the vessel is in the shipyard (from keel laying to delivery). If the building time is unknown, 30 months can be

SWBS Group	Cost Driver Material	Labor	Application
100	cubic number		- aluminum superstructure, all hull steels
	100 wt.		- aluminum superstructure, all hull steels
200	SHP		- steam, geared GT, electric GT - single & twin shaft
300	KW	300 wt.	- steam & diesel generators
400	400 wt.		- early & current technology
500	500 wt.		- steam & electric heat
600	length x beam		- pre & post 1965 habitability
	600 wt.	----	- pre & post 1965 habitability
700	700 wt.		- early & current technology
800	constant values		
900	months construction		

One-Digit SWBS Group Cost Drivers
(Ref. 23)

Table 3.8

assumed for an FFG-7 type vessel.

In order to estimate the total material and labor for the lead ship, the individual SWBS group costs and labor manhours are summed. Labor costs are calculated using the appropriate labor rate. The total direct labor plus material cost estimated using this method does not include any design & builders margin. Adjustments for inflation and productivity are based on the curves shown in Figs. 3.3 and 3.4.

The one-digit estimate presumes a given combination of subsystems within each SWBS group. The disadvantage of this type of estimate is its inability to differentiate between particular design features of a new ship and those of the baseline ship from which the algorithms were derived. The two-digit cost model attempts to overcome this limitation.

3.1.2.2.2 Two-Digit Model

The two-digit level model consists of 22 cost groups, each of which is represented by at least one material cost CER and a labor manhour CER. Table 3.9 indicates the cost group structure for the two-digit model. This structure was developed after it was recognized that the BIW shipyard data was not accumulated in the identical manner that the USN used.

The definition of each cost group in Table 3.9 is determined by its equipment content, as defined by the SWBS three-digit breakdown. Appendix D shows the SWBS weight groups that contribute to each of the 22 cost groups. The main advantage of the two-digit level model is that the increased number of cost groups are more specifically related to weight, volume, or power

Cost Group	Group Title	Cost Group	Group Title
1A	Structural Envelope/ Subdivisions	5A	Environment System
1B	Superstructure	5B	Fluid System
1C	Foundations	5C	Maneuvering System
1D	Structural Attachments	5D	Equipment Handling System
2A	Propulsion Energy System	6A	Hull Fittings
2B	Propulsion Train System	6B	Non-Structural Subdivisions
2C	Propulsion Gases System	6C	Preservation
2D	Propulsion Service System	6D	Facilities
3A	Electrical Power Generation	6E	Habitability
3B	Electrical Power Distribution	7	Ordnance
		8	Design & Engineering Services
4A	Vehicle Command		
4B	Weapon Command	9	Construction Services

Two-Digit Cost Model Structure
(Ref. 23)

Table 3.9

Cost Group	Cost Driver Material	Labor	Application
1A	cubic number		- all hull steels
	1A wt.		- all hull steels
1B	1B wt.		- aluminum, steel superstructure
1C	1C wt.		- steam, gas turbine
1D	1D wt.		
2A	SHP		- steam, geared GT, electric GT - single & twin shaft
2B	SHP		- fixed, controllable pitch
2C	SHP		- steam, gas turbine
2D	SHP	2D wt.	- steam, gas turbine
3A	KW	3A wt.	- steam & diesel generators
3B	3B wt.		
4A	4A wt.		- early & current technology
4B	4B wt.		- early & current technology

Two-Digit Cost Model Cost Drivers
(Ref. 23)

Table 3.10

Cost Group	Cost Driver Material	Cost Driver Labor	Application
5A	5A wt.		- steam & electric heat
5B	5B wt.		- steam & gas turbine
5C	length x draft		
5D	5D wt.		
6A	length x beam	6A wt.	- early & current technology
6B	length x depth	----	- pre & post 1965 habitability
	6B wt.		- pre & post 1965 habitability
6C	length x beam		- early & current technology
6D	complement	6D wt.	- pre & post 1965 habitability
6E	6E wt.		- pre & post 1965 habitability
700	700 wt.		- early & current technology
800	constant values		
900	months construction		

Two-Digit Cost Model Cost Drivers
(Ref. 23)

Table 3.10 (continued)

than are the more general seven cost groups of the one-digit model.

Material and labor estimates are linearly related to various cost drivers in a manner identical to that described for the one-digit model (i.e., according to Eqn. 3.21). The cost drivers for the 22 cost groups are listed in Table 3.10. A comparison of Tables 3.8 and 3.10 shows that the cost drivers for the one- and two-digit models are similar. This is not surprising since the two models are closely related through the SWBS groupings.

As noted previously, the model does not include the cost of GFM, but does account for the costs associated with shipyard installation. Installation includes material and labor for foundations, mounts, magazines and hoists, supporting hydraulics, cables, and electrical systems and their testing. Cost groups 4B and 7 are most affected by GFM considerations.

The more detailed two-digit cost breakdown is warranted wherever there is sufficient technical data to distinguish the separate groups listed in Table 3.9. When there is a lack of weight data for a particular cost group, the weight amount can be estimated by use of a weight algorithm (see Ref. 23, Appendix B), or by comparing the known new ship weight percentage distribution with a baseline ship. Table 3.11 lists the percentage distributions of lightship weight for the six ships included in the Gibbs & Cox study (see Table 3.7) plus the average SWBS group weight distribution for 12 Navy combatant ships.

Cost Group	DD 931	DDG 2	CG 16	CG 26	FFG 4	FFG 7	Avg
1A	28	28	37	38	37	35	
B	3	3	3	3	3	4	
C	4	4	3	3	4	5	
D	2	2	2	3	3	2	
	36	37	46	47	46	46	45.9
2A	21	18	12	11	9	5	
B	4	4	3	3	3	3	
C	1	1	1	1	1	1	
D	4	3	2	2	2	1	
	30	26	18	17	15	10	16.9
3A	2	2	2	2	2	4	
B	2	2	2	2	2	4	
	4	4	4	4	4	7	4.8
4A	1	1	1	1	1	1	
B	2	4	6	6	5	3	
	3	5	7	7	6	4	5.7

Percentage Distribution of Lightship Weight
for Two-Digit Model Groups
(Ref. 23)

Table 3.11

Cost Group	DD 931	DDG 2	CG 16	CG 26	FFG 4	FFG 7	Avg
5A	3	3	3	3	3	4	
B	6	7	6	6	6	9	
C	1	1	1	1	2	2	
D	1	1	1	1	3	2	
	11	12	11	11	14	17	13.0
6A	1	1	1	1	1	1	
B	1	1	1	1	1	3	
C	2	3	2	3	4	4	
D	1	1	1	1	2	3	
E	1	1	1	1	2	2	
	7	8	7	8	10	12	8.3
7							
	9	8	7	6	5	4	5.5
Total	100	100	100	100	100	100	100.0

Percentage Distribution of Lightship Weight
for Two-Digit Model Groups
(Ref. 23)

Table 3.11 (continued)

3.1.2.3 Input Information

The following input information is required by the NCA - Gibbs & Cox ship cost models in order to estimate the shipyard material and direct labor costs (excluding margins) of the lead ship. The inputs indicated in Table 3.12 do not differentiate between the more detailed weight inputs required for the two-digit model and the SWBS weight group data for the one-digit

---

TECHNOLOGY

Ship type (frigate, destroyer, or cruiser)
Hull & Superstructure material
Propulsion plant type
Electrical plant type
Early or Current level of technology

SHIP DESIGN

Hull structure weight (SWBS group 100)
Propulsion plant weight (SWBS group 200)
Electric plant weight (SWBS group 300)
Command & Surveillance systems weight (SWBS group 400)
Auxiliary systems weight (SWBS group 500)
Outfit & Furnishing weight (SWBS group 600)
Armament weight (SWBS group 700)
Number of Propeller Shafts
Length, Beam, Draft
Steam or Electric Heating System
Missile magazine flooding requirement
Habitability Standards
Cubic Number
SHP
Generator rating (KW)

NCA Lead Ship Shipyard Cost Parameters

Table 3.12

PAYLOAD DESIGN

Cost of payload GFE
(includes armament and weapons portion of com. & surv.)

MANUFACTURING

Labor rate
(manufacturing & engineering)

PROGRAMMATIC

Length of Construction

ECONOMICS

Base year $
Base year for BLS data
BLS material indices

NCA Lead Ship Shipyard Cost Parameters

Table 3.12 (continued)

model. The parameters listed under the economic category are required for base year calculations outside of the range indicated in Figs. 3.3 & 3.4.

Calculation of the remaining end cost categories shown in Fig. 3.2 for the lead and follow ships are carried out in a manner similar to that outlined for the NAVSEA Code 017 UPA cost model.

3.1.2.4 Output Information

Output from the NCA - Gibbs & Cox cost model is limited to shipyard material costs, MC ($), and direct labor manhours, MH, for the major SWBS groups (or a specified two-digit subset). These values are shown below in Table 3.13. Material and direct labor costs estimated using this methodology can be considered accurate to within 20% of actual costs (Ref. 23).

Cost Category	Cost Variable (Eqn #) Lead Ship
Construction	
Material Cost	
SWBS Group 100-900	MC_i (3.21)
Labor Manhours	
SWBS Group 100-900	MH_i (3.21)

NCA Lead Ship Output Summary

Table 3.13

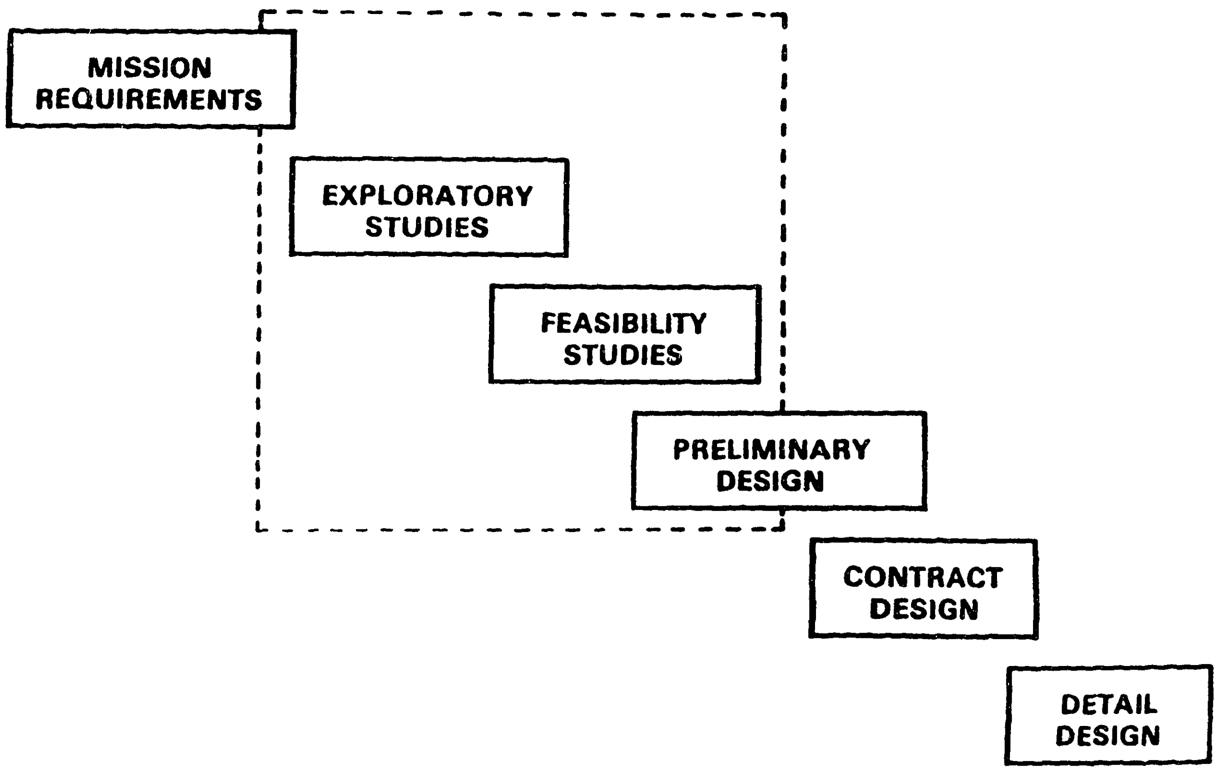
3.1.3 ASSET

3.1.3.1 General

ASSET, which is an acronym for Advanced Surface Ship Evaluation Tool, addresses most of the major technological domains of naval architecture that are relevant to the design of Navy warships (e.g., see Ref. 15). ASSET was developed by Boeing Computer Services Company for the David Taylor Naval Ship Research and Development Center (DTNSRDC). As indicated in Fig. 3.6, ASSET is intended to be used primarily in the exploratory and feasibility phases of the ship design process. The program has proven useful in assessing a variety of whole ship technology impacts in a consistent manner. Because it is essentially a synthesis model, ASSET also serves as a repository of current USN design practises.

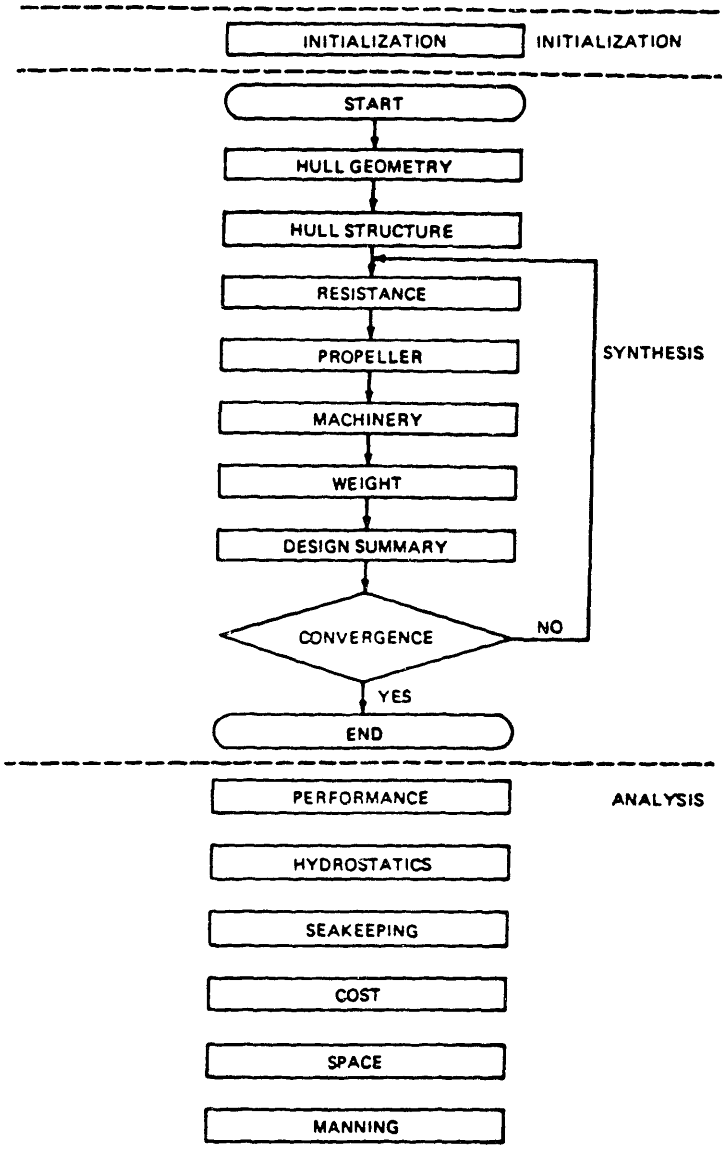
Technical information, ship data, algorithms and empirical formulae were principally supplied by the US Navy. Updated versions of ASSET are available for a variety of ship types. At the present time, ASSET can handle hydrofoils, monohull surface combatants and SWATH (Small Waterplane Area Twin Hull) ships.

The ASSET program has been divided into three sections: initialization, synthesis and analysis. During initialization, the data entered to define the current ship is checked for completeness and fatal errors. Next, the data is synthesized until an integrated ship design is acheived, in that each element of data that defines the ship is consistent with every other element of ship data. Once the design has converged, various analyses, such as cost, are carried out. The different



ASSET Applicability Within the Ship Design Process
(Ref. 60)

Figure 3.6



ASSET Computational Modules
(Ref. 1)

Figure 3.7

computational modules within each section are indicated in Fig. 3.7.

The intent of the costing module in ASSET is to provide data which can be used to evaluate the relative life cycle costs of competing ship systems. Life cycle costs are considered in three major categories: research and development (R&D), investment and operations and support (O&S).

The theoretical basis of the ASSET cost analysis module is the cost evaluation program developed for the Advanced Naval Vehicle Concept Evaluation (ANVCE) study. This study, done in the early to mid 1970s, used the latest available lead shipbuilding cost data on a variety of surface, air and special purpose naval vehicles to develop CERs of future vessel types. The ship sample used for the ANVCE study and the resulting SWBS group CERs have been placed in Appendix E.

The ship sample database used in the development of the ASSET cost module is shown in Table 3.14. The list of vessels indicates the wide range of vessel types (i.e., hydrofoil, ACV, SWATH, monohull, etc.) and displacements that can be accommodated.

Base Year	Contractor	Ship Class	Cost Basis	Total Maximum Continuous shp	FLD (LT)
1960	Bath Iron Works	DE 1037	BID	20,000	2,654
1961	" " "	DE 1040	"	35,000	3,331
1964	" " "	DE 1053	"	35,000	4,066
1973	" " "	FF 109	PROPOSAL	40,000	3,561
1957	" " "	DDG 2	BID	70,000	4,562
1956	" " "	DLG 12	"	85,000	5,786
1958	" " "	DLG 16	"	85,000	7,645
1961	" " "	DLG 26	"	85,000	7,839
1973	" " "	SWATH DE	STUDY	60,000	3,710
1976	" " "	SWATH MCM	"	40,000	3,441
1959	Bethlehem Steel	DLGN 25	PROPOSAL	60,000	8,514
1962	" "	DLGN 35	BID	70,000	8,947
1968	Newport News	DLGN 36	"	70,000	10,056
1970	" "	DLGN 38	PROPOSAL	70,000	10,497
1973	Tacoma	CPIC	BID	6,140	76
1967	Peterson/Tac.	PG 92	"	15,600	254
1976	" "	PGG 1	"	25,850	390
1967	Grumann	PGH 1	PROPOSAL	3,470	66
1967	Boeing	PGH 2	ACTUAL	3,260	58
1961	"	PCH 1	"	6,800	111
1974	"	PHM 1	"	17,300	232
1964	"	AGEH 1	BID	29,800	295
1975	"	DBH	STUDY	54,020	1,042
1974	"	ARTIC SEV	"	48,000	540
1974	Aerojet	JEFF A	49% ACTUAL	11,200	152
1974	Bell	JEFF B	75% ACTUAL	16,800	152
1975	"	2KSES (B)	PROPOSAL	96,000	1,950
1974	Rohr	2KSES (R)	"	96,000	1,800

ASSET Cost Module Ship Database
(Ref. 1)

Table 3.14

3.1.3.2 Cost Estimating Relationships

The calculative sequence employed by the ASSET cost module is a seven step process, as illustrated in Figure 3.8. The first step involves a complete review of all data input to the module via the current model. The input data are scanned for missing or invalid entries. Where appropriate, missing data are replaced with default values.

The next step involves the calculation of miscellaneous ship data that are required as input to various CERs. These data include the following:

N_{Ci} = the i^{th} element of the number of crew aboard ship (1=officers, 2=petty officers, 3=enlisted men),

P_{SUM} = the total power available from all of the ship's propulsion engines,

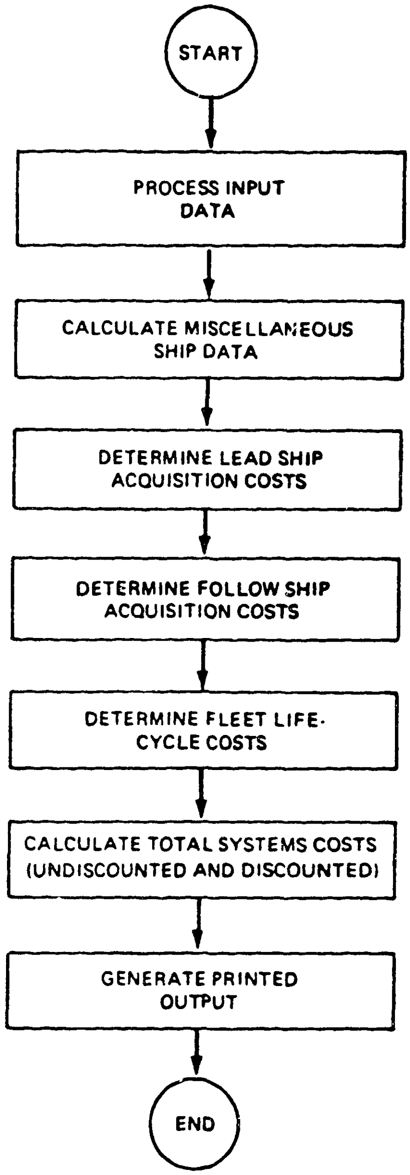
N_H = the number of helicopters aboard ship,

W_{LS} = the lightship weight, equal to the sum of the SWBS weight groups plus margins, and

W_{MP} = the weight of the ship's costed military payload, listed in Appendix A.

Following the calculation of the miscellaneous ship data, lead and follow ship acquisition costs are determined. Construction costs are the first costs estimated for the total acquisition cost.

For the lead ship, the cost of the ship elements or services within each of nine major SWBS groups, plus the margin cost, is



ASSET Cost Module Calculative Sequence
(Ref. 1)

Figure 3.8

computed according to the following equations;

$$
\begin{aligned}
C_1 &= (33.95\ K_{N1})(W_{100})^{0.772} \\
C_2 &= (1.86\ K_{N2})(P_{SUM})^{0.808} \\
C_3 &= (75.05\ K_{N3})(W_{300})^{0.910} \\
C_4 &= (108.57\ K_{N4})(W_{400})^{0.617} \\
C_5 &= (94.87\ K_{N5})(W_{500})^{0.782} \\
C_6 &= (98.59\ K_{N6})(W_{600})^{0.784} \\
C_7 &= (8.38\ K_{N7})(W_{700})^{0.987} \\
C_M &= (W_M/(W_{LS} - W_M))(C_{L1} + \ldots + C_{L7}) \\
C_8 &= (0.019\ K_{N8})(C_{L1} + \ldots + C_{L7} + C_{LM})^{1.099} \\
C_9 &= (0.385\ K_{N9})(C_{L1} + \ldots + C_{L7} + C_{LM})^{0.839}
\end{aligned}
\tag{3.22}
$$

where C_i = the appropriate lead ship SWBS group cost, \$K

K_{Ni} = the technology factor for the i^{th} SWBS group

W_i = the appropriate SWBS group weight, LTON

and subscript M refers to the D&B and growth weight margins.

The K_N technology factors used for Eqn. (3.22) are selected based upon the characteristics of the ship to be costed. Tables of K_N values for various ship configurations are included in Appendix B. These tables were originally derived from the cost evaluation program of the ANVCE study.

Follow ship construction costs are principally a function of lead ship costs and a factor that accounts for production learning. For the first follow ship, this factor, F, is defined by the following equation;

$$F = 2.0\ R_L - 1.0 \tag{3.23}$$

where R_L = learning rate

The ASSET model uses a cumulative learning rate (default value equal to 0.97) to account for the decrease of the average cost per ship resulting from increased production.

Follow ship construction costs, C_i (\$K), are given by the following expressions;

$$C_{1,2,\ ..\ 7,9,M} = F\ C_{L1,L2,\ ..\ L7,L9,LM}$$

(3.24)

$$C_8 = (0.019\ K_{N8})(C_{L1} + \ldots + C_{L7} + C_{LM})^{1.099}$$

where C_{Li} = appropriate lead ship SWBS group and margin costs from Eqn. (3.22).

The ship construction cost, C_{CC} ($K), is the sum of weight group costs, such that;

$$C_{CC} = C_1 + C_2 + \ldots + C_9 + C_M \tag{3.25}$$

Profit, C_{profit} ($K), is assumed to equal a fraction of the construction cost and the price, P_{BC} ($K), equals construction cost plus profit. As a result;

$$C_{profit} = F_P \, C_{CC} \tag{3.26}$$

and

$$P_{BC} = C_{CC} + C_{profit} \tag{3.27}$$

where F_P = profit fraction (ASSET default value of 0.15)

A series of miscellaneous program (G&A) costs must be computed and added to the price to determine the acquisition cost of the ship. These costs are described below:

C_{cord} = cost of change orders, $K

C_{nsea} = NAVSEA support costs, $K

C_{pdel} = post delivery charges, $K

C_{outf} = outfitting costs, $K

C_{hmeg} = hull/mechanical/electric plus growth, $K

They are estimated as a percentage of the acquisition price, P_{BC}, according to the values listed in Table 3.15 for lead and follow ship applications.

Cost Element	Lead Ship Percentage	Follow Ship Percentage
C_{cord}	12	8
C_{nsea}	2.5	2.5
C_{pdel}	5	5
C_{outf}	4	4
C_{hmeg}	10	10

NAVSEA Program Cost Percentages

Table 3.15

The total ship acquisition cost, C_{acq} (\$K), is given as;

$$C_{acq} = P_{BC} + C_{cord} + C_{nsea} + C_{pdel} + C_{outf} + C_{hmeg} \tag{3.28}$$

The "sailaway" cost of the ship, C_s (\$K), is given by;

$$C_s = C_{acq} + C_p \tag{3.29}$$

where C_p = ship payload cost, \$K

The value of C_p may be input or estimated by the following equation;

$$C_p = ((V_{payload} W_{MP}) + (18.71 N_H)) 1000. \qquad (3.30)$$

where $V_{payload}$ = 0.373 for the lead ship

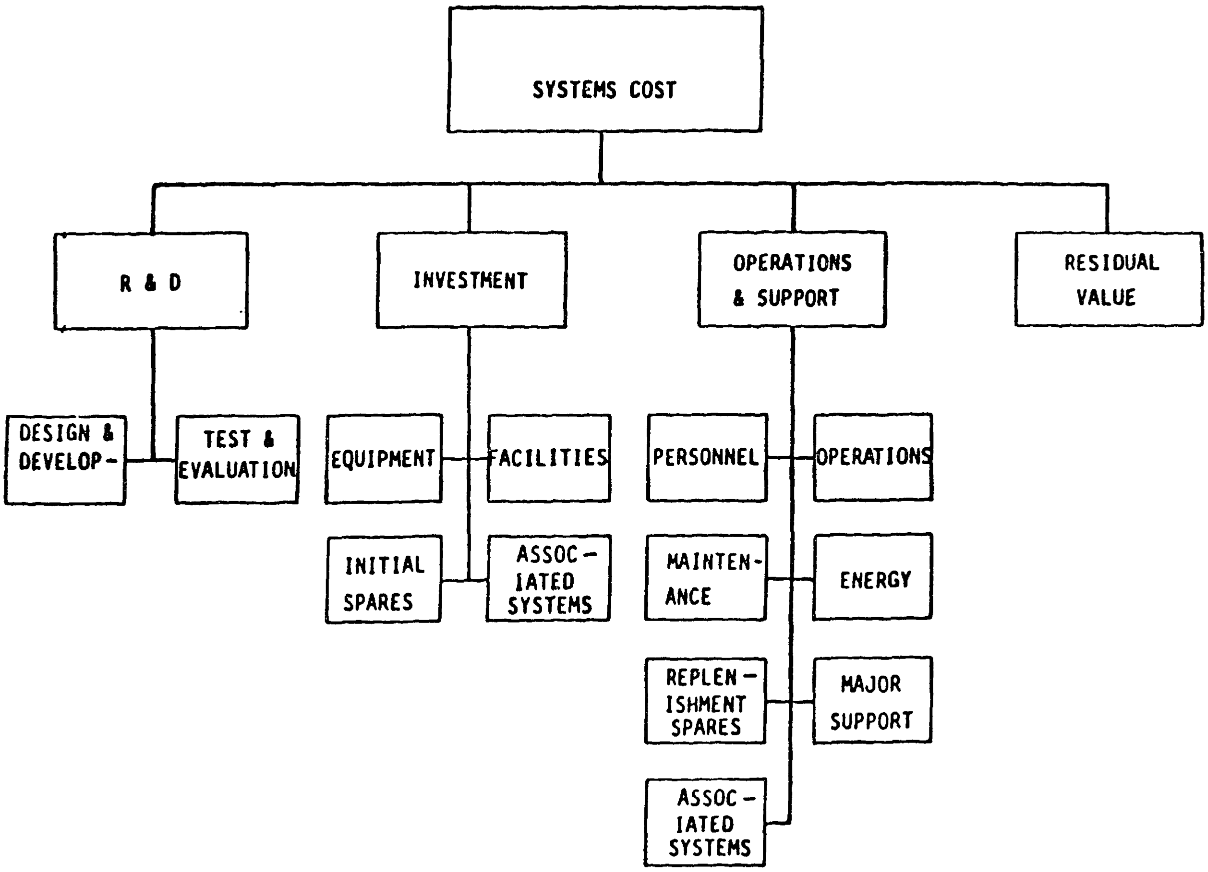
= 0.326 for the follow ship

The factor 18.7 approximates the cost (in millions) in FY (fiscal year) 81 dollars of acquiring a helicopter. Payload costs are defined as the sum of ordnance and electronics costs.

The next sequence in the ASSET cost module (see Fig. 3.8) is the estimation of fleet life-cycle costs, consisting of research and development, investment, and operations and support categories. The major life cycle cost elements addressed under these categories can be seen in Fig. 3.9.

R&D costs are calculated as the sum of two components: the cost of design and development, and the cost of test and evaluation.

Design and development costs are computed as the sum of ship



ASSET Life Cycle Cost Elements
(Ref. 1)

Figure 3.9

design and development cost, C_{SDD} (\$M), and other design and development cost, C_{ODD} (\$M);

$$C_{SDD} = 0.0011\ (0.571\ C_{Facq}/F + 0.072\ C_{Lp}) + C_{TECH}$$

$$C_{ODD} = 1.1\ (0.06\ C_{FI}) \qquad (3.31)$$

where C_{Facq} = acquisition cost of the first follow ship, \$K

C_{Lp} = lead ship payload cost, \$K (see Eqn. 3.30)

C_{TECH} = technical advancement cost, \$M (user supplied input)

C_{FI} = additional facilities cost, \$M (user supplied input)

The value of C_{Facq}/F represents an adjusted lead or first ship cost, and is probably the most important input to the ASSET life-cycle cost model (Ref. 1). This cost is intended to capture the recurring production cost of the lead ship.

The technical advancement cost is the cost of developing any technological advances that will be necessary before the ship can be built.

The cost of additional facilities refers to the construction of facilities such as shipyards and piers that will be necessary for the support of the ship.

Test and evaluation costs are computed as the sum of the ship test and evaluation cost, C_{STE} (\$M), the payload test and evaluation cost, C_{PTTE} ($M), and other test and evaluation costs, C_{OTE} ($M);

$$C_{STE} = 0.0012\ (\ 0.499\ C_{Facq} / F + 0.647\ C_{Lp} + C_{OAS}\ )$$

$$C_{PTTE} = 1.2\ C_{PHTE} \qquad (3.32)$$

$$C_{OTE} = 1.2\ (0.02\ C_{FI})$$

where C_{PHTE} = payload hardware test and evaluation cost, $M (see Eqn 3.33)

C_{OAS} = total operations and support cost, $M (see Eqn. 3.49)

The payload hardware test and evaluation cost may be input by the users or estimated by the following equation;

$$C_{PHTE} = 0.0646\ W_{MP} \qquad (3.33)$$

The total research and development phase cost, C_{RD} ($M), is given by the following equation;

$$C_{RD} = C_{SDD} + C_{ODD} + C_{STE} + C_{PTTE} + C_{OTE} \qquad (3.34)$$

Investment costs are made up of prime equipment cost, support equipment cost, cost of facilities, cost of initial spares and repair parts, and the cost of associated system (e.g. underway replenishment). Investment costs are primarily the acquisition costs of these equipments. The prime equipment cost has two distinct components, the ship prime equipment cost, C_{SPE}

($M), and the payload prime equipment cost, C_{PPE} ($M), given by the following expression;

$$C_{SPE} = ((C_{Facq}/F)/1000))\ N_S^{(\ln(2R_L)/\ln(2))}$$

$$C_{PPE} = (\ C_{Lp} + (N_S - 1)\ C_{Fp}\ )\ /\ 1000 \qquad (3.35)$$

where R_L = average learning rate

N_S = total number of ships to be acquired

C_{Lp} = lead ship payload cost, $K

C_{Fp} = follow ship payload cost, $K

ln = natural logarithm

An average ship cost, C_{avg} ($K), is computed as a function of the ship prime equipment investment for use by other life-cycle cost algorithms;

$$C_{avg} = 1000\ (\ C_{SPE} + C_{PPE}\ )\ /\ N_S \qquad (3.36)$$

The cost of support equipment is divided into ship support equipment cost, C_{SSE} ($M), and payload support equipment cost, C_{PSE} ($M), such that;

$$C_{SSE} = 0.05\ C_{SPE}$$

$$C_{PSE} = 0.20\ C_{PPE} \qquad (3.37)$$

The costs of initial spares for the ship, C_{ISS} ($M), and for the payload, C_{ISP} ($M), are given by;

$$C_{ISS} = 0.03\ C_{SPE}$$

$$C_{ISP} = 0.13\ C_{PPE} \qquad (3.38)$$

The final investment cost to be estimated is the associated systems investment cost, C_{IASOC} ($M);

$$C_{IASOC} = .25\ N_S\ H\ (W_S + 0.1\ W_P)\ \times$$

$$(C_{URU}/U_{CAP})(L_S/30) \qquad (3.39)$$

where H = ship operating hour per year, HR/YR

W_S = ship fuel rate, LTON/YR

W_P = payload fuel rate, LTON/YR

C_{URU} = cost of underway replenishment unit, $M (user supplied input)

U_{CAP} = underway replenishment unit fuel capacity, LTON/YR

L_S = ship service life, YRS

The cost of underway replenishment is the acquisition cost of each underway replenishment ship. The underway replenishment unit fuel capacity is the weight of fuel that a typical underway replenishment ship can deliver per year to the ship fleet. The associated systems cost accounts for the cost of buying and operating UNREP ships over and above the support forces currently operated by the USN.

The total investment phase cost is given by the following sum:

$$C_{INV} = (C_{SPE} + C_{PPE}) + (C_{SSE} + C_{PSE}) + C_{FI} +$$

$$(C_{ISS} + C_{ISP}) + C_{IASOC} \qquad (3.40)$$

Operations and support (O&S) costs are computed as the sum of seven components: personnel costs, operations costs, maintenance costs, energy (fuel) costs, cost of replenishment spares, major support costs, and associated systems costs. The data base used to estimate the operations, maintenance and major support cost CERs can be seen in Table 3.16.

Personnel costs are divided into pay and allowances costs, C_{PAY} ($M), and temporary additional duty pay costs, C_{TAD} ($M);

$$C_{PAY} = (\ (26{,}184\ N_{C1}) + (11{,}510(N_{C2} + N_{C3}))\ ) \times$$

$$(N_S\ L_S\ /\ 10^6) \qquad (3.41)$$

$$C_{TAD} = .65(40)\ (\ (N_{C1} + N_{C2} + N_{C3})(N_S\ L_S)\ )/10^6$$

Operations cost, C_{OPOS} ($M), is given by the following;

$$C_{OPS} = N_S\ L_S\ (188 + 0.0013\ C_{avg} +$$

$$2.232\ (N_{C1} + N_{C2} + N_{C3}) - \qquad (3.42)$$

$$(0.4459\ H/12) + (1000\ C_{ATC})\ )\ /1000$$

where C_{ATC} = annual cost of training ordnance, $M

Ship Class	Maintenance (000s) ($FY81)	Operations (000s) ($FY81)	Major Support (000s) ($FY81)	Ship Cost (000s) ($FY81)	Ship Personnel	Steaming Hours Per Month
CG26	4,689	1,212	3,184	266,104	434	296
CG16	4,770	1,212	3,089	271,302	407	373
DDG37	3,888	1,176	3,105	213,189	391	308
DDG31	5,661	1,014	2,819	120,646	251	291
DDG2	5,592	1,095	3,271	163,863	347	319
DD931	4,139	858	2,733	122,148	315	393
DD963	3,268	934	2,492	188,649	293	463
LST1179	2,926	715	1,707	66,023	221	198
LPD1	3,884	1,055	2,839	174,566	403	428
LSD28	5,389	857	2,743	99,466	333	293
LPD4	3,847	1,055	2,894	142,732	419	289
LKA113	2,264	989	1,703	89,968	209	287
LHA1	8,963	2,724	6,425	364,797	884	229
LSD36	4,214	1,055	2,547	92,898	338	398
LCC19	3,899	1,712	4,652	216,083	787	381
LPH2	5,047	1,779	4,192	205,666	641	362
AE26	3,705	701	2,460	115,437	345	360
AE21	3,811	745	2,295	74,632	321	330
AOE1	5,685	1,440	3,996	286,129	565	457
AFS1	4,670	998	3,058	97,896	427	356
AOR1	3,676	1,181	2,893	120,209	420	371
ASR21	3,141	448	1,489	173,863	181	188
ATS1	2,908	454	1,103	33,255	101	325
FFG7	3,999	796	1,422	124,155	201	404
FFG1	4,721	796	2,555	119,543	252	316
FF1052	3,646	729	2,377	80,840	270	316
FF1040	5,253	729	2,724	100,008	261	236
FF1037	3,896	729	2,138	68,977	204	364
CV59	22,331	7,659	19,546	1,071,799	2,781	425

Operations and Support Data for Selected USN Ships
(Ref. 1)

Table 3.16

The annual cost of training ordnance may be input by the user or estimated using the following expression:

$$C_{ATC} = 0.0051\ C_{Fp}\ /1000 \qquad (3.43)$$

The decrease in operations cost with ship operating hours, as shown in Eqn (3.42), reflects the increased operations cost associated with being in port.

Maintenance costs, C_{MTC} ($M), are estimated by the expression:

$$C_{MTC} = (N_S\ L_S)\ (2967 + 0.0064\ C_{avg} + 4.814\ (N_{C1} + N_{C2} + N_{C3}) - (3.939\ H/12) + (10\ H_{DEF}\ /168)\ )\ /1000 \qquad (3.44)$$

where H_{DEF} = deferred maintenance manhours, HRS

The deferred maintenance manhours is the average number of additional maintenance manhours per ship that will have to be supplied each week by a shore based facility to perform required preventative and corrective procedures. A value of zero indicates that ship's crew can perform these tasks between overhaul periods.

Eqn (3.44) indicates that maintenance costs decrease as ship operating hours increase, whereas maintenance costs would be expected to increase under such circumstances. This apparent anomaly reflects the fact that historically, ships requiring minimal maintenance and therefore minimal maintenance costs, were able to operate for longer periods at sea.

The cost of energy (fuel), C_{EGY} ($M), includes that used by the ship and helicopters, if any. The expression is:

$$C_{EGY} = (N_S\ L_S)\ (C_{FUEL}/10^6)\ (2240\ H/6.8)\ \times$$

$$(W_S + 0.1\ W_P) \qquad (3.45)$$

where C_{FUEL} = fuel cost per gallon, $/GAL

The cost of replenishment spares, C_{REP} ($M), is:

$$C_{REP} = (\ (L_S - 4)\ (C_{ISS} + C_{ISP})\ )/4.0 \qquad (3.46)$$

Values of C_{ISS} and C_{ISP} are calculated in Eqn. (3.38). This expression reflects the assumption that the initial spares cover the first four years of ships operations and that replenishment spares are required at four year intervals thereafter.

Major support costs, C_{MSP} ($M), are calculated as follows:

$$C_{MSP} = (N_S\ L_S)\ (698 + 0.0022\ C_{avg} +$$

$$5.988\ (N_{C1} + N_{C2} + N_{C3}) - \qquad (3.47)$$

$$(\ 1.158\ H/12)\ )/1000$$

The associated systems cost, C_{OASOC} ($M), is;

$$C_{OASOC} = 0.25\ N_S\ L_S\ H\ (W_S + 0.1\ W_P)(C_{UOAS}/U_{CAP}) \qquad (3.48)$$

where C_{UOAS} = annual cost of operations and support of each underway replenishment unit, $M (user supplied input)

The total operations and support cost, C_{OAS} (\$M), is given by the following expression:

$$C_{OAS} = C_{PAY} + C_{TAD} + C_{OPS} + C_{ATC} + C_{MTC}$$

$$C_{REP} + C_{MSP} + C_{OASOC} + C_{EGY} \qquad (3.49)$$

Total systems costs are computed in the next step. The total systems costs equals the research and development, investment, and operations and support costs minus the residual value of the platforms at the end of their useful life. The total systems costs are computed both in terms of constant year dollars (undiscounted) and discounted dollars.

The residual value of the platform, R (\$M), is estimated using the double declining balance method (e.g., see Ref. 1):

$$R = C_{SPE} \ (1 - 2/L_S)^{L_S} \qquad (3.50)$$

This depreciation method most closely approximates the decline in value of capital assets which are not worn out at the end of a nominal service life, but are capable of being restored, modernized and/or converted to other uses (Ref. 1).

The undiscounted life cycle total systems cost for the ships, C_{LIFE} (\$M), is given by the equation:

$$C_{LIFE} = C_{RD} + C_{INV} + C_{OAS} - R \qquad (3.51)$$

The discounted cost of a given phase is a function of the non-discounted cost and a discounted cost factor. The discounted cost factor is calculated as a function of a beginning year of the cost phase, B, and an ending year, E. The beginning and ending years are assumed to be integers and are normalized to the base year. The discounted cost factor, F_d, is given by the following equation:

$$F_d = (E - B + 1)^{(-1)} \left((1/1.1)^{B} + (1/1.1)^{B+1} + \ldots + (1/1.1)^{E-1} + (1/1.1)^{E} \right) \quad (3.52)$$

This expression assumes that the costs associated with each particular phase (i.e., R&D, investment, O&S) becomes due at the end of each year that the program runs and that each yearly payment is equal to the average cost/yr over the program length. In addition, Eqn (3.52) assumes a constant discount rate of 10% for all discounting calculations.

The ending and beginning years for the research and development phase, E_{RD} and B_{RD}, respectively, are calculated as follows:

$$E_{RD} = Y_{IOC} + 2 - Y_B$$
$$B_{RD} = E_{RD} - L_{RD} + 1 \quad (3.53)$$

where Y_B = the base year (ASSET default value of 1981)

L_{RD} = length of research and development phase, YRS

Y_{IOC} = year of initial operational capability

The end of the R&D program is assumed to occur two years after the IOC date.

The discounted cost of the research and development phase, C^*_{RD} ($M), is given as:

$$C^*_{RD} = F_{dRD}\, C_{RD} \tag{3.54}$$

where F_{dRD} = discounted cost factor for the research and development phase using the beginning and ending years calculated in Eqn. (3.53)

The beginning and ending years for the investment phase, B_{INV} and E_{INV}, respectively, are calculated below:

$$B_{INV} = E_{RD} + 1$$

$$E_{INV} = B_{INV} + (N_S/R_d) + 0.9999 - 1 \tag{3.55}$$

where R_d = ship production rate

If the value of E_{INV} is a non-integer, the value is truncated to the next lower integer. The length of the investment phase is the number of years required to construct all of the ships, including the lead ship, at the given production rate. Also, no overlap between the R&D and investment phases is assumed.

The discounted cost of the investment phase, C^*_{INV} ($M), is calculated from:

$$C^*_{INV} = F_{dINV}\, C_{INV} \tag{3.56}$$

where F_{dINV} = discounted cost factor for the investment phase using the beginning and ending years calculated in Eqn. (3.55)

The beginning and ending years for the operations and support phase, B_{OAS} and E_{OAS}, respectively, are given as:

$$B_{OAS} = E_{INV} + 1$$

$$E_{OAS} = B_{OAS} + L_S - 1 \quad (3.57)$$

O&S costs are not charged until all the ships have been constructed, and the operating period is set equal to the ship service life.

The discounted cost of the operations and support phase, C^*_{OAS} ($M), is;

$$C^*_{OAS} = F_{dOAS} \; C_{OAS} \quad (3.58)$$

where F_{dOAS} = discounted cost factor for the operations and support phase using the beginning and ending years calculated in Eqn. (3.57)

The discounted residual value of the platform, R^* ($M), is given by:

$$R^* = R \; (1/1.1)^{(E_{OAS} + 1)} \quad (3.59)$$

where R = the non-discounted residual value from Eqn. (3.50)

The total discounted life-cycle systems cost, C^*_{LIFE} ($M), is given by the following equation:

$$C^*_{LIFE} = C^*_{RD} + C^*_{INV} + C^*_{OAS} - R^* \quad (3.60)$$

Cost outputs from the module may be expressed in terms of dollars of any year. Because all cost equations used by the module reflect dollars of the year 1981, cost figures must be adjusted to account for inflation occurring between the base year and 1981.

Table 3.17 indicates the calculated escalation indexes for actual and projected inflation rates from 1977 to 1996. To convert to base year dollars, the 1981 dollar figure is multiplied by the appropriate base year index.

The Costing and System Design Office at DTNSRDC has recently modified the life cycle portion of the ASSET cost module. These improvements include a greater emphasis on discounting, relaxation of some of the simplifying assumptions in the original discounting analysis, an ability to compute and display cash flow diagrams, and the ability to study the impact of relative cost escalation of particular cost categories such as energy or personnel.

The improvements are accomplished primarily through changes in the structure of the calculations. For the most part, the original module's cost estimating relationships (as documented in this study) are retained.

YEAR	INFLATION RATE %	FACTOR
1977	5.87	.6722
1978	8.40	.7287
1979	9.80	.8001
1980	12.30	.8995
1981	11.30	1.0000
1982	8.50	1.0850
1983	8.90	1.0816
1984	7.50	1.2702
1985	7.60	1.3667
1986	7.60	1.4706
1987	7.60	1.5823
1988	7.60	1.7026
1989	7.60	1.8320
1990	7.60	1.9712
1991	7.60	2.1210
1992	7.60	2.2822
1993	7.60	2.4557
1994	7.60	2.6423
1995	7.60	2.8431
1996	7.60	3.0592

ASSET USN Ship Construction Escalation Indices
(Ref. 1)

Table 3.17

3.1.3.3 Input Information

Input information required by the ASSET cost module has been divided into ship acquisition plus payload cost parameters and life cycle cost parameters. These parameters are grouped into the common cost driver classifications outlined in Table 1.5. Ship acquisition plus payload costs are the so-called "sailaway" costs for the lead and follow ships (e.g., see Eqn. 3.29).

TECHNOLOGY

Ship type (i.e., SWATH, Hydrofoil, etc.)
Hull & Superstructure material
Propulsion plant type
Electrical plant type
Control systems complexity (*)
Electronics complexity (*)
Weapons complexity (*)

SHIP DESIGN

Weight limited considerations (i.e., SES vs Monohull)
Amount of trials testing (**)
Hull structure weight (SWBS group 100)
Propulsion plant horsepower
Propulsion plant weight (SWBS group 200)
Electric plant weight (SWBS group 300)
Command & Surveillance systems weight (SWBS group 400)
Auxiliary systems weight (SWBS group 500)
Outfit & Furnishing weight (SWBS group 600)
Armament weight (SWBS group 700)
Margin weight (SWBS group M00)

(*) simple, modest, complex
(**) limited, extensive

ASSET Sailaway Ship Cost Parameters

Table 3.18

PAYLOAD DESIGN

Number of helicopters
Costed military payload weight

MANUFACTURING

Tooling complexity (*)
Learning rate

PROGRAMMATIC

Profit fraction

ECONOMICS

Base year $

ASSET Sailaway Ship Cost Parameters

Table 3.18 (continued)

Inputted Costs

Lead ship acquisition cost
Lead ship payload cost
1st follow ship acquisition cost
Follow ship payload cost

SHIP DESIGN

Ship fuel rate
Crew accommodations

PAYLOAD DESIGN

Costed military payload weight
Payload fuel rate

MANUFACTURING

Learning rate

PROGRAMMATIC

R & D program length
Technological advancement costs
Payload testing and evaluating costs
IOC (initial operational capability) date
Number of ships required
Ship production rate

ASSET Life Cycle Cost Parameters

Table 3.19

ECONOMICS

Base year $
Inflation rates

OPERATIONS AND SUPPORT

Additional facility costs
Deferred manhours required

Annual cost of training ordnance

Underway replenishment ship operating and support costs per year
Underway replenishment ship acquisition cost
Underway replenishment ship fuel delivery capacity per year

Annual operating hours
Service life

Fuel cost/gal

ASSET Life Cycle Cost Parameters

Table 3.19 (continued)

The inputted cost information required to estimate the fleet life cycle costs can be obtained from the previous ASSET calculations for lead and first follow ship construction plus payload costs.

The ASSET cost module makes use of several default values or expressions to facilitate ease of operation and to supply representative values to the program. Table 3.20 lists these cost parameters and their default values or expressions.

ASSET Parameter	ASSET Value or Expression
Year $	1981
Inflation Rate	Table 4
Production Rate	5 ships/year
Learning Rate	0.97
Fuel Cost	$1.20 /gallon (*)
Payload Testing and Evaluation Cost	$0.0
Lead Payload Cost	Eqn. (12)
Follow Payload Cost	Eqn. (21)
Annual Training Ordnance Cost	$0.0
Payload Fuel Rate	0.334 LTON/hr/helo

(*) in 1981 dollars

ASSET Parameter Default Values

Table 3.20

ASSET Parameter	ASSET Value or Expression
R&D Program Length	0 years
Number of ship Acquired	25
Profit Fraction	0.15
Service Life	30 years
Annual Operating Hours	2500 hours
Technology Advancement Cost	$0.0
Additional Facilities Cost	$0.0
Deferred Manhours Required	0.0
UNREP Unit Capacity	258,585 LTON/year
UNREP Unit Cost	$120.209 Million (*)
UNREP O&S Cost	$14.656 Million (*)

(*) in 1981 dollars

ASSET Parameter Default Values

Table 3.20 (continued)

3.1.3.4 Output Information

Output information from the ASSET cost model includes a breakdown of lead and follow ship acquisition costs, and a breakdown of life cycle costs.

The ship acquisition costs output consists of the following cost variables and their applicable equations.

Cost Category	Cost Variable (Eqn #) Lead Ship	Follow Ship
Construction		
SWBS Group 100-900	C_i (3.22)	C_i (3.24)
Margins	C_M (3.22)	C_M (3.24)
Total Construction	C_{CC} (3.25)	same
Profit	C_{profit} (3.26)	same
Construction Price	P_{BC} (3.27)	same
Miscellaneous		
Change Orders	C_{cord}	same
NAVSEA Support	C_{nsea}	same

ASSET Ship Sailaway Output Summary

Table 3.21

Cost Category	Cost Variable (Eqn #)	
	Lead Ship	Follow Ship
<u>Miscellaneous</u> (continued)		
Post Delivery Charges	C_{pdel}	same
Outfitting	C_{outf}	same
H/M/E + Growth	C_{hmeg}	same
Total Acquisition	C_{acq} (3.28)	same
Payload	C_p (3.30)	same
Sailaway	C_s (3.29)	same

ASSET Ship Sailaway Output Summary

Table 3.21 (continued)

For the life cycle costs output, the following cost variables and their corresponding equations are listed below.

Cost Category	NonRecurring				Recurring
	Cost Variable (Eqn #)				
	Ship	Payload	Other		
R & D					
Design & Development	C_{SDD}		C_{ODD}	(3.31)	
Test & Evaluation	C_{STE}	C_{PTTE}	C_{OTE}	(3.32)	
Investment					
Prime Equipment	C_{SPE}	C_{PPE} (3.35)			
Support Equipment	C_{SSE}	C_{PSE} (3.37)			
Initial Spares	C_{ISS}	C_{ISP} (3.38)			
Associated Systems			C_{IASOC}	(3.39)	
Facilities			C_{FI}	(**)	

** user input value

ASSET Life Cycle Cost Output

Table 3.22

Cost Category	NonRecurring — Cost Variable (Eqn #): Ship	Payload	Other	Recurring
<u>Operations & Support</u>				
Personnel				C_{PAY} (3.41)
				C_{TAD} (3.41)
Operations				C_{OPS} (3.42)
Maintenance				C_{MTC} (3.44)
Energy				C_{EGY} (3.45)
Replenishment Spares				C_{REP} (3.46)
Major Support				C_{MSP} (3.47)
Associated Systems				C_{OASOC} (3.48)
Residual Value	R (3.50)			

ASSET Life Cycle Cost Output

Table 3.22 (continued)

Cost Category	Cost Variable (Eqn #)
<u>Total Systems</u>	
UnDiscounted	C_{LIFE} (3.51)
Discounted	C^*_{LIFE} (3.60)

ASSET Life Cycle Cost Output

Table 3.22 (continued)

3.1.4 USCG

3.1.4.1 General

Preliminary ship cost estimating in the US Coast Guard is derived from a procedure which is generally referred to as "Flanagan's Method". This method is based upon an unpublished report written by Flanagan in 1969 (see Ref. 12).

The methodology described in this study is based upon information found in Flanagan's report, previous MIT theses, and from discussions with USCG cost estimating personnel.

Flanagan's Method has also been used in conjunction with computer ship synthesis models. Goodwin (Ref. 7) first used the method to estimate conceptual and preliminary lead ship costs for USCG search and rescue and patrol type cutters with lengths between 150 and 400 feet. Goodwin stated that the synthesis program predicted full load displacements within 4% of existing Coast Guard cutter designs. There was no mention of the accuracy of the cost estimating procedure.

A synthesis model was developed by Tuttle (Ref. 8) for application to ocean going boats between 50 and 150 feet in length, especially for Coast Guard search and rescue patrol boats. Since Flanagan's Method was developed for cutters, Tuttle modified some of the cost estimating relationships (CERs) from existing cost data for patrol-sized boats. The CERs were also updated to reflect more recent Navy information on changes in propulsion machinery, hull materials and overhead charges (e.g., see Ref. 10).

Flanagan's Method is the basis for the current USCG ship cost estimating methodology. Changes have been incorporated to account for the addition of return cost data, and different accounting methods and administrative changes that have been introduced since the late 1960's. The output from the present day cost model provides estimates ranging from concept development decisions to budget submissions.

3.1.4.2 Cost Estimating Relationships

Flanagan's Method is based upon the weights of the seven standard US Navy weight groups. If these weights are incorrect, the estimate will be correspondingly incorrect. Flanagan reasoned that since the average dispersion of bids for new construction vary by 20% about the mean bid, any technique that can come to within 10-20% of actual costs should be considered adequate.

Estimates of the SWBS (Ship Work Breakdown Structure) weight groups are used to determine material costs and manhours. The weight groups include all government furnished equipment (GFE), including all material supplied by other government agencies (e.g., the US Navy).

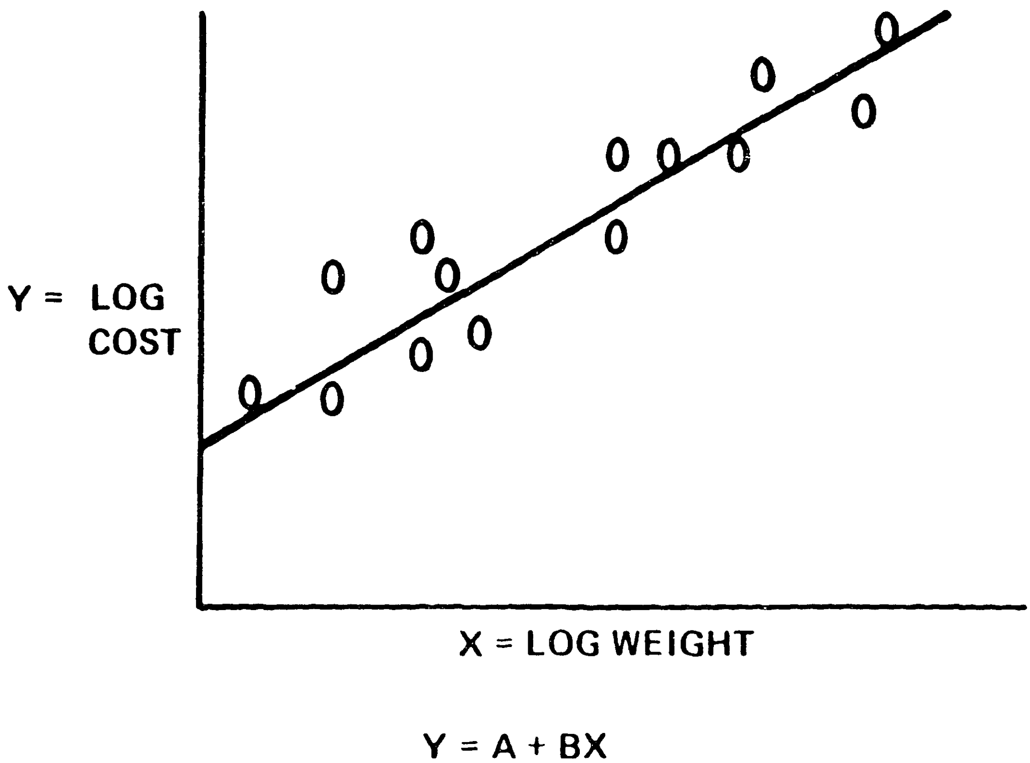
In Flanagan's report, log-log plots of material cost versus weight and manhours versus weight for each weight group were presented. Fig. 3.10 presents a representative plot of material cost versus weight. From these plots, Goodwin (Ref. 7) developed the following CERs for material cost, MC_i ($M), and manhours, MH_i ($M);

$$MH_1 = 10^{[\log(W_{100}\ F_{DG})\ .752\ +\ 2.973]}$$

$$MH_2 = 10^{[\log(W_{200}\ F_{DG})\ 1.027\ +\ 2.344]}$$

$$MH_3 = 10^{[\log(W_{300}\ F_{DG})\ 1.078\ +\ 2.630]} \qquad (3.61)$$

$$MH_4 = 10^{[\log(W_{400}\ F_{DG})\ 1.078\ +\ 2.630]}$$



Basis of USCG Material Cost to Non-Cost Relationships
(Ref. 64)

Figure 3.10

$$MH_5 = 10^{[\log(W_{500}\ F_{DG})\ .763 + 3.237]}$$

$$MH_6 = 10^{[\log(W_{600}\ F_{DG})\ .974 + 2.742]} \qquad (3.61)$$

$$MH_7 = 10^{[\log(W_{700}\ F_{DG})\ .752 + 2.973]}$$

and

$$MC_1 = 10^{[\log(W_{100}\ F_{DG})\ .954 + 2.790]}$$

$$MC_2 = 10^{[\log(W_{200}\ F_{DG})\ 1.019 + 3.634]} + F_1$$

$$MC_3 = 10^{[\log(W_{300}\ F_{DG})\ 1.073 + 3.668]}$$

$$MC_4 = \text{input value} \qquad (3.62)$$

$$MC_5 = 10^{[\log(W_{500}\ F_{DG})\ .871 + 3.974]}$$

$$MC_6 = 10^{[\log(W_{600}\ F_{DG})\ 1.068 + 3.604]}$$

$$MC_7 = \text{input value}$$

where F_{DG} = design and builders margin factor (set equal to 1.02)

F_1 = \$0 for diesel propulsion

= \$1,500,000 for CODAG (combined diesel and gas)

W_i = the appropriate SWBS group weight, LTON

The design and builders margin of 2% is distributed evenly among the seven weight groups that make up the lightship weight.

As indicated in Fig. 3.10, the manhour and material cost versus weight curves are assumed linear when plotted on log-log paper.

Since all material costs curves are based on 1959 prices, inflation indices must be used to correct prices to more recent years. These indices can be obtained from Bureau of Labor Statistics (BLS) data (e.g., see Ref. 11) for the shipbuilding industry.

In order to account for different hull materials, Flanagan cites data from the US Navy and Newport News Shipbuilding that indicates that HY-80 requires 40% more man-hours to fabricate into structure than mild steel. In 1969, the material cost of HY-80 was 3.4 times that for mild steel. Ship estimates must be adjusted to reflect the percentage of structure which is made of high-strength steels (HSSs).

For aluminum structures, US Navy and Maritime Administration (MARAD) data from June 1969 indicate that a given weight of aluminum structure has a total (material + labor) cost 1.8-2.2 times the cost of the same weight of mild steel structure. However, Flanagan notes that computations from WMEC and WHEC contracts ignored the presence of aluminum in their construction estimates without introducing any significant additional error. From more recent Navy information on changes in hull materials, Tuttle found that the effects of all aluminum hull construction for patrol boats could be accounted for by multiplying the material costs only, by 2.192 (see Eqn. 3.64).

Material costs for command and control equipment and for armament (SWBS weight groups 400 and 700, respectively) are input directly into the model. Better estimates are generally obtained when there exist good shopping lists for material costs, particularly electronic, armament and machinery hardware. The minimum cost data required for any equipment is the price, year of purchase, and weight.

When using a shopping list in conjunction with Eqns (3.61) and (3.62) it is important not to "double-bill". Although the weight used for the labor estimate remains equal to the total for the particular weight group, that used in the material cost calculation must be reduced by the equipment weight. The cost of the item is then added to the revised material cost calculated from Eqn (3.62).

Eqns (3.61) and (3.62) were developed by Goodwin directly from Flanagan's report. Tuttle modified some of these CERs in order for the results to be more consistent with CG patrol boats in the 50-150 foot length range. Eqns. (3.63) and (3.64) show these adjusted relationships.

For calculating manhours, only the equation for armament was modified, so that:

$$MH_7 = 10^{[\log(W_{700}\ F_{DG})\ .954\ +\ 2.790]} \qquad (3.63)$$

For material costs, the relationships for structural and propulsion equipment costs were updated using more recent Navy data from Ref. 10:

$$MC_1 = 10^{[\log(W_{100}\ F_{DG})\ 1.019\ +\ 2.790]}\ F_2$$

$$MC_2 = 10^{[\log(W_{200}\ F_{DG})\ 1.019\ +\ 3.634]}\ F_3 + F_4 \qquad (3.64)$$

where F_2 = 1.0 for steel construction

= 2.192 for aluminum construction

F_3 = 1.0 for diesel prime mover or CODAG

= 1.57 for gas turbine prime mover

F_4 = \$0 for diesel and gas turbine PM

= \$1,500,000 for CODAG

For calculating the labor cost, the labor rate is assumed to be the same for all weight groups. Therefore, the labor cost, LC_i (\$M), is given by the simple expression:

$$LC_i = MH_i \ \$/HR \tag{3.65}$$

where MH_i = estimated manhours from Eqn. (3.61) or (3.63)

\$/HR = labor rate (dollars per hour), adjusted to the appropriate year of shipbuilding

For the lead ship, the labor and material costs of design and engineering services (i.e., SWBS weight group 800), LC_8 and MC_8 (\$M), respectively, are given by the following expressions:

$$LC_8 = (.114\ L_{OA} - 1.6)(LC_1 + \ldots + LC_7)\ /\ 100$$

$$MC_8 = (-.01\ L_{OA} + 7.5)(MC_1 + \ldots + MC_7)\ /\ 100 \tag{3.66}$$

where L_{OA} = overall ship length (ft)

The percentage calculated in Eqn. (3.66) for the costs associated with design and engineering services assumes that the contract design is available to the shipyard at the time of construction.

The labor and material costs for lead ship construction services (i.e., SWBS weight group 900), LC_9 and MC_9 (\$M), respectively, are as follows:

$$LC_9 = (.014\ L_{OA} + 7.0)(LC_1 + \ldots + LC_7) \ / \ 100$$

$$MC_9 = (-.015\ L_{OA} + 6.5)(MC_1 + \ldots + MC_7) \ / \ 100 \qquad (3.67)$$

For vessels under approximately 160 ft in length, the material cost for SWBS weight group 900 is estimated at 4% of the sum of the construction material costs.

Overhead cost, OV_i (\$M), is calculated from the labor cost of each SWBS weight group by the simple relationship:

$$OV_i = F_{ovhd}\ LC_i \qquad (3.68)$$

where F_{ovhd} = labor overhead fraction

The cost of construction for each SWBS weight group, C_i (\$M), is the sum of material, MC_i, and labor, LC_i, plus overhead, OV_i, costs and can be written as:

$$C_i = MC_i + LC_i + OV_i \qquad (3.69)$$

The ship construction cost, C_{CC} (\$M), is given as the sum of the weight group costs, such that:

$$C_{CC} = C_1 + C_2 + \ldots + C_8 + C_9 \qquad (3.70)$$

Profit, C_{profit} (\$M), is assumed to equal a fraction of the construction cost and the price or base estimate, P_{BC} ($M), equals the construction cost plus profit. As a result:

$$C_{profit} = F_P \, C_{CC} \qquad (3.71)$$

and

$$P_{BC} = C_{CC} + C_{profit} \qquad (3.72)$$

where F_P = profit fraction (set equal to 0.15)

A series of add-on costs must be calculated and added to the price of the ship to determine the "sailaway" cost of the ship. These costs are determined by the following expressions:

$$\begin{aligned} C_{outf} &= 0.02 \, P_{BC} \\ C_{retro} &= 0.04 \, P_{BC} \\ C_{misc} &= \text{input value} \\ C_{spares} &= .09 \, MC_2 + .08 \, MC_3 + .25 \, MC_4 + .10 \, MC_5 \end{aligned} \qquad (3.73)$$

where C_{outf} = initial outfit costs ($M)

C_{retro} = retrofit costs ($M)

C_{misc} = miscellaneous and contingency costs ($M)

C_{spares} = cost of spares ($M)

Instead of issuing change orders for all design modifications decided upon during ship construction, the CG accumulates some of these modifications throughout the construction period. Retrofit costs are the costs incurred when this work is done by CG shipyards immediately after the ship is built.

Miscellaneous and contingency costs include such items as design work studies, training mock-ups, use of large-scale automation, specialized training requirements, and additional technical services. Other costs under this category are the initial ship load of all fluids and the inclusion of cost margins.

Administrative costs, C_{admin} ($M), are estimated from the following equation:

$$C_{admin} = F_{admin} (P_{BC} + C_{outf} + C_{retro} + C_{misc} + C_{spares} - P_{OGA}) \qquad (3.74)$$

where F_{admin} = administrative cost fraction (set equal to 0.035)

P_{OGA} = cost (including profit) of material supplied by other government agencies

Administrative costs are made up of the salaries of CG personnel attached to Resident Inspector Offices (RIOs) and at headquarters, travel claims, office equipment purchases, and other related expenses. When the size of the RIO and HQ personnel working on a particular project are known, this portion of the cost can be input directly into the estimate.

Equipments supplied by other government agencies (OGAs) include the US Navy contributions to SWBS weight groups 700 and the weapons command and control portion of the 400 group. Included with these items are the spares supplied by OGAs.

The "sailaway" cost of the ship, C_s (\$M), is given by:

$$C_s = P_{BC} + C_{outf} + C_{retro} +$$

$$C_{misc} + C_{spares} + C_{admin} \qquad (3.75)$$

The actual lead ship cost for the CG would be equal to Eqn. (3.75) minus P_{OGA}, the cost of material from other government agencies.

For follow ship costs, Flanagan found from multi-ship contracts that for succeeding ships there was a reduction in total labor manhours according to the schedule in Table 3.23.

SHIP #	PERCENT DECREASE IN LABOR FROM PREVIOUS SHIP
1	Eqns. (3.61)-(3.67)
2	10
3	5
4	2
5	2
6	2
7	1
8	1
> 8	same as 8th

Follow Ship Reduction in Total Labor Manhours

Table 3.23

This reduction in labor accounts for learning. For ships delivered more than six (6) months apart, Flanagan states that little learning occurs other than for design and construction services.

For design and engineering services on follow ships, the percentage of costs in Eqn. (3.66) becomes:

$$LC_8 = (.025\ L_{OA})(LC_1 + \ldots + LC_7) \ / \ 100$$

$$MC_8 = (-.002\ L_{OA} + 2)(MC_1 + \ldots + MC_7) \ / \ 100 \qquad (3.76)$$

Eqn. (3.76) accounts for a substantial portion of the reduction in labor noted in Table 3.23.

For construction services on follow ships, the percentage of costs in Eqn. (3.67) is modified to:

$$LC_9 = (.022\ L_{OA} + 1.5)(LC_1 + \ldots + LC_7) \ / \ 100$$

$$MC_9 = (-.0125\ L_{OA} + 5.5)(MC_1 + \ldots + MC_7) \ / \ 100 \qquad (3.77)$$

For vessels under approximately 200 ft in length, the material cost of construction services is estimated at 3.0% of the sum of the construction material costs.

Regardless of the magnitude of the reduction in labor calculated using Eqns. (3.76) and (3.77), the total reduction in labor for each follow ship must be consistent with the values found in Table 3.23.

Apart from any differences associated with miscellaneous and contingency costs, Flanagan noted the following adjustment to the cost of spares for follow ships:

$$C_{spares} = .045\ MC_2 + .07\ MC_3 + .23\ MC_4 + .1\ MC_5 \quad (3.78)$$

Administrative costs are estimated in an identical manner as for the lead ship, using Eqn. (3.74) with appropriate follow ship costs.

The "sailaway" cost of the follow ship, C_s ($M), is given by Eqn. (3.75), where P_{BC} is the price of the follow ship adjusted for the required reduction in manhours. As before, the actual follow ship cost for the CG would be equal to Eqn. (3.75) minus P_{OGA}, the cost of material from other government agencies for the follow ship. The cost of OGA material includes any relevant portion of the cost of spares calculated in Eqn. (3.78).

The previous discussion was based entirely upon the report written by Flanagan in 1969. After discussion with USCG cost estimating personnel, the following changes and/or explanations were noted as being applicable to the CG model as it now exists.

The procedure for estimating the ship price or base estimate is essentially correct. The numerical values of the variables used for calculating material and labor costs may be different than those listed in Eqns (3.61)-(3.67). This is due mainly to additional data becoming available in recent years.

The effects of learning on the base estimate cost are related to the rate of production. This introduces a time factor into the learning curve, so that learning decreases as time between construction starts increases. For periods of time greater than 2 years, learning is taken to be non-existent.

Return data from recent multi-ship acquisitions indicate, that for CG vessels, it is more appropriate to apply the learning curve to the labor plus material costs.

The categories under which costs are grouped have been changed from those reported by Flanagan to reflect differences in current cost accounting procedures. These categories are listed in Table 3.24.

Categories		
Contract Award		
Contract Spares		
Contract PTD		
Escalation		
Related Costs	-	Outfitting
		RIO
		Retrofit
		Ship & ICP Spares
		Self Insurance
		Training

USCG Cost Model Categories

Table 3.24

The categories of contract award and PTD and related costs require some explanation. The dollar amount of the contract award is equal to P_{BC} in Eqn (3.72). PTD refers to provisioning, technical, documentation and accounts for most of the miscellaneous costs (e.g., C_{misc}).

The related costs listed in Table 3.24 make up the rest of the add-on costs listed in Eqns. (3.73) and (3.74). Ship and ICP (inventory control point) spares are calculated in a manner similar to that outlined in Eqns (3.73) and (3.78). RIO costs are the administrative costs associated with the Resident Inspection Offices at private shipyards. The related costs are estimated to be some percentage of the contract award amount.

A simple risk analysis has been incorporated into the present model by presenting a range of cost estimates. This range of values is obtained by varying design (i.e., weight) and economic (i.e., forecast inflation) inputs. Costs are estimated for inflation rates of 3%, forecast, and 6% and SWBS weights of 10% below estimated, estimated, and 25% above.

3.1.4.3 Input Information

The following input information is required by Flanagan's Method for the estimation of CG ship acquisition costs. These costs are equal to the "sailaway" cost of the lead and follow ships minus the cost of equipments supplied by other government agencies (e.g., the US Navy). The parameters below are grouped into the common cost driver classifications outlined in Table 1.5.

TECHNOLOGY

Ship type (e.g., cutter or patrol boat)
Hull & Superstructure material
Propulsion plant type

SHIP DESIGN

Hull structure weight (SWBS group 100)
Propulsion plant weight (SWBS group 200)
Electric plant weight (SWBS group 300)
Command & Surveillance systems weight (SWBS group 400)
Auxiliary systems weight (SWBS group 500)
Outfit & Furnishing weight (SWBS group 600)
Armament weight (SWBS group 700)
Design & Builders margin
Overall ship length

PAYLOAD DESIGN

Cost of payload material
(includes armament and weapons portion of com. & surv.)

USCG Ship Acquisition Cost Parameters

Table 3.25

MANUFACTURING

Learning rate
Labor rate

PROGRAMMATIC

Profit fraction
Overhead fraction

ECONOMICS

Base year $
Base year for BLS data
BLS material indices

USCG Ship Acquisition Cost Parameters

Table 3.25 (continued)

Output from Flanagan's Method gives cost information for lead and follow ships. The following additional information is used to escalate/discount the CG costs throughout the construction period to a common year dollar value.

Inputted Costs

Lead ship acquisition cost
Lead ship payload cost (*)
Follow ship acquisition costs
Follow ship payload costs

PROGRAMMATIC

Contract award date
Length of construction
Time between ships
Number of ships required

ECONOMICS

Base year $
Inflation rates

(*) payload refers to material cost (plus profit) of armament and weapons portion of command and surveillence (SWBS weight groups 700 & 400).

USCG Fleet Escalation/Discounted Cost Parameters

Table 3.26

3.1.4.4 Output Information

Output information from Flanagan's Method includes a breakdown of lead and follow ship material, labor, overhead and total acquisition costs.

Cost Category	Cost Variable (Eqn #) Lead Ship	Follow Ship
Construction		
Material Cost		
SWBS Group 100-200 (*)	MC_i (3.62 or 3.64)	same
300-700	MC_i (3.62)	same
800	MC_8 (3.66)	MC_8 (3.76)
900	MC_9 (3.67)	MC_9 (3.77)
Labor Manhours		
SWBS Group 100-600	MH_1 (3.61)	same
700	MH_7 (3.61 or 3.63)	same

(*) all construction costs include the design and builders margin

USCG Ship Output Summary

Table 3.27

Cost Category	Cost Variable (Eqn #) Lead Ship	Follow Ship
Labor Costs		
SWBS Group 100-700	LC_i (3.65)	same
800	LC_8 (3.66)	LC_8 (3.76)
900	LC_9 (3.67)	LC_9 (3.77)
Overhead		
SWBS Group 100-900	OV_i (3.68)	same
Material + Labor + Overhead		
SWBS Group 100-900	C_i (3.69)	same
Total Construction	C_{CC} (3.70)	same
Profit	C_{profit} (3.71)	same
Total Ship Price	P_{BC} (3.72)	same

USCG Ship Output Summary

Table 3.27 (continued)

Cost Category	Cost Variable (Eqn #)	
	Lead Ship	Follow Ship
Add-on		
Outfit	C_{outf} (3.73)	same
Retrofit	C_{retro} (3.73)	same
Miscellaneous	C_{misc} (3.73)	same
Spares	C_{spares} (3.73)	C_{spares} (3.78)
Administrative	C_{admin} (3.74)	same
Sailaway	C_s (3.75)	same

USCG Ship Output Summary

Table 3.27 (continued)

3.1.5 RCA PRICE

3.1.5.1 General

RCA PRICE has developed a family of automated, parametric, cost estimating models. PRICE (Programmed Review of Information for Costing and Evaluation) was originally developed for internal RCA use in the early 1960's. Commercial operations began in 1975, with applications to hardware development and production, software design and implementation, microcircuits and associated maintenance and support costs. Fig. 3.11 gives an indication of the diversity of areas covered by PRICE modeling systems.

For ship acquisition cost estimating, the PRICE H model has been used extensively. The PRICE H model is applicable to all aspects of hardware acquisition, be it development, production, government furnished, or modification of existing equipment. The model estimates costs associated with design, drafting, project management, documentation, engineering, special tooling and test equipment, material, labor and overhead. Also, costs to integrate subassemblies into a system and to test the system for required operation can be estimated. A detailed explanation of the PRICE H model can be found in Ref. 20.

PRICE H is characteristic of traditional cost estimating methods (e.g., NAVSEA, NCA) in that it performs cost estimates on a cost per pound basis. However, its output does not contain a breakdown of material and labor costs. These figures must be "backed" out using a post-processor (i.e., PRICE LABOR) or some other method, as outlined in Section 3.1.5.4.

There is strong resistance to the use of PRICE among traditional "material list and labor" ship cost estimators. There

HARDWARE COST ESTIMATING

PRICE H
PRICE HL

PLANNING AND MANAGEMENT

PRICE PM

MICROCIRCUIT COST ESTIMATING

PRICE M

SOFTWARE COST ESTIMATING

PRICE S
PRICE SL

SUPPORTING MODELS

PRICE A
PRICE D

PRICE Parametric Modeling Systems
(Ref. 20)

Figure 3.11

are several reasons for this distrust, including the following points: (1) the model is proprietary and must be operated as a black box; (2) it was originally developed for avionic and aerospace applications; (3) the user must pay to use it, and; (4) it doesn't give material/labor figures.

Despite these reservations, PRICE has been used for several years for early stage estimating of Navy weapons systems. Also, the Costing and Design Systems Office, Code 1204, at David Taylor Naval Ship Research and Development Center (DTNSRDC) has found the PRICE H model useful for: early-stage ship design cost assessment; advanced technology cost impacts; alternative systems cost analysis, and; R&D resource planning.

PRICE modeling systems are extensively discussed in the Journal of Parametrics and in the proceedings of the International Society of Parametric Analysts (ISPA) (e.g., see Refs. 17-19). Articles relating PRICE to ship costing can be found in Refs. 25-27.

Cost estimates obtained using PRICE are generally intended for acquisition planning purposes and not for budget submissions. Even so, PRICE can estimate costs at any level of detail, from a whole ship viewpoint down to individual equipments. The DCAA (Defense Contract Audit Agency) Audit Manual states the "parametric estimating provides an excellent cross-check on completeness of proposal coverage."

3.1.5.2 Cost Estimating Relationships

This section is intended to provide a brief overview of the PRICE H model. The discussion that follows is based upon information available in the users manual (Ref. 20) and from personnel in the Costing and Design Systems Office at DTNSRDC. For additional clarification, PRICE offers users an intensive two week training program to familiarize users with the concepts and use of the model.

The PRICE H model estimates costs for both development and production elements of the program. Table 3.28 lists the categories included under the development and production cost headings and a brief description of their make-up.

	Cost Category	Description
Development	Engineering	- drafting, design, systems engineering, project management and data
	Manufacturing	- labor and material associated with prototype production - tooling & test equipment costs
Production	Engineering	- non-recurring production costs such as drafting, design, project management and data
	Manufacturing	- production costs - tooling & test equipment costs

PRICE H Cost Output Categories

Table 3.28

The basis for the development of the PRICE proprietary CERs is multiple regression curve fitting of historical data. The result of this analysis is literally thousands of mathematical equations relating the various input variables to cost.

Input data consists of 67 variables used to describe the physical, qualitative, programmatic, economic, engineering dependent and system dependent characteristics of the particular system. However, the model has been designed to estimate costs with a minimal amount of hardware information, since missing input variable values are internally generated. This feature makes the model useful for cost estimating in the conceptual stage of development. It is important to realize that the proper user specification of all the input variables will reduce the statistical uncertainty of the model.

Of all the inputs, the more fundamental parameters are listed in Table 3.29.

Description
Number of production units built
Learning curve
Integration difficulty
Schedules for development and production
Weights
Amount of new design required
Operational environment
Manufacturing complexity
Technology improvement

Fundamental Cost Drivers in the PRICE H Model

Table 3.29

Weight and manufacturing complexity are the most powerful cost drivers, so that in its simplest form;

$$\text{Cost} = f\ (\text{Weight} \times \text{Manufacturing Complexity}) \qquad (3.79)$$

where f( ) is a nonlinear function. For ship costing applications, weights are based on SWBS. PRICE can be run at any level of detail (i.e., whole ship, one-, two- or three-digit SWBS levels) provided the necessary information exists.

Separate manufacturing complexities are computed for mechanical/structural and electronics items. Ship costing applications are almost exclusively based upon estimated mechanical/structural complexities (MCPLXS).

MCPLXS can be thought of in terms of a cost/lb for manufacturing processes and a cost/drawing or required effort for engineering work. It exhibits a wide range of values depending upon the technology required for its fabrication, the operating environment and the employment history of the manufacturer. Typical values for a variety of non-ship systems can be found in Fig. 3.12.

An important trend to note from Fig. 3.12 is the increase in manufacturing complexities with more severe operating requirements. Fabricating specifications and reliability standards are more stringent for space applications than those for ground assemblies. The number associated with a particular operating environment is referred to as the platform specification level (PLTFM). The variable WSCF is equal to the density of the structure in pounds per cubic foot.

Equipments	Typical Examples	WSCF	1.0 Ground	1.4 Mobile	1.8 Airborne	2.0 Space	2.5 Manned Space
Antennas	Small, Spiral, Horn, Flush, Parabolic	4	4.75	5.39	5.64	6.55-7.04	6.92-7.44
	Scanning Radar 10-40' Wide	8	5.3	5.4	5.5	–	–
	Phased Arrays (Less Radiators)	6-8	5.9	6.2	6.4	7.0	7.2
Engines & Motors	Automobile - 100 to 400 H.P.	25-35	–	4.30	–	–	–
	Turbo-Jet (Prime Propulsion)	25-35	–	–	6.6-7.9	–	–
	Rocket Motors	14-15	–	–	6.1-6.5	6.4-7.3	7.2-8.2
	Electric Motors	75-100	4.47	5.08	5.3	5.4-6.3	5.4-6.3
Drive Assemblies	Machined Parts, Gears, etc.	7-10	5.11-5.24	5.5	5.6	–	–
	Mechanisms w/Stampings (Hi Prod)	12	3.33-3.73	–	–	–	–
Microwave Transmission	Waveguide, Isolators, Couplers,	11-20	5.4-5.6	5.4-5.6	5.5-5.7	5.5-5.9	5.5-5 9
	Stripline Circuitry	9	5.7	5.8	5.9	6.0	6 1
Optics	Good (Commercial)	70-90	5.1	5.4	6.3	6.7	7 3
	Excellent (Military)	70-90	5.4	5.8	7.3	7.8	8.0
	Highest (Add 0.1 per 10% Yield)	70-90	5.9	6.8	8.0	8.3	8 5
Ordnance Fuze	Automated Production	14-20	–	4.3-4.65	4.3-4 65	–	–
	Small Production-Min. Tooling	14-20	–	5.11-5.33	5.11-5.33	–	–
Servo	Mech Drive & Coupling Networks	65-75	5.63	5.63-5.7	5.7-6 26	5.7-6.86	ɔ.7-6 86
Tools	Machine Tools	25-30	4.45-4.52	–	–	–	–
Printed CKT Cards (Boards Only)	Paper Phenolic	83	4.1-4.3	4.1-4.3	4.1-4.3	4.1-4.3	4.1-4.3
	Glass Expoxy, Double Sided (Add 0 2 for 3 Layers & 0.05 for Addn'l) Add 0.1 for Plated-Thru Holes	110	5.3	5.3	5.3	5.3	5.3
Cabling	Multiconductor w/MS Connectors	40	4.9	5.0	5.0	5.1	5 2
	Same w/ Hermetically Sealed Connectors	40	5.1	5.2	5.2	5.3	5 3
Battery	Nickel – Hydrogen	80			6.85	7.81	8.55
	Nickel Cadmium	75	5.39	5.83	6.73	7.63	8 38
Gyro	Inertial Platform Type	79	6.01	6.56	6.8	6.9-9.1	7.0-9.4
Laser Module			7.6	8.5	9.4	9.5	9.6

Typical MCPLXS Factors for Mechanical Assemblies
(Ref. 20)

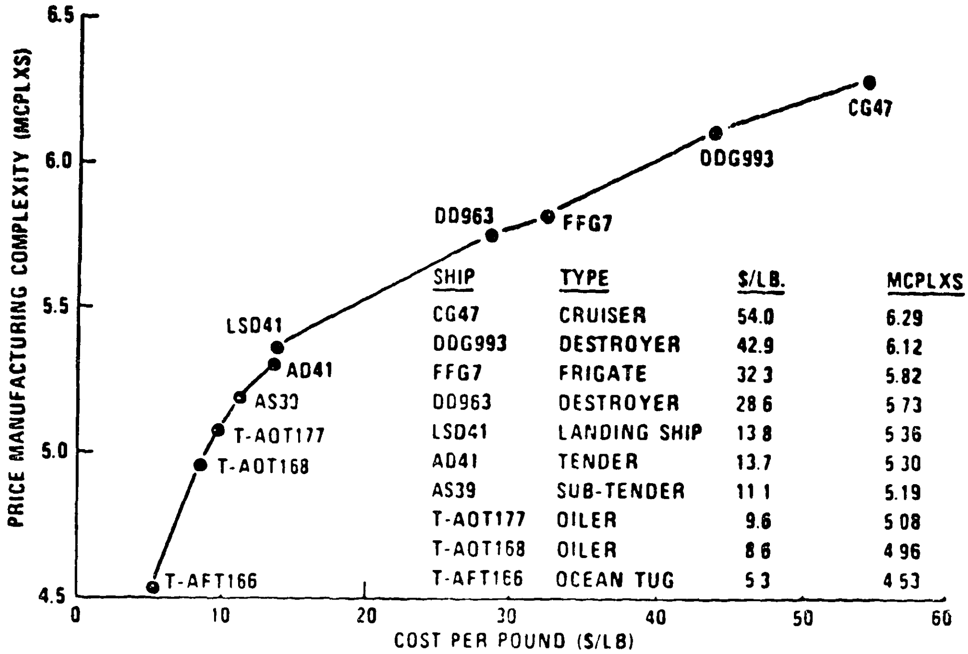
Figure 3.12

Ships also experience a range of manufacturing complexities. Fig. 3.13 illustrates the variation of "whole ship" MCPLXS for several USN vessels. Note that the cost per pound figure increases proportionately with MCPLXS. The platform specification level used in deriving these complexities was estimated at 1.4 for conventional ships and at PLTFM=1.6 for weight critical ships (i.e., hydrofoils, SESs and ACVs).

The affect of technology on the value of manufacturing complexity is clearly shown in the comparative cost analysis of alternative WPB designs done at DTNSRDC (see Ref. 27). Values of MCPLXS equal to 5.531 and 5.082 were estimated for hydrofoil and planing boats, respectively. The result of the higher level of technology for the hydrofoil was a cost that was 70% more than the planing boat.

The effects of the level of technology and manufacturing complexity on costs vary with time according to the trends indicated in Figure 3.14. The curves show the cost reductions expected with improvements in design methods and manufacturing efficiency with time. The year at which the curve crosses the abscissa indicates the year of maturity for the particular technology. As expected, lower technology matures earlier than high tech., but typically has less effect on costs.

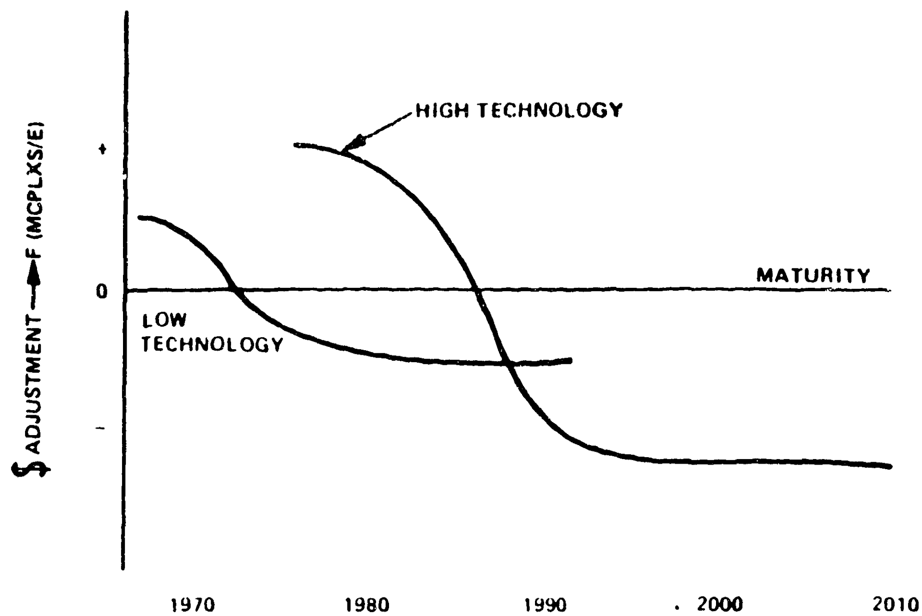
Scheduling effects on the costs of the development and production phases can also be explored with the PRICE model. Penalties are assessed for accelerated and stretched-out schedules as shown in Figure 3.15.



SHIP	TYPE	$/LB.	MCPLXS
CG47	CRUISER	54.0	6.29
DDG993	DESTROYER	42.9	6.12
FFG7	FRIGATE	32 3	5.82
DD963	DESTROYER	28 6	5 73
LSD41	LANDING SHIP	13 8	5 36
AD41	TENDER	13.7	5 30
AS39	SUB-TENDER	11 1	5.19
T-AOT177	OILER	9.6	5 08
T-AOT168	OILER	8 6	4 96
T-AFT166	OCEAN TUG	5 3	4 53

MCPLXS Factors for Selected USN Vessels
(Ref. 60)

Figure 3.13



Effect of Technology Improvement on Costs
(Ref. 64)

Figure 3.14

Schedule	$ DEV	$ PROD	$ TOTAL
DEVELOPMENT / PRODUCTION	190	6,887	7,077
DEVELOPMENT / PRODUCTION	190	7,133	7,323
DEVELOPMENT / PRODUCTION	190	7,841	8,031

Influence of Schedule on Costs
(Ref. 64)

Figure 3.15

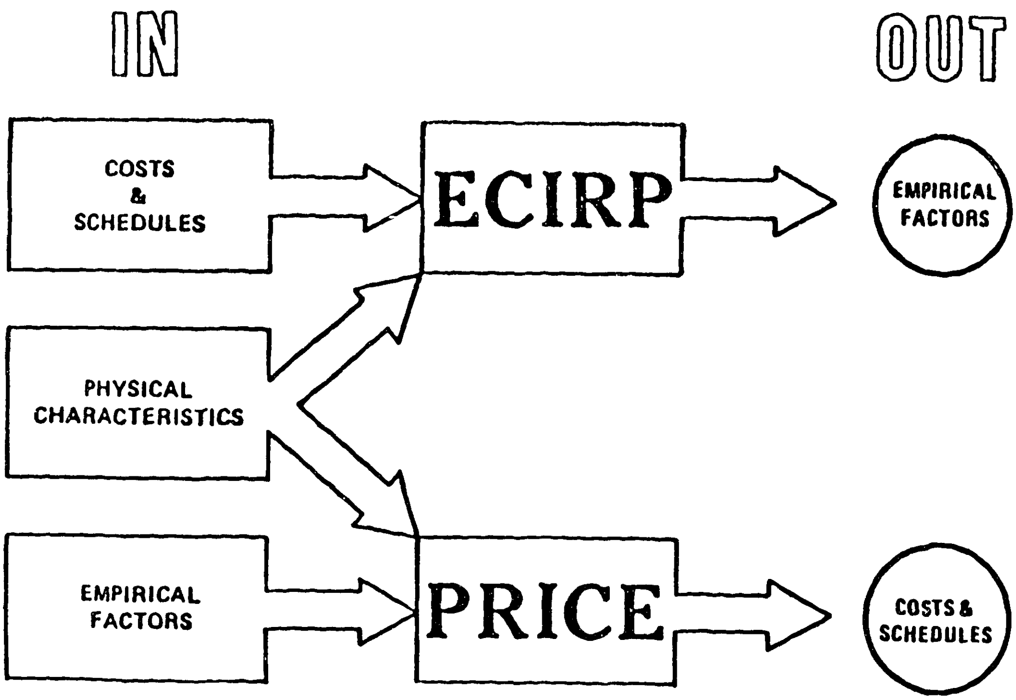
The PRICE model incorporates several other features, including: incorporation of a learning curve for multiple production units; estimating the cost of multiple lot production runs; a factor to account for component integration difficulty; discounting costs in proportion to existing design data, and; allowing the through-put of vendor quotes to prevent double billing.

PRICE also has a design-to-cost mode, which allows the user to input a target cost, quantities and level of technology information. Output consists of design limits for weight. This type of analysis would be especially beneficial during concept development and the early stages of feasibility design.

One of the main reasons that the model has found such widespread use is its adaptability to any hardware application through an easy to use calibration process, as illustrated in Figure 3.16.

Basic inputs for calibration consist of cost and schedule data plus the physical characteristics of the system. The model then iterates on MCPLXS values until a complexity is calculated that matches the input data. The empirical factors calculated when the data is ECIRPed (PRICE spelled backwards) are now representative of the system and the supporting organization and can be used independently to estimate costs and schedules.

Once a user has performed this process on a variety of related cost data, a pattern usually emerges for the complexities that can be related to the system characteristics. The effectiveness of the calibration is highly dependent on the



The PRICE Calibration Process
(Ref. 64)

Figure 3.16

availability and accuracy of the cost data used.

Fig. 3.17 shows the information required to do a 1 box (i.e., whole ship) calibration. The variables PSTART and PEND refers to the start and end of production, respectively, and their value is given in terms of month/year (e.g., 252 is February, 1952). Costs are given in British pounds.

Similar 1 box calibrations for selected US Navy ships were performed by Cost and System Design Office personnel at DTNSRDC. The data was obtained from an IDA (Institute for Defense Analyses) study (e.g., see Ref. 44).

From the ship data contained in Fig. 3.17, a trend showing the increase in manufacturing complexity with the start of production was developed and is shown in Fig. 3.18. The figure shows that the complexity has been steadily increasing with time.

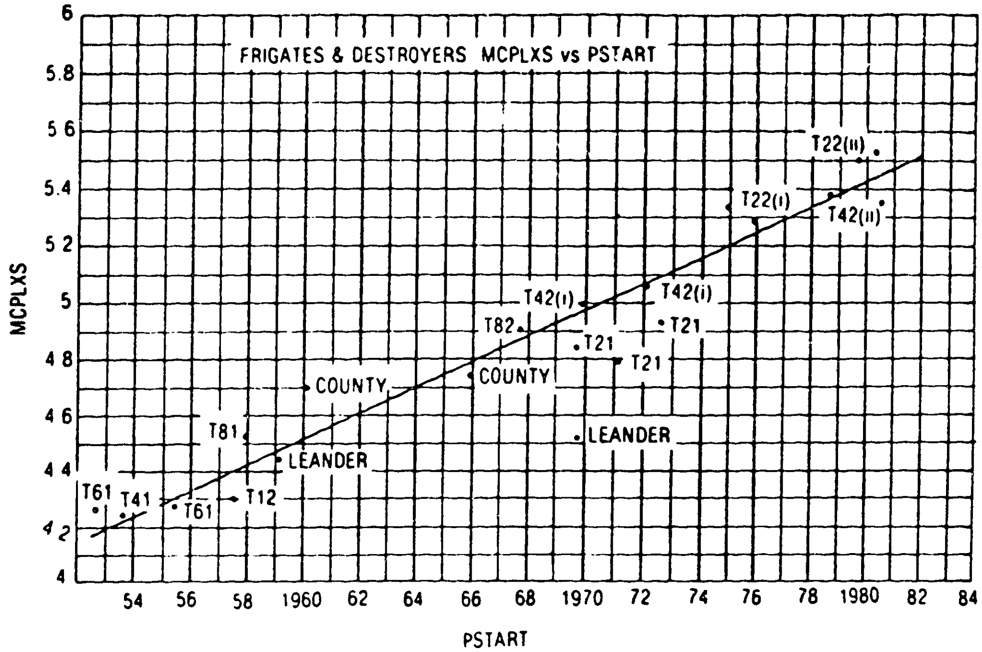
The model incorporates a risk analysis program in conjunction with the cost estimates for development and manufacturing. However, this analysis is developed using the uncertainty of the PRICE algorithms and not of the input data.

Understandably, the accuracy of the model is highly dependent upon the input data. Bearing this in mind, Ref. 20 indicates that the PRICE model produces results within 10% of actual costs.

CLASS	TYPE	NAME	STANDARD DISP'T (WT)	SCHEDULED PSTART-PEND	LENGTH	HP (TOTAL)	COST M (AT PEND)
SALISBURY	61	SALISBURY	2170	252-257	339 8	14400	3 3
"	61	LINCOLN	2170	655-660	339 8	14400	3 3
LEOPARD	41	LYNX	2300	853-257	339 8	14400	3 2
WHITBY	12	BRIGHTON	2380	857-961	370	30000	3.6
ASHANTI	81	ASHANTI	2300	158-1161	360	20000	5 22
LEANDER		LEANDER	2450	459-363	372	30000	4.7
"		ARIADNE	2500	1169-273	372	30000	7 0
COUNTY		KENT	5440	360-863	520 5	60000	13.8
"		ANTRIM	5440	266-770	520 5	60000	16 8
BRISTOL	82	BRISTOL	6100	1167-373	507	60000	27
AMAZON	21	AMAZON	2750	1169-574	384	64500	14 4
"	21	ANTELOPE	2750	471-775	384	64500	14 4
"	21	ARROW	2750	1072-776	384	64500	20 2
SHEFFIELD	42(I)	SHEFFIELD	3500	170-275	412	64500	23 2
"	42(I)	BIRMINGHAM	3500	372-1176	412	64500	30 9
"	42(II)	GLOUCESTER	4000	1179-1283	463	64500	78 5(1980)
"	42(II)	EDINBURGH	4000	980-1284	463	64500	85 0(1980)
BROADSWORD	22(I)	BROADSWORD	3500	275-579	430	64500	68 6
"	22(I)	BATTLEAXE	3500	276-380	430	64500	69 2
"	22(II)	BOXER	3800*	1179-1183*	471	64500	125(1981)
"	22(II)	BEAVER	3800*	680-684	471	64500	130(1981)
TON	MCMV	WILTON	450	1170-773	150	3000	2 3
HUNT	MCMV	BRECON	615	975-380	197	3540	30
HYMARINE 32	MCMV	(PROPOSAL)	120	980-683*	107	1000	13 5*
VALIANT	SSN	WARSPITE	4000	1263-467	285	NK	24
"	SSN	CONQUEROR	4000	1267-1171	285	NK	30
SWIFTSURE	SSN	SWIFTSURE	4000	469-473	272	15000	37 1
"	SSN	SUPERB	4000	372-1176	272	15000	41 3
RESOLUTION	SSBN	RESOLUTION	7500	264-1067	360	NK	40 24
"	SSBN	RENOWN	7500	664-1168	360	NK	39 95
"	SSBN	REPULSE	7500	365-968	360	NK	37 5
"	SSBN	REVENGE	7500	565-1269	360	NK	38 6

PRICE H Ship Calibration Data
(Ref. 25)

Figure 3.17



Frigates & Destroyer MCPLXS vs PSTART Trend
(Ref. 25)

Figure 3.18

When the output from PRICE H is coupled with PRICE HL, life cycle costs can be estimated. Life cycle costs are defined as the cost of supplying and maintaining a particular system. The model can discount future costs or present funding by year.

The costs estimated depend on the characteristics of the: equipment; employment/deployment; organization, and; maintenance concepts used. The model uses over 250 preset variables, each of which may be altered by the user, to describe the system's support environment.

3.1.5.3 Input Information

The following input information is considered to be the minimum data required by the PRICE H model to obtain a "reasonable" estimate of development and manufacturing costs during the feasibility/preliminary design phase. A glossary for all the input variables and the data sheet used to input system information into the PRICE H program can be found in Appendix F. The parameters below are grouped into the common cost driver classifications outlined in Table 1.5.

TECHNOLOGY

Manufacturing complexities
Technology base year

SHIP DESIGN

Hull structure weight (SWBS group 100)
Propulsion plant weight (SWBS group 200)
Electric plant weight (SWBS group 300)
Command & Surveillance systems weight (SWBS group 400)
Auxiliary systems weight (SWBS group 500)
Outfit & Furnishing weight (SWBS group 600)
Armament weight (SWBS group 700)
Design & Builders margin
Operating environment

PRICE H Development & Production Cost Parameters

Table 3.30

MANUFACTURING

Manufacturing complexities
Learning rate

PROGRAMMATIC

Scheduling
Development start & end dates
Production start & end dates
Number of ships

ECONOMICS

Base year $

PRICE H Development & Production Cost Parameters

Table 3.30 (continued)

3.1.5.4 Output Information

The PRICE H output cost data is in terms of development and production costs, not the usual material/labor format seen with "shipbuilding only" cost methods. Table 3.31 shows the major cost categories previously indicated in Table 3.28, and contains a brief description of the various elements that make up their total.

Program Cost	Cost Element	Description
Engineering		
	Data	Documentation costs for manuals, lists, reports, deliverable drawings, and other related items
	Design	Cost of design and development engineering
	Drafting	Cost of manufacturing drawings, data lists, specifications, and incorporation of engineering changes in drawings
	Project Management	Cost of program management and control to include travel expenses, computer operation costs, in-house reports and the "ilities"
	Systems	Cost of conversion of performance requirements into design specifications
Manufacturing		
	Production	Manufacturing costs to include material, labor, set-up, overhead, and quality control
	Prototype	Production costs for prototypes including material, labor, overhead, and qualification testing
	Tool-Test Equipment	Cost of all special tools and test equipment to include their design and any refurbishment

Description of PRICE H Cost Elements

Table 3.31

The Costing and Design Systems Office at DTNSRDC has enough familiarity with PRICE to correlate USN SWBS based and PRICE output cost accounting categories in order to obtain the more recognizable ASSET and NAVSEA formats. Table 3.32 indicates the relationship for lead and follow ships between PRICE cost outputs and NAVSEA construction plans (CP) and basic construction (BC) end cost categories (e.g., see MCCs 111/113 and 211, respectively, in Fig. 3.2).

PRICE Cost Category	Development	Production
Engineering		
Drafting	CP (lead)	0.0
Design	CP (lead)	0.0
Systems	SWBS 800 (lead)	Not Applicable
Project Mgmt	SWBS 800 (lead)	SWBS 800 (lead & follow)
Data	SWBS 800 (lead)	SWBS 800 (lead & follow)
Manufacturing		
Production	NA	SWBS 1-7, margins, GFM (lead & follow)
Prototype	0.0	NA
Tool-Test Eqmt.	0.0	SWBS 900 (lead & follow)

Total Cost = Development + Production Costs

Relating PRICE and SWBS-based Ship Costs

Table 3.32

The following PRICE sum is used to estimate the cost of construction plans, C_{CP} (see Eqn. 3.12):

$$C_{CP} = (\text{Dev. Drafting}) + (\text{Dev. Design}) \tag{3.80}$$

The basic construction cost, C_{CC} (see Eqn. 3.8), is then estimated from the remaining PRICE cost elements, so that:

$$C_{CC} = F_{G\&A} \left((\text{Total cost}) - \left((\text{Dev. Drafting}) + (\text{Dev. Design}) \right) \right) \tag{3.81}$$

where $F_{G\&A} = 1.165$

$F_{G\&A}$ is a factor that accounts for general and administrative overhead not included in the PRICE cost algorithms. The numerical value of this factor is the result of experience gained by DTNSRDC in comparing NAVSEA formatted cost estimates with PRICE outputs (e.g., see Ref. 26). GFM cost lists are through-put by PRICE and their sum will appear separately from the total cost figure in Eqn. (3.81).

Once the construction cost is obtained, the other end cost categories indicated in Fig. 3.2 can be calculated as described in Section 3.1.1.

3.1.6 Other Cost Models

There are several cost models which have not been discussed in this study. In this section these models are broken into three groups: the FAST-E parametric model; models for merchant ships, and; contractor/shipyard models.

3.1.6.1 FAST-E

FAST-E (Freiman Analysis of Systems Technique - Equipment) is a parametric cost model for estimating acquisition and life-cycle costs of various equipments. the model is very similar to the RCA PRICE model. This is not surprising, since Frank Freiman originally developed the RCA PRICE model back in the 1960s. The FAST-E model is explained in greater detail than found in this study in Refs. 18 and 37.

This model has a unique feature of being linearly adjustable, which is said to emulate designers' and managers' cost change perceptions (Ref. 18). This allows analysts to express change from a known design (or shedule, reliability, etc.) to a new one using descriptions such as 25% less, 50% more, etc.

Costs are related to an overall complexity factor which is itself related to a variety of general equipment technologies, integration factors and reliability & maintainability impacts. Complexities are calculated by calibrating the model using input data. FAST complexity factors represent a complete electro-mechanical system unlike those in PRICE which represent structural and electronic separately.

This feature of combining the two PRICE complexities into one variable makes it easier to calibrate FAST because no assumption has to be made as to the weight and density of the various components. Only the total weight is required as input.

An unpublished Navy report on the FAST-E model suggests that it is a useful tool for obtaining approximate total ship costs. To date no Navy personnel are actively pursuing the use of this model in Navy ship costing, although several personnel in the Costing and System Design Office at DTNSRDC have taken FAST training.

3.1.6.2 Merchant Ship Cost Models

Merchant ship cost estimates are usually broken down into manhours and material costs for three cost categories. These categories are;

(1) Steel

(2) Outfit

(3) Machinery

Cost estimates are obtained in each area through the use of weight/cost CERs for general cost trends. Conventional engineering cost estimating procedures are employed for more detailed design definitions.

Perhaps the most well-known cost model in this field was developed at MARAD (Maritime Administration) by J.A. Fetchko (e.g., see Ref. 38). A description of the procedures available at MARAD for estimating ship costs is given in a paper by Landsburg (Ref. 39). There are several other references to costing of merchant ships in the open literature. Some of these are listed under Refs. 40 - 43.

3.1.6.3 Private Contractor Models

Private contractors typically estimate ship construction costs using the conventional engineering method. Labor manhour and material costs are estimated on a system basis and summed to obtain a total ship cost. Generally, the work breakdown system used by private contractors is not the SWBS system found in the Navy.

Private contractors rely heavily upon their extensive shipyard experience (most have spent several years working in shipyards). Their databases are considered highly proprietary and are closely guarded. Because they seldom publish cost studies in the open literature, access to even their methodologies is difficult.

3.2 COST MODEL COMPARISONS

This section is intended to provide a comparative study of the NAVSEA Code 017, NCA, ASSET, USCG and PRICE cost models. Any comprehensive cost model comparison will involve a detailed examination of input/output sensitivities, comparative cost studies, the influence of design standards, treatment of program costs, database requirements, plus a variety of other cost issues. The ability to perform such an analysis requires complete access to the models and data bases involved. Given the proprietary nature of costing in general, this access is seldom granted.

The result of this reluctance to share information is that research papers on costing in the open literature apply to the above issues in a general way. Since this study is primarily based upon data available in published journals and unclassified government documents, the following discussion on cost model comparisons is also forced to be of a general nature.

3.2.1 General Model Characteristics

The five cost models selected in this study present a fairly complete spectrum of methodologies used for new ship construction costing. These include the following categories;

(1) conventional engineering

(2) CER

(3) parametric

The NAVSEA Code 017 model is representative of the conventional engineering or so-called bottoms-up approach, where the ship is broken down into discrete blocks for which material and labor costs are estimated. The highest level of detail obtained for this approach occurs when the estimator is in possession of a bill of material for the entire job. Once the individual material and labor costs have been calculated, they are summed for the total ship construction cost.

The USCG, NCA and ASSET models use cost estimating relationships (CERs) to estimate costs. CERs employ a single non-cost to cost relationship to estimate ship construction costs. Although CERs can be developed down to any level of technical detail, they are usually applied on the 1 digit SWBS level and are referred to as a top-down approach.

The RCA PRICE model is representative of models at the other end of the cost methodology spectrum and estimate costs parametrically. Parametric estimates are also top-down approaches, intended for use under conditions in which there is not a detailed breakdown of the ship. Typically, the parametric approach differs from the use of CERs, in that it uses more than one non-cost variable in its regression.

All the models use weight as the main cost driver, plus a method to account for different technologies. Technologies include a multitude of influences, including but not limited to, variations in materials, propulsion, electrical power generation and distribution and electronics. Combat related systems, which invariably are "high tech", are generally intended to be input using a shopping list.

Technology differences are accounted for in the NAVSEA model through the extensive data base. The NCA model has different linear trend lines for the various technologies represented in its cost elements. The ASSET and RCA PRICE models use technology factors to describe the variations in technology (although there is no relationship between each model's factors). The USCG model adjusts CER outputs directly using appropriate multipliers.

3.2.2 Range of Applicability

3.2.2.1 Vessel Type and Displacement

Range of applicability refers to the variety of ship types and displacements for which each model is capable of producing "accurate" results. Accurate model results are assumed for ships whose design features place them within the range of ship costing information available in the database. In other words, accurate results are produced when cost information on similar ship types has been incorporated into the model CERs.

Table 3.33 indicates the vessels for which each model is intended and has in fact been used. This information was obtained from personnel using the specified model.

The wide range of applicability for the NAVSEA cost model is primarily due to the existence and continual updating of its database. The NCA checks the NAVSEA estimate for conventional monohull combatants using the model discussed in this study. For other vessels, NCA uses a model developed by the RAND Corporation. Due to the classified nature of this model, it could not be documented.

The ASSET model indicates a wide range of vessels for which it can be used. It is important to note that the data for the ASSET CERs is from the early to mid 1970's and so is becoming

Cost Model	Range of Applicability Vessel Type	Displacement (LT)
NAVSEA Code 017	any new construction	2 - 100,000
NCA	frigates, destroyers, cruisers	5,000 - 12,000
ASSET	all monohulls, SWATH, hydrofoils, SES, ACV	10 - 20,000
USCG	all CG vessels (i.e, patrol boats to polar icebreakers)	69 - 12,000
RCA PRICE	any new construction	2 - 100,000

Cost Model Vessel Applicability

Table 3.33

dated. In addition, several of the advanced vehicles included in the ASSET database were built in an aircraft and/or R&D environment and are therefore not indicative of a production setting.

The Coast Guard model has incorporated a wide range of USCG vehicles in its database. Due to limited construction in the CG, the database for each vessel type is typically small. However, it has been found to be representative of the indicated range.

The RCA PRICE model has an all encompassing range due to its ability to be calibrated and the universality of its complexity factors. The flexibility of the complexity factors allows any vessel type ot be estimated, even if extrapolating outside the range of the database.

Cost analysts, by necessity, may be called upon to estimate a ship cost for a vessel type not included in the current database. For these situations, it is important to understand how each model can be perturbated (and by how much) to account for new design variations.

As mentioned for the RCA PRICE model, the complexity factors allow for extrapolation outside of the database range. The technology factors in the ASSET model do not have any universality, in that a new technology factor cannot be estimated from a knowledge of the current database values, and the factors scale differently for each SWBS group.

By the nature of their development, cost models are intended to be used to estimate ships similar to those in the database. If it becomes necessary to extrapolate outside of this range, it must be done so logically and intelligently. Phrases like, "relate existing data tempered with experience" become applicable (but certainly not helpful) and show the importance of knowledgeable personnel in the cost analysis process.

3.2.2.2 Ship Design Phase

All of the models discussed in this study are intended to provide some measure of ship cost estimates during the conceptual, and on into the preliminary design phase. Typically, the technical definition available during these periods are weights in the 1 - 2 digit SWBS level.

Due to its conventional engineering approach, the NAVSEA

Code 017 model is applicable from ROM to budget estimates, provided the appropriate level of technical definition is available. Although, any of the cost methodologies will produce a more accurate estimate (as related to its database) if there is less uncertainty in the input data.

The ASSET cost model was intended for comparative cost analyses of naval vehicles rather than specific point estimates. Therefore, ASSET cost estimates may be the most questionable (i.e., uncertain) for specific ship design applications.

3.2.3 Model Input/Output Comparisons

All the models discussed in this study address the estimation of ship acquisition costs. As previously mentioned, weight and technology level are the main inputs for estimating construction costs. Scheduling and programmatic costs are also important for calculating total acquisition costs.

Only the ASSET cost model directly estimates the total life-cycle cost (LCC) associated with a ship. LCCs are most frequently used for select comparative studies and require information on operating profile, fuel consumption, personnel salaries, equipment spares and maintenance policies.

Financial spreadsheet comparisons, such as those obtained using the USCG's CASHWHARS program (e.g., see Ref. 34), or direct analogy comparisons with the USN's VAMOSC data, are popular methods of doing these LCC studies.

3.2.3.1 Minimum Input Requirements

In this section, the cost parameters that are representative of the technical definition necessary to cost a ship during the conceptual/preliminary design phase are presented. The amount of data required for each model, or its definition, may differ from the inputs given below.

The NAVSEA model would require the most input data by the user because of its conventional engineering approach. The RCA PRICE model would require the least amount of data to obtain a reasonable estimate, provided it was calibrated initially.

Table 3.34 shows the representative input data required to estimate the construction cost of a lead ship. The categories listed in this table are the general cost driver categories in Table 1.5 and were used previously to group the cost parameters associated with each model.

Weight cost drivers in Table 3.34 are in the form of the 1-digit level SWBS groups and the margin weights. Cost influences from the appropriate levels of technology apply to manufacturing, materials, propulsion, electric power generation and electronics. Expensive combat systems related components enter through shopping lists. Scheduling effects are affected through the interaction of length of construction and the rate of inflation.

Other parameters reflect the shipyard labor and material costs or provide a base date for technology effects and monetary conversions.

TECHNOLOGY

Ship type (i.e., SWATH, Hydrofoil, etc.)
Hull & Superstructure material
Propulsion plant type
Electrical plant type
Year of technology

SHIP DESIGN

Hull structure weight (SWBS group 100)
Propulsion plant horsepower
Propulsion plant weight (SWBS group 200)
Electric plant weight (SWBS group 300)
Command & Surveillance systems weight (SWBS group 400)
Auxiliary systems weight (SWBS group 500)
Outfit & Furnishing weight (SWBS group 600)
Armament weight (SWBS group 700)
Margin weights

PAYLOAD DESIGN

Cost of payload material
(includes armament & weapons portion of com. & surv.)

MANUFACTURING

Labor rate
Production technology

PROGRAMMATIC

Profit fraction
Overhead fraction
Construction start date
Delivery date

ECONOMICS

Inflation rates
Base year $
BLS material indices
Base year for BLS data

Representative Lead Ship Construction Cost Parmeters

Table 3.34

Table 3.35 shows the additional data required to estimate construction costs for a multi-ship procurement. Primary inputted data include a labor and material cost breakdown for the lead ship, inflation rates, and profit and overhead fractions.

Major influences on multi-ship construction costs result from the relationships between learning, scheduling and inflation. Drawn out scheduling can substantially increase costs due to inflation. Multiple production lots increase costs due to a reduction in production learning effects.

Increased costs due to uneconomical scheduling or unforeseen inflation can easily result in a decrease in the number of ships that can be produced if there is only a fixed amount of money to be spent.

Inputted Data

Lead ship construction costs
Inflation rates
Profit fraction
Overhead fraction
Base year $

MANUFACTURING

Learning rate
(material and labor)

PROGRAMMATIC

Number of ship required
Construction start dates
Delivery dates

Representative Multi-Ship Construction Cost Parmeters

Table 3.35

LCCs discussed in this study deal mainly with acquisition and operations & support (O&S) costs. Acquisition costs are equal to the construction price plus various program and G&A add-on costs. These add-on costs are generally estimated as a percentage of the construction price. Typically, the total program cost is 30-40% above the construction price.

O&S costs include contributions from the areas of personnel, operations, maintenance, fuel and spares. Personnel costs are related to salaries, benefits and training. Operations determine the time the ship will be underway. Maintenance, fuel and equipment spares costs are self-explanatory. Table 3.36 indicates the additional information required to estimate LCCs. Inputted data consists of total ship acquisition (i.e., program) costs and the necessary economic data.

Research & development plus testing & evaluation costs are incurred to enable the introduction of high technology systems into the ship design. The additional facilities costs relate to the construction or refurbishment of maintenance or docking facilities.

The ship's residual value refers to the scrap value of the vessel at the end of its service life. The service life is generally in the range of 25-30 years.

Inputted Data

Total ship acquisition costs
Ship delivery dates
Inflation rates
Interest rates
Base year $

SHIP DESIGN

Ship fuel rate
Crew accommodations

PAYLOAD DESIGN

Payload fuel rate

PROGRAMMATIC

R & D, T & E costs

OPERATIONS AND SUPPORT

Annual cost of training ordnance.
Equipment spares
Additional facilities costs
Salaries, benefits and training
Annual operating hours
Ship residual value
Service life
Fuel cost/gal

Representative Life-Cycle Cost Parameters

Table 3.36

3.2.3.2 Cost Output Sensitivities

In this section, the sensitivity of the cost model outputs to variations in the input data are discussed. This is accomplished by examining marginal cost factors (i.e., the major subsystem cost drivers) and total acquisition (program) cost sensitivities.

There is no quantitative comparison between cost sensitivities of the different models reviewed in this study. To have done this would have required a detailed comparison of model outputs for various ship types. Unfortunately this was not feasible given that these results would have been considered of a proprietary nature.

3.2.3.2.1 Marginal Cost Factors

Marginal cost factors provide a convenient method to determine the effect of subsystem changes to ship costs (e.g., see Ref. 5, 13 and 35). The marginal cost is the change (in cost) associated with a unit change of weight of a particular system. For this study, the subsystems are identified by their 1-digit SWBS designation.

In terms of this breakdown, cost analysts have typically found that the four (4) SWBS groups with the greatest cost leverage are;

(1) combat systems & related electronics

(2) electric generation and distribution

(3) propulsion systems

(4) auxiliary machinery

This list is representative of the naval surface combatants subsystem cost percentage breakdowns noted in Ref. 36. The electrics and propulsion systems may be interchanged depending upon the systems chosen for each. Table 3.37 lists the cost/weight sensitivities calculated for the DDG 51 navy surface combatant. Note that the factors for combat systems and command & control groups do not include the cost of equipment.

SWBS Group		Marginal Cost* Factor ($/LT)
100	Structure	17,500
200	Propulsion	110,800
300	Electrics	180,200
400	Command	46,300**
500	Auxiliary	80,800
600	Outfit	78,500
700	Armament	16,000**

* costs in FY 83 $

** shipyard installation costs only, equipment procured separately

Naval Surface Combatant Marginal Cost Factors
(Ref. 5)

Table 3.37

Personnel in the costing and design systems office at DTNSRDC indicated that the cost/weight sensitivities for the ASSET and RCA PRICE models were similar.

3.2.3.2.2 Program Cost Factors

Program cost sensitivities examine the additional program cost contributions resulting from a one dollar reduction or addition in loaded labor (i.e., direct plus overhead) and material costs.

Table 3.38 shows that effect of the dollar increase in loaded labor during construction on subsequent elements of cost using NAVSEA format. A dollar change in labor results in a program cost change of $2.73. This example provides a direct illustration of the importance of add-on costs to ship costing.

Table 3.39 shows a similar effect for a material cost increase. The smaller program cost is primarily the result of lower dollar percentages for engineering and construction services material.

3.2.3.3 Cost Output Accuracy

This section is an attempt to provide a quantitative measure of the accuracy that a user can expect with the cost models presented, and a qualitative measure of cost estimating accuracy in general.

The personnel using the five models in this study were contacted and asked to provide a representative percentage error figure that would given an indication of the uncertainty of a point estimate. For example, the value of the estimate is $X + or - 10%. Some interesting points were brought up.

Element		Cost Factor	
No.	Description	Calculation	$ Amount
1	SWBS 100-700	-	1.00
2	Margins	12.5% (1)	.125
3	SWBS 800	30% (1 + 2)	.396
4	SWBS 900	27% (1 + 2) LR*	.304
5	SWBS 100-900	1 + 2 + 3 + 4	1.825
6	Profit	10% (5)	.183
7	FCM	5% (5) OV**	.044
8	BCC	5 + 6 + 7	2.052
9	Change Orders	10% (8)	.205
10	Escalation	20% (5)	.365
11	PM Growth	5% (8 + 9)	.113
12	Program Cost	8 + 9 + 10 + 11	2.735

* LR = engineering/manufacturing labor rate ratio
** OV = engineering direct/burdened labor rate ratio

Labor/Program Cost Sensitivity

Table 3.38

Element		Cost Factor	
No.	Description	Calculation	$ Amount
1	SWBS 100-700	-	1.00
2	Margins	12.5% (1)	.125
3	SWBS 800	1% (1 + 2)	.011
4	SWBS 900	4% (1 + 2)	.045
5	SWBS 100-900	1 + 2 + 3 + 4	1.181
6	Profit	10% (5)	.118
7	FCM	-	-
8	BCC	5 + 6	1.299
9	Change Orders	10% (8)	.129
10	Escalation	20% (5)	.236
11	PM Growth	5% (8 + 9)	.072
12	Program Cost	8 + 9 + 10 + 11	1.737

Material/Program Cost Sensitivity

Table 3.39

First of all, each person contacted was more than a little hesitant to give a representative figure. If nothing else, this demonstrates the uncertainty that pervades cost analysis. Figures that were given were typically in the range of plus or minus 15-25% for estimates during the conceptual phase and 7-15% at the end of preliminary design.

Such a percentage figure is strictly applicable only if there is no uncertainty involved. For instance, if a single cost estimate is compared to the return costs for that vessel, the percentage error would completely define the accuracy of the estimate. However, if the figure is given as a general measure of the accuracy, then in order for it to be statistically meaningful, it requires an indication of the analyst's confidence that any given estimate will fall within the specified range. This point is illustrated in Section 2.3.1.

Percentage error differences for cost estimates versus return cost data vary significantly. Differences can be expected to decrease as input data becomes more accurate. Although more accuracy is usually accompanied by greater detail, greater detail is not a necessary requirement for accuracy. Ref. 26 shows similar percentage errors for ACV cost estimates versus return costs for input data ranging in detail from whole ship down to the 3-digit SWBS level.

Current point estimate errors for the ASSET model were indicated to be double those of the other cost models. Two reasons were given for this; (1) the KN technology factors were uncertain to within 20% of their values due to the 15 year old database from which they were derived, and; (2) the model was initially intended for comparative studies.

The relative cost percentage errors for the ASSET model can be expected to be significantly lower than those of the point estimates. This statement is true for any comparative study, since only selected baseline characteristics are perturbated to create the variant. Because of this strong correlation between the baseline and variant, there is less overall cost uncertainty (i.e., a smaller variance) and therefore reduced errors.

It is important to note that in cost estimating, there is not a lot of confidence associated with any one estimate. Although this can easily be shown to be statistically true (e.g., see Section 2.3.1), it can also be seen at a more practical level.

For any request for bids, there will be a wide variation in the bids received, each reflecting the particular needs and characteristics of the yard at the time. Because each of these bids can be rationalized in relation to the yard submitting it, the bid is "accurate" for the assumptions and data used (provided that there are no blatant errors).

The preceding discussion indicates that a comparison of the accuracy or correctness of any cost methodology with another requires a detailed examination of the assumptions used in the development of the model. These assumptions will impact the areas related to standards, management and scheduling, to name but a few.

CHAPTER 4

DEVELOPING A SHIP COST ESTIMATING CAPABILITY

The increased emphasis on the economic feasibility of ship design (e.g., see Ref. 52), requires a greater involvement and visibility from the cost estimating community. However, any costing capability must be developed to operate within the constraints dictated by the perceived needs and resources of the organization. Even throughout the conceptual/preliminary design phase, these needs can vary from cost comparisons for feasibility trade-off studies through to budgetary estimates for specific ship designs. Table 4.1 lists a wide variety of functions that require a costing capability. Fig. 4.1 groups these functions according to their applicability within the ship design process.

Because most organizations are continually evolving, their priorities may also experience changes. It is important to realize that a priority shift can affect costing requirements. Therefore, cost estimating capabilities should be periodically re-evaluated in view of current management direction.

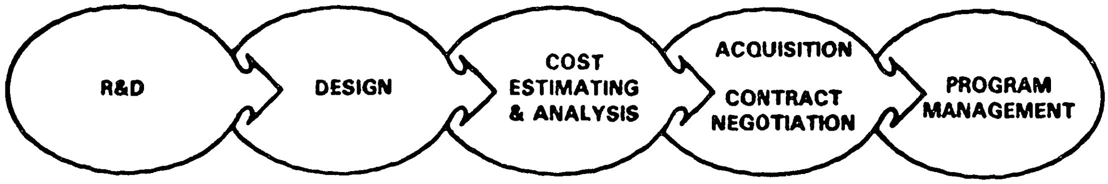
In addition to fulfilling these needs, there must be an associated quantifiable accuracy and the estimate must be available within a specified timeframe. Estimates for trade-off studies require relative accuracy between comparative designs. Budgetary estimates on the other hand, must be accurate in an absolute sense. Accuracies in the range of 10-20% are usually indicated for estimates in the early stages of design.

The obvious time for an estimate to be available is whenever a decision point is reached in the design process. During the conceptual/preliminary design phase, this requirement generally translates into immediate availability. This rapid turnaround has led to the development of cost estimating models which will interface with the output from design synthesis models.

Design-To-Cost
Source Selection
Proposal Review
Trade-Off Studies
Budgeting
Contract Cost Control
Technology Impact
Specification/Standards Impact
Economics Effects
Scheduling Effects
Bid - No Bid Decisions
Contract Negotiations

Organizational Cost Estimating Functions
(Ref. 58)

Table 4.1



R&D
- COST IMPACT
- ADV. VEHICLE DATA BASE
- R&D PROGRAMS FOR COST REDUCTION
- ESTIMATE RELATIVE COST

DESIGN
- COST DRIVERS
- COST AS A DESIGN PARAMETER
- ABILITY TO ESTIMATE RELATIVE COST CHANGE AS DESIGN ADVANCES

COST ESTIMATING & ANALYSIS
- COST STANDARDS
- IMPROVED COST ESTIMATING TOOLS
- IMPROVED METHODS TO ESTIMATE NON-HARDWARE COSTS
- IMPROVED COST DATA BANK
- HIGH QUALITY COST ESTIMATES

ACQUISITION / CONTRACT NEGOTIATION
- COST TRADEOFF ANALYSIS
- COST IMPACT OF ACQUISITION POLICIES
- INCREASED COST DETAILS
- EFFECTIVE COST ESTIMATING PARTICIPATION
- INDEPENDENT COST ESTIMATE
- ANALYZE CONTRACTOR COST ESTIMATE

PROGRAM MANAGEMENT
- COST IMPACT OF CHANGES, DELAY, DISRUPTION, ETC.
- ABILITY TO ADJUDICATE COST CHANGES
- AWARENESS OF COST DRIVERS

Cost Estimating Functions for the Ship Design Process
(Ref. 59)

Figure 4.1

4.1 COST MODEL DEVELOPMENT

This section deals with some of the factors to be considered for developing a parametric cost estimating model (of which CERs are assumed to be a subset). The primary motivations for using parametrics are to reduce the costs of estimating, and to provide consistent, repeatable results. Although parametrics are primarily used as an independent check for contract proposals, there is increasing interest in using them for contract pricing (e.g., see Ref. 57). A list of criteria for meeting this objective is given in Table 4.2.

Cost-to-Noncost Estimating Relationships
Must Be Logical

Data Used For CERs Must Be Verifiable

A Significant Statistical Relationship
Must Exist Between The Variables

CERs Must Predict Well

Parametric Estimating Systems Have To Be
Easy to Monitor

Compliance To The Previous Criteria
Must Be Verifiable

Criteria for Parametric Contract Pricing
(Ref. 57)

Table 4.2

The first criteria in Table 4.2 has been discussed in Chapter 2. Data verification will ensure that the estimates are within the database's range of applicability and that the database is kept current. In order to predict well, the model must be sensitive to a multitude of factors, including technology improvements, design and manufacturing complexities, scheduling, programmatic considerations and the "ilities" (maintainability, reliability, etc.). Ease of monitoring indicates that the CERs should be able to be easily updated and calibrated. The last criteria requires that documentation sufficient to verify the previous requirements accompanies the estimate.

Although most models are based upon similar non-cost versus cost relationships (e.g, weight versus construction cost), the particular model chosen is largely dependent upon the interests and experience of the organization and should reflect the requirements of its customers. For example, the labor/material format requirement for budget submissions makes the engineering costing method the only practical approach for NAVSEA (e.g., see Section 3.1.1). Cost models not only reflect the needs of the particular group, but also the resources that were available to the group during the model development.

Before a parametric estimating system is developed, some form of cost/benefit analysis should be performed. The prospective costs of a new system can then be weighed against the benefits of potential savings in estimating effort and/or increased estimating accuracy.

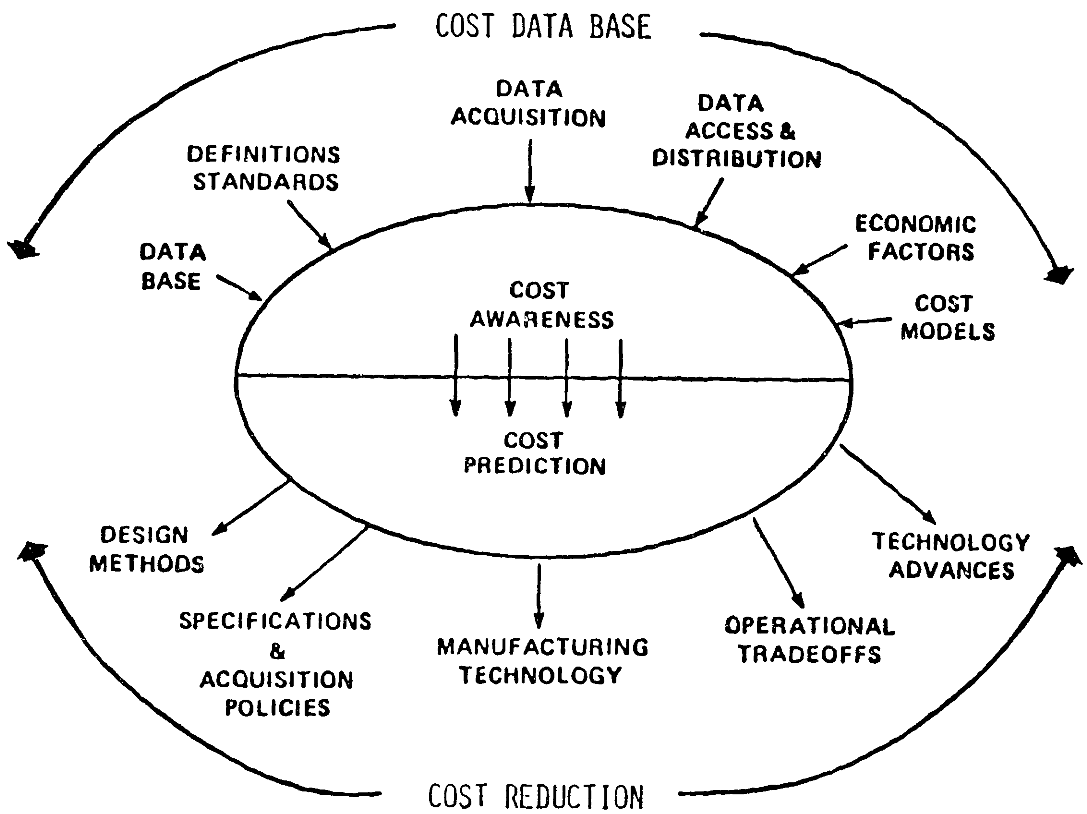
Most parametric models require essentially the same input data (e.g., see Section 3.2), although they may weigh these parameters differently within the algorithms of the model. Also, since these models are trend indicators, they tend to reflect the projects in the database.

4.1.1 Data Gathering

The most difficult part of cost estimation in early program phases is that of finding the proper mix of cost model and model input data. The model should require inputs based on the properties of the system that are well defined and can be established with a reasonable degree of certainty at the time the estimate is required (e.g., SWBS 1-digit weights during feasibility studies).

Data gathering is just one of the factors that must be considered for the development of the cost database. Fig. 4.2 indicates six factors, including data acquisition, that determine the characteristics of the cost database. Data access considerations are important for information of a proprietary nature. Cost definitions and standards (e.g., sailaway costs, mil specs, etc.) specify the format in which the cost data will be found. The economic factors and definitions allow for consistency in the cost reported (e.g., see Section 1.5.1). The size and level of detail of the available database greatly influences the choice of costing technique.

If there is an abundance of data for a particular system, then it becomes much easier to develop accurate and representative cost estimating relationships. Whether these CERs are developed within the organization or by outside agencies is



Factors Affecting the Cost Database and Cost Predictions
(Ref. 60)

Figure 4.2

dependent on the monies and personnel available to the organization. The cost models at NAVSEA Code 017 and the USCG are examples of internally (i.e. in-house) developed CERs.

When the cost data resides with other companies, it is undoubtably proprietary and therefore not easily obtainable. Due to limited resources, NCA contracted the naval architecture firm of Gibbs & Cox to develop a cost model using an outside proprietary data source. Gibbs & Cox in turn subcontracted BIW shipyard to supply cost information, which it was unwilling to supply of its own volition.

When there is little data available for the design, such as for advanced technology applications, it becomes difficult to estimate costs. The extrapolation of existing CERs can lead to erroneous results. Models that have been developed to account for all ranges of technology include the RCA PRICE and FAST-E models.

Fig. 4.2 also illustrates that a cost database can create a level of cost awareness sufficient to allow analysts to determine the cost impacts from changes in design methods and specifications, technology and operational capabilities.

Data can be collected from individuals or from existing cost data (e.g., shipyard data). In either case, data gathering can be broken down into three steps;

(1) find the right experts or cost data files

(2) ask the right questions or retrieve necessary data

(3) transform the responses or data into data compatible with the model input data

The processing involved in retrieving cost data from individuals is illustrated in Fig. 4.3. The data collected may be biased by the respondent's perception of the event in question; it may be irretrievable based upon the respondent's understanding of the question, or; it may even be forgotten.

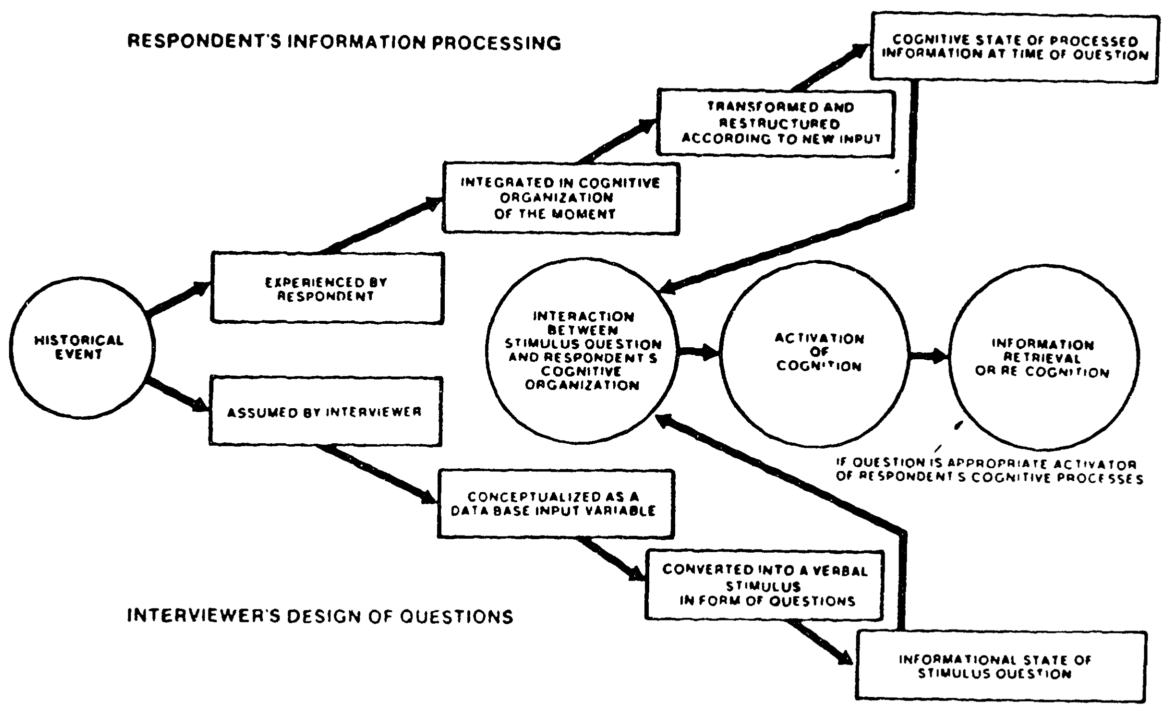
Once access to cost data files is available, the main problem with existing data is the conversion of the data. Much of the effort in developing the NCA cost model involved the transformation of shipyard cost data into SWBS compatible groupings (see Ref. 23).

The most important consideration for the maintenance of an historical database is to have a process to comprehensively and consistently collect data. If personnel other than cost analysts are required to document return costs, it is imperative that the forms used be simple and short. Also, repeated personal contact provides continuing reminders and gets the job done!

4.1.1.1 Establishing User Needs

Information on user needs can be divided into costing methodologies (i.e., CER, Parametric) and model features that are important to the analyst. Table 4.3 provides a partial listing of some of these desirable features. Since each analyst will have his own ranking for this list, a cost model can be developed which is cognizant of those priorities.

In order to establish the cost estimating and modeling requirements within the USCG, a questionnaire was distributed throughout various departments at HQ in Washington, D.C. The



Behavioural Information Processing Model
(Ref. 19)

Figure 4.3

Input Data Availability
Is the input data required by the model available during the conceptual/feasibility design phase?

Design Evaluation Capability
Does the model consider factors appropriate for design trade-off studies?

Ease of Use
Is the model easy to use with minimal training?

Ease of Calibration
Can the model be calibrated to the stated situation with available data?

Data Base Validity
Is the model database relevant to and valid for the situation addressed?

Currentness
Is the model based on current information which reflects the latest technology?

Accessibility
Is the model easy to access at a low cost?

Range of Applicability
Is the model applicable to a wide variety of programs?

Ease of Modification
Can the model be easily modified to incorporate new data?

Cost Model User Features
(Ref. 19)

Table 4.3

survey, found in Appendix C, addresses all of the features in Table 4.3, as well as asking for specific costing requirements. The intent of the survey was to develop an awareness of the different costing requirements thoughout the CG, so that any recommended cost model selection or selections would be responsive to these needs.

Unfortunately, of the twenty surveys distributed at USCG HQ, only one was returned, making it impossible to obtain a representative sampling of the costing requirements. There is only one reason that the information was not available for this study, and that was the lack of personal follow-up after the questionnaires were distributed. A more effective procedure would have been to meet personally on a one-on-one basis and let them answer the survey questions orally. In this manner, they would not have been intimidated by a lengthy survey, a minimum amount of their time would be lost, and any misunderstandings arising could be settled immediately.

4.1.2 Resource Requirements

Personnel and monetary resources are closely related through the costs of salaries and training. Most organizations generally have several individuals who have been associated with cost estimating for several years. Two people should be regarded as a minimum number. A constant nucleus of people provides a stable pool of knowledge and experience, which tends to increase the analysts' (and management's) confidence in their ability, and ensures that new staff members receive extensive formal and on-the-job training.

Monetary resources are not only required for the front-end costs associated with the development of a viable cost model (e.g., software, equipment purchases, manuals, training), but also with recurring operations and support costs (e.g., salaries, training, model updates, equipment repair). Model updates can result from programmatic changes and/or CER changes due to the effects of new materials and fabrication processes (e.g., robotics, zone-outfitting, etc.).

4.1.3 Organizational Considerations

For cost estimating to function properly, the organization must be (a) committed to maintaining the capability, and (b) responsive to the results. As part of its commitment, the organization must allow the costing group to communicate within the organization as the need arises.

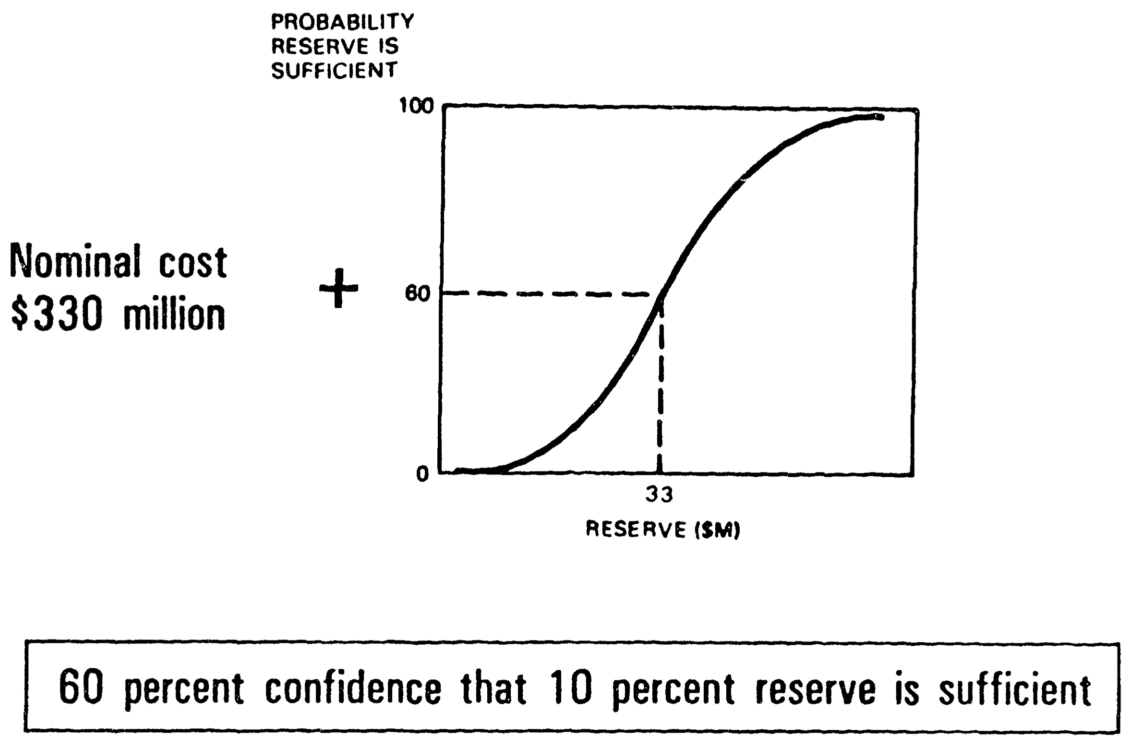
Effective communication can overcome 90% of the problems encountered for both information gathering and analysis reporting. The presentation of estimating results (i.e., text, graphics, tables) can greatly affect the receptivity of management. For example, financial spreadsheet programs are becoming popular because results can be obtained and displayed immediately as inputs are changed. Thus, programs similar to the USCG CASHWHARS (see Ref. 34) give management fast feedback for program trade-offs.

Historically, costs have been presented as a point value, although risk analysis, with its range of costs and associated probabilities (see Section 2.3), defines costs in a more intuitively (and statistically) correct manner. Fig. 4.4 illustrates how costs can be presented combining management's desire for "a" cost figure with risk analysis. Such presentations can overcome management bias and resistance and still provide all the necessary data for decision-making.

Management can show its commitment to sustaining a cost estimating capability in several ways. Primarily, the cost team must be included in the early stages of design, where costing has maximal impact on design. Early planning of cost resources reduces financial uncertainty in the project. As the design progresses, cost analysts must be allowed to interact on a real-time basis with design engineers to establish relationships between costs and design engineering. This will allow the cost impacts of design changes to be known quickly.

If the need for a cost estimating team has been established, management must support the development of a time-phased plan to make it a viable, independent group. This involves prioritizing activities for database and model development, training and support (e.g., see Ref. 58).

To gain management's confidence, the cost team must be able to demonstrate repeatably that the estimates produced are reliable. Because this can only be done using actual return data, the rate that management trust is built-up is highly dependent upon the product cycle. For a very short cycle, this process may take only a few months. For shipbuilding in the USCG, the product cycle is several years, and so many of the current decision makers have yet to go through a ship acquisition program in their present billets.



Point Estimate with Cost Reserve Probability
(Ref. 19)

Figure 4.4

4.2 COST MODEL SELECTION

The approach to selecting a cost model can be divided into four basic steps:

(1) determining needs

(2) selecting candidate models

(3) choosing the best model(s)

(4) reconsidering the choice

The previous sections in this chapter have discussed some of the needs that may require the development of a cost estimating capability and several existing models have been discussed in Chapter 3. The choice of the best model(s) should consider both qualitative (see Table 4.3) and quantitative (i.e., accuracy) considerations.

Most models can support a cost estimating activity if the limitations of the models are understood, they are used consistently, and are calibrated for the particular organization. From the limited information available on the accuracy of the various costing techniques discussed in Chapter 3, there is no evidence to suggest that the existing USCG cost estimating model is not appropriate for new ship costing in the CG. However, it is generally recommended (e.g., see Ref. 19), that more than one model be utilized: one as the primary estimating resource and the other(s) for comparison and validation of primary outputs (i.e., an independent reasonableness check).

CER and model development can be done in-house, contracted to an outside source, or purchased on a time-sharing basis. Due to the front-end resource requirements for in-house and outside source development, time-sharing models are becoming increasingly attractive, particularly as back-up models.

The RCA PRICE parametric cost model is the most commonly used model in the time-sharing category. It is primarily used as a back-up model for validating bottoms-up cost estimates (i.e., the NAVSEA Code 017 model) and generating internal cost targets (Ref. 19). The attractive features of this model (see Section 3.1.5) include its ability to analyze systems at any level of detail, it is easily calibrated, and has unlimited system applicability. However, as with any costing technique, its accuracy is dependent upon the quality and quantity of input data available.

At the present time, the current USCG cost model (see Section 3.1.4), combined with the RCA PRICE parametric model as a back-up seems appropriate for ship estimating in the CG. However, as suggested in the four steps above, any model choice should be reconsidered periodically due to changes in projects being analyzed, organizational structure, database, personnel and experience.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

This study discusses some of the technical and managerial considerations that must be examined before a cost estimating capability can be established within any organization. The cost estimating techniques are applicable to new ship construction during the feasibility phase of ship design. The techniques can overlap with the costing requirements for the conceptual/exploratory, as well as preliminary phases.

The translation of a mission profile into the final ship design necessitates a ship optimization process. Synthesis models are one method used to provide the alternative designs required to produce this optimization. Any method generally has the following common elements;

(1) selection of criteria, or measures of merit, that will indicate which alternative ship design is the optimum

(2) development of CERs

(3) construction of LCC models

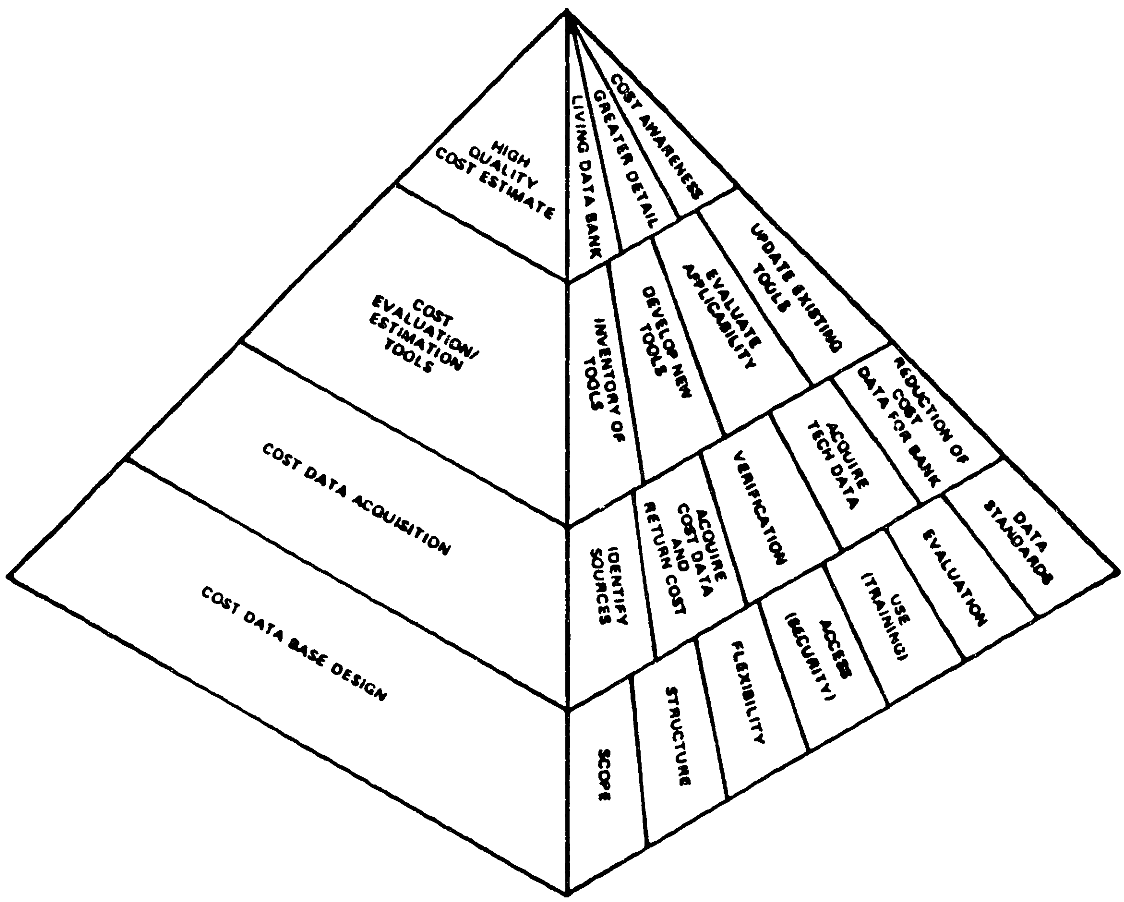
Measures of merit can be rated according to military effectiveness, LCCs, or techical design characteristics. The CERs require the determination of ship design, construction and/or operational factors which have an effect on costs. LCCs are the total ship costs from inception to retirement and are assumed to occur in three distinct phases; R&D, investment or acquisition and O&S. This study is primarily concerned with so-called initial investment costs associated with the delivery of the vessel to the owner. These include material, labor, overhead and profit for hull, outfit, machinery and auxiliary procurement and fabrication. Economic and production learning effects can have significant cost impacts on final vessel costs.

The need for early design definition for new ships has put increased demands for greater costing accuracy at lower levels of design detail. The accuracy of any estimate is dependent upon the skill of the analyst, the quality and quantity of data available and the time available to make the estimate. Results seem to be independent of the costing technique used.

Fig. 5.1 illustrates the development of high quality cost estimating as being supported by a pyramid structure. The cost database design and acquisition defines the foundation for any costing effort. Cost models provide the means necessary to transform historical cost trends into current or projected estimates. Several criteria may be selected to determine the applicability of a cost model for any organization.

The single most important factor that determines the skill of the analyst is experience. Experience can be defined as the knowledge (skill) gained from a period of activity that includes training, observation of practice, and personal participation. The key ingredient of experience is allowing the time necessary to gain knowledge.

Organizations can assist analysts in gaining this experience by ensuring continuity. This means supporting long-term planning which includes hiring full-time cost analysts, providing lead-in



Cost Estimating Building Blocks
(Ref. 60)

Figure 5.1

training for new personnel, additional training as required, documentation of costing techniques and allowing access to necessary documentation within the organization.

Even a skilled cost analyst requires an extensive database from which to base estimates. Any costing group requires the ability to: collect data; validate it; incorporate it into their database, and; re-calibrate the CERs to reflect the trends established by the additional information. The more good data available, the more accurate the estimate will be. On the other hand, if large departures are made from any sized database, errors will increase substantially.

The problem involved with data collection is the proprietary nature of the majority of the information. Of course, this is particularly true for obtaining data from agencies outside of your own. If outside data is required, it typically must be paid for.

Within any organization, the problem of data gathering typically reduces to inadequate communications. Return costs must be sent to the costing group, and in a form that is useful to them (e.g., in SWBS format). Generally, personal interviews are the best way to get information from individuals, since surveys and cost data forms may be intimidating in their length and/or content or they can be easily "buried".

Cost models used during feasibility studies are characterized by their rapid turn around time and limited technical design data requirements. The five models for estimating new ship construction costs that were examined displayed important commonalities in two areas: SWBS weight group non-cost parameters for calculating costs, and incorporating the influence of different technologies on costs. It is important to realize that all estimates, regardless of the technique used to calculate them, are extrapolations from experience.

Different cost estimates cannot be regarded as right or wrong, since any differences can be rationalized from the point of view of the various model assumptions (e.g., design and manufacturing standards). All of the models examined can be expected to give feasibility cost estimates to within 10-20% of return costs. However, figures as high as 40% have been suggested (e.g., see Ref. 2).

An important consideration for the adoption of a commercially available parametric cost model is the commonality associated with its structure, language and approach. Disadvantages include the proprietary nature of these models and the difficulty of getting management confidence in their outputs. The RCA PRICE model appears to have the most flexibility, in terms of its ability to estimate costs at any level of detail with a minimum of required data.

Combat systems, electronics and machinery were found to have the highest cost leverage for construction costs. These costs are also very dependent upon the standards to which a particular ship is designed and fabricated. Possibly the biggest controllable cost factor in any ship acquisition program is scheduling. Costs increase dramatically for multi-lot versus single batch productions. In addition, production learning is influenced by ship quantities and time between construction starts.

There are a number of assumptions made in any cost estimate: various economic, managerial, scheduling, and technical ones being the more obvious. The purpose of risk analysis is to quantify these effects to produce a range of possible costs, as opposed to the more traditional point or most likely estimate. Programmatic and schedule effects appear to have the largest cost uncertainty (i.e., risk). In the final analysis, models don't estimate costs, people do, and so there is a highly variable uncertainty associated with the cost analyst.

For a cost estimating group to be able to provide guidance for management decisions, the organization within which it operates must be: committed to maintaining its expertise; responsive to its results, and; allow the group to operate within the organization as the need arises (e.g., receiving return cost data).

The primary benefits of developing a credible and explainable cost estimating capability during the feasibility design phase are that it shows the: lost causes that need to be discarded; the winners that must be pursed more vigorously, and; the marginal cases requiring more careful examination.

5.2 RECOMMENDATIONS

This study has examined a variety of cost models intended for use during the feasibility phase of ship design and some of the factors that must be considered to incorporate any costing technique into an organizational structure. The recommendations found here address issues of both a technical and managerial nature.

5.2.1 General Recommendations

The majority of this study deals with the documentation of cost models now in use for new ship costing. It would be most instructive to investigate the sensitivities and accuracies of these models in a more systematic and quantitative manner. The primary difficulty with an exercise of this type would be dealing with any proprietary model inputs and outputs.

This study discussed the effects of scheduling, inflation, input uncertainty, technology, plus a variety of other issues in a rather general sense. A more exhausive and again, quantitative examination of any of the topics mentioned within would be enlightening to the cost estimating community.

Weight is a primary cost driver for the majority of CERs. For the models considered here, SWBS weight groups are defined as cost elements with similar trends. However, the effect of new fabricating techniques (i.e., zone outfitting and other producibility methods) on CER development and even on the applicability of SWBS cost elements has yet to be evaluated. Current shipyard accounting practises generally do not use SWBS. Perhaps a better procedure for grouping cost elements can be found.

Only cost estimating procedures used in the USN and the USCG were discussed here. It may prove extremely useful to look at how other Navies and Coast Guard equivalents have incorporated a cost estimating capability into their ship acquisition programs. The difficulty with this suggestion would be the high travel expenses, since only by personal contact would any useful information be passed along. Typically, this contact would have to occur 3 or 4 times over a 4-6 month period to be effective for establishing a satisfactory working relationship between the persons involved.

Because of the amount of information collected from various sources and the number of individuals that were contacted in regards to this work, it represents a "first cut" at establishing some degree of cooperation within the cost estimating community. Perhaps more work in this area could establish some sort of dialogue between estimators for selected topics. A good step towards developing a dialogue is to participate in professional organizations working in related areas of interest.

Typically, a cost analysis requires inputs from economists, engineers, managers, accountants, plus other estimators. It is important that analysts learn to communicate with these individuals on a personal basis. Developing people skills will go a long way to enabling a cost analyst to obtain necessary or desired information and establishing credibility through properly prepared presentations (e.g., the use of graphics to explain and examine trends) and discussions.

It is important that neither the cost analyst nor management regard cost estimating as a separate function. Costing must be thought of in a systems integration approach, since cost estimators interface with all the functional-type areas mentioned above and operate within the framework defined by the needs and resources of their organization.

5.2.2 US Coast Guard Recommendations

The cost survey (see Appendix C) distributed throughout USCG HQ was not successful in determining the cost estimating needs within the Coast Guard. A similar survey should be carried out on a personal interview basis before any further work in this area is carried out.

USCG cost estimating operates in the Ship Building Branch of the Office of Engineering. The limited size of this cost estimating group (i.e., one individual), presents several long-term problems, some of which are addressed below.

Experience is an essential element of any cost estimating capability and continuity is the method by which experience can be maintained. With only one individual involved in cost estimating, continuity within this area for the CG is impossible. The only solution to this problem is the addition of personnel. The actual number can only be determined by the future needs and projected resources for cost estimating.

Augmenting the cost estimating group with additional personnel requires the development of a training program. To this end, it is recommended that the existing CG costing methodology be documented, perhaps in a similar manner to that found in the NAVSEA Cost Estimating Manual (see Ref. 16).

The CERs used for costing in the CG are based on a limited database for a wide variety of vessel types. Currently within the CG, the CPM (Critical Path Method) Network program requires contractors to supply material and labor cost data broken down by SWBS weight groups. This program should undoubtably be continued. However, it would be extremely useful for funding to be made available for various projects to expand and improve the database.

Improvements could include a detailed shopping list for major functional components and high cost equipments such as electronics, which can be non-weight related. There could also be a formal tracking of CG operating and support costs similar to the VAMOSC system employed by the USN (see Ref. 21). Since general and administrative (G&A) and shipyard support costs can make up a substantial part of the acquistion costs, it would be advantageous that they be more accurately known.

Feasibility studies have proven useful for CG vessel applications (e.g., see Ref. 27). The USCG cost estimating model should be capable of interfacing with a variety of synthesis models: the USN's ASSET (Ref. 15), Goodwin's Cutter model (Ref. 7) and Tuttle's Patrol Boat model (Ref. 8). In addition, the cost model outputs should be available for life cycle costing calculations using the CG developed CASHWHARS spreadsheet (see Ref. 34).

Cost estimates gain credibility and consistency if there exists a capability of cross-checking them using an independent method. The recommendation in this area is for the simultaneous development of another cost model. The RCA PRICE model is used in many organizations as a means to provide analysts and managers with a reasonableness check on cost estimates. In fact, Ref. 27 uses the RCA PRICE model to investigate the cost of several USCG patrol boat concepts. Also, for an increased emphasis on quantifying the cost impacts of various design and technical innovations, the RCA PRICE model may prove valuable (Ref. 46).

Ideally, CG cost estimating would operate in the following fashion: (1) the CG cost model would be run to get first pass results (including G&A and shipyard support functions); (2) the RCA PRICE model would be run simultaneously to obtain a cross-check (the differences should be easily explainable with a knowledge of each model); (3) the contractor would have a cost expenditure program to enter the shipyard costs, and; (4) return costs from the shipyard would be tracked to obtain a history of the expenditures and to re-calibrate or validate the cost models. This constant feedback is necessary to ensure that costing becomes an integral part of the team managing any ship construction project.

REFERENCES

1. Reeves, J.M.L., D.D. Findley and M.A. Logue, 1980. ASSET Theory Manual - Cost Analysis Module. David Taylor Naval Ship Research & Development Center, Technical Director's Technology Application Team, Technical Contribution No. 4, 111 pp.

2. Carstensen, R.V., 1975. Cost Considerations for Electrical/ Electronic System Installation Design. Marine Technology, 12, 378-389.

3. Anon., 1986. Building Canadian Patrol Frigates, Marine Engineering/Log, 91(4), 33-40.

4. Anon., 1986. A New Approach to Warship Design, Marine Engineering/Log, 91(4), 52-59.

5. Hope, J.P. and Stortz, V.E., 1985. Warships and Cost Constraints. Naval Sea Systems Command. 26 pp.

6. Mills, J., Feasibility Studies and Ship Synthesis Models. Lectures 7,8,9. Unpublished lecture notes, Professional Summer at Massachusetts Institute of Technology. Cambridge, MA, 112 pp.

7. Goodwin, M.J., 1975. Ship Synthesis Model for Coast Guard Cutters. Ocean Engineering Thesis, MIT, 278 pp.

8. Tuttle, J.G., 1981. Synthesis Model for Ocean Going Boats between 50 and 150 feet in Length. Ocean Engineering Thesis, 323 pp.

9. Maritime Administration (MARAD), 1986. Relative Cost of Shipbuilding, U.S. Department of Commerce, Washington D.C.

10. International Maritime Associates, 1977. A Study of Ship Acquisition Cost Estimating in the Naval Sea Systems Command. Washington D.C., NTIS AD-A046 978.

11. Shipbuilders Council of America, January 1986 Statistical Summary, Washington D.C., 20 pp.

12. Flanagan, D.B., 1969. A Cost Estimating Procedure Recommended for Coast Guard Cutters. Unpublished Report, Naval Engineering Division, Office of Engineering, US Coast Guard.

13. Turner, D.K., 1978. Marginal Cost Factors for High Performance Ships and their Impact on Subsystem Design. Ocean Engineering Thesis, MIT, 192 pp.

14. Brennan, A.J., J.D. Burroughs, D.H. Wacker, 1976. HANDE - A Tool for Integrating the Hydrofoil Preliminary Design Cycle, SNAME, Pacific Northwest Section, Salishan, Oregon.

15. Greenwood, R.W. and Fuller, A.L., 1986. Development of a Common Tool for Ship Design and Technology Evaluation. Presented at SNAME (New England) Symposium "Marine Computers '86", 17-18 April 1986, Boston, MA, 24 pp.

16. NAVSEA Ship Cost Estimating. A Reference Document for the Entry-Level Ship Cost Estimator. Naval Sea Systems Command, Washington, D.C., 30 September 1986.

17. Proceedings of The International Society of Parametric Analysts (ISPA), Fifth Annual Conference, St. Louis, Missouri, April 26-28, 1983. Vol. II, No. I, 502 pp.

18. Proceedings of The International Society of Parametric Analysts (ISPA), Sixth Annual Conference, San Francisco, California May 15-17, 1984. Vol. III, No. I, 751. pp.

19. Proceedings of The International Society of Parametric Analysts (ISPA), Eighth Annual Conference, Kansas City, Missouri, May 12-15, 1986. Vol. V, No. I, 607 pp.

20. PRICE Systems User's Reference Manual, RCA PRICE Systems.

21. Visibility and Management of Operating and Support Costs - Ships (VAMOSC - Ships), Total Support System Report, Fiscal year 1985, DD-I&L(A&AR)1422(SHIPS 5200), March, 1986.

22. Accelerating Utilization of New Materials. Prepared by The Committee on Accelerated Utilization of New Materials, National Materials Advisory Board, Division of Engineering - National Research Council. Publication NMAB - 283, National Academy of Sciences, Washington, D.C., May 1971.

23. Cost Model U.S. Naval Vessels (Destroyer-type) Final Report. Prepared for Office of Naval Research, Contract No. N00014-80-C-0950. Prepared by Gibbs & Cox, Inc., August 1981.

24. Shipbuilders Council of America, Statistical Quarterly, Third Quarter, 1980.

25. Salmon, C.L. and A.J. Locke. The Application of PRICE to Ships and other Large Structures. J. of Parametrics, Vol. II, No. 3, Winter 1982-83, pp. 11-17.

26. Jones, R.R., D.L. Mayo, and D.J. Clark. The Application of the RCA PRICE Hardware Parametric Cost Model to Air Cushion Vehicles, J. of Parametrics, Vol. 5, No. 2, June 1985, pp. 66-89.

27. Jeffers, M.F., and R.R. Jones. A Comparative Cost Analysis of a Hybrid Ship Concept for the Coast Guard WPB Mission. Ship Systems Integration Department, Departmental Report, DTNSRDC/SSID/87/DRAFT, January 1987.

28. Walsh, S.P., 1985. An Improved Method of Risk Analysis for the Naval Ship Design Process, Ocean Engineering Thesis, MIT, 88 pp.

29. Hutchison, B.L., 1985. Application of Probabilistic Methods to Engineering Estimates of Speed, Power, Weight, and Cost. Marine Technology, Vol. 22, No. 4, pp. 358-372.

30. Byington, J.A., 1985. The Estimating and Administration of Commercial Shipbuilding Contracts. Marine Technology, Vol. 22, No. 3, pp. 286-292.

31. Black, R.L. and J.J. Wilder, 1984. Determining Cost Uncertainty In Bottoms-up Estimating. J. of Parametrics, Vol. 4, No. 2, pp. 51-64.

32. Black, R.L. and J.J. Wilder, 1982. Probabilistic Cost Approximation When the Inputs are Dependent. J. of Parametrics, Vol. 2, No. 1, pp. 3-8.

33. McNichols, G.R. (editor), 1984. Cost Analysis. Operation Research Society of America, Arlington, Virginia, 332 pp.

34. Sappern, A.S., S. Kimbrough, C. Pritchett and T. Coe, 1986. CASHWHARS - Wharton Cash Flow Analysis Model, Version 0, 1 July 1986, USCG R&D Center, Avery Point, Groton, CT, 44 pp.

35. Moy, J., J. Vail and S. Williams, 1973. Marginal Cost Analysis of Major Ship Design Parameters for DG Shipborne System Trade-Off Studies. Prepared for Naval Ship Systems Command, PMS 305, Report No. 6112-74-3.

36. Judge, S.D., 1985. Minimizing Ship O&S Cost. SNAME Hampton Roads Section Paper, December 5, 1985.

37. Mauro, C.V., 1985. The FAST-E Cost Estimating Model. J. of Parametrics, Vol. 5, No. 1, 87-102.

38. Fetchko, J.A., 1968. Methods of Estimating Investment Costs of Ships, Department of Naval Architecture and Marine Engineering, University of Michigan, Ann Arbor, Michigan, June 1968, 201 pp.

39. Landsburg, A.C., 1982. Interactive Shipbuilding Cost Estimating and Other Cost Analysis Computer Applications. Presented at the IFIP/IFAC Conference "Computer Applications in the Automation of Shipyard Operation and Ship Design", US Naval Academy, Annapolis, MD, 7-10 June 1982.

40. Landsburg, A.C., A. Jenks, S. Lee and E.B. Schimler, 1986. Analysis of Japanese and Korean Shipbuilding Prices, SNAME Chesapeake Section, June 18, 1986.

41. Jenks, A. and J.E. Larner. A Tanker Owner's Perception of Newbuilding Costs and Prices in Japanese, North European, and United States Shipyards 1971 to 1981. Tanker Department, Exxon International Company, Florham Park, NJ.

42. Carreyette, J., 1978. Preliminary Ship Cost Estimation. Transactions of the Royal Institution of Naval Architects, Vol. 120, 235-246.

43. McNeal, J.K., 1969. A Method for Comparing Costs of Ships Due to Alternative Delivery Intervals and Multiple Quantities, SNAME Transactions, Vol. 77, 71-103.

44. Shafer, W.J.E., 1983. Cost Estimating Relationships for US Navy Ships. IDA Paper P-1732, Prepared for Office of the Under Secretary of Defense for Research and Engineering Special Assistant for Assessment.

45. Leopold, R., O.P. Jons and J.T. Drewry, 1974. Design-to-Cost of Naval Ships. SNAME Transactions, Vol. 82, 211-237.

46. Spaulding, K.B., 1984. The CONFORM Program - An Update, Naval Engineering Journal, Vol. 96, No. 3, 94-110.

47. Rawson, K.J., 1973. Towards Economic Warship Acquisition and Ownership. Trans. Royal Institution of Naval Architects, Vol. 115, 43-56.

48. Keane, R.G., W.C. Sandberg, 1984. Naval Architecture for Combatants, A Technology Survey. Naval Engineers Journal, Vol. 96, No. 5, 47-64.

49. Kehoe, J.W., K.S. Brower, H.A. Meier, 1982. The Impact of Design Practices on Ship Size and Cost. Naval Engineering Journal, Vol. 94, No. 2, 68-86.

50. Dart, C.E. 1970. Cost Estimating - Ship Design and Construction. University of Michigan. Department of Naval Architecture and Marine Engineering. No. 082, 61 pp.

51. Summers, L.S., 1973. The Prediction of Shipyard Costs. Marine Technology, Vol. 10, No. 1, 8-15.

52. Kazek, M.S., 1985. A Comparison of Offshore Patrol Vessels. Marine Technology, Vol. 22, No. 4, 351-357.

53. Whitlock, R.D., 1982. Estimates at Completion Using Beta Curves. Journal of Parametrics, Vol. 2, No. 2, 15-18.

54. Advanced Naval Vehicles Concept Evaluation (ANVCE) Final Report, CNO (OP-96), December, 1979.

55. Daschbach, J.M., K.F. Matta and W. Frank, 1983. Regression in Parametrics: Estimation versus Prediction Errors. Journal of Parametrics, Vol. 2, No. 3, 3-8.

56. Moy J. and J. Vail, 1974. CV Ship Acquisition Cost Model, Final Technical Report. NAVSEC Report C-6113B3-75-15, October 1974.

57. Starrett, C.O., 1982. Parametric Cost Estimating - An Audit Perspective. Journal of Parametrics, Vol. 1, No. 4, 3-5.

58. Cost Analysis Capability at NUSC. Report of the Work Group Session 15-17 August, 1984. Encl (3) to MAT-01F41 memo 5050 Ser 01F41/410 of 28 Sep 1984.

59. Jeffers, M.F., The Costing and Design Systems Office at David Taylor Naval Ship Research & Development Center. PRICE Presentation to NAVSEA Cost Engineering Task Force, 21 August, 1986.

60. Unpublished material. Costing and Design Systems Office, Code 1204, David Taylor Naval Ship Research and Development Center.

61. Gaffney, R., 1980. Avionics Software Costing. Journal of Parametrics, Vol. 1, No. 3, 26-30.

62. Unpublished material. Cost Estimating and Analysis Division, SEA 017, Naval Sea Systems Command.

63. Unpublished material. Ships Cost Analysis Division, NCA-2, Naval Center for Cost Analysis.

64. Breiling, R.W., 1984. Parametric Cost Estimating and the PRICE H Model. Presentation to Graduate Program in Technology Strategy and Policy. Boston University, October 4, 1984.

APPENDIX A

SWBS Weight Group Keys

for Costed Military Payload

(Ref. 1)

SWBS Weight Group	SWBS Group Name
410	Command and Control Systems
440	Exterior Communications
450	Surveillance Systems (surface)
460	Surveillance Systems (underwater)
470	Countermeasures
480	Fire Control Systems
490	Electronic Test, Checkout and Monitoring Equipment
498	Command & Surveillance Operating Fluids
710	Guns and Ammunition
720	Missiles and Rockets
750	Torpedoes
780	Aircraft Related Weapons
790	Special Purpose Systems
F21	Ship Ammunition
F22	Ordnance Delivery Systems (Ammo)
F23	Ordnance Delivery Systems
F24	Ordnance Repair Parts (Ships Ammo)
F25	Ordnance Repair Parts (Ordnance Delivery Sys. Ammo)
F26	Ordnance Delivery Systems Support Equipment
F60	Cargo

APPENDIX B

ASSET K_N Factors

for

SWBS Groups 100 - 900

(Ref. 1)

K_N VALUE	INTERPRETATION	SUGGESTED APPLICABILITY IN ANVCE			DATA BASE CASES USED FOR K_N		
1.000	Mild/HT steel displacement hull with aluminum deckhouse	FFG7	MCM	VSS	DE 1037 PF 109	DE 1040 SWATH DE	DE1053
1.570	Mild steel plus 25% HY-80 monohull with aluminum deckhouse	SWACVN			DDG 2 DLGN 35	DLG 12 DLGN 36	DLGN 25 DLGN 38
2.191	Conventional aluminum hull	CPICX PC1	LCPC SWA4	MONO3	CPIC PGG 1(P)	PG 92	PGG 1(T)
5.586	HT aluminum hull	ACV1 HYD7 LSES SESCV	ACV3 HOC PHM SESCVN	HYD2 LCAC SES3	PGH 1 DBH	PCH 1 2K SES(R)	AGEH 1 2K SES(B)

CASES NOT USED

DLG 16	DLG 26	PG 93
SWATH MCM	PGH 2	PHM 1
JEFF A	JEFF B	ARCTIC SEV

HULL STRUCTURE (SWBS 100) GROUP K_N VALUES

K_N VALUE	INTERPRETATION	SUGGESTED APPLICABILITY IN ANVCE			DATA BASE CASES USED FOR K_N		
1.000	CODOG/CODAG power plant, high speed marine propulsors and straight drive train	CPICX	LCPC		CPIC	PG 92	PGG 1(T)
1.502	GT/CODAG power plant, high speed marine propulsors and right angled drive train	ACV3 HOC PHM	HYD2 LSES SES3	HYD7 PC1	PGH 1 PHM 1 2K SES (B)	PGH 2 DBH	PCH 1 2K SES (R)
1.979	Steam turbine power plant, low speed CP propeller and long shafts				DDG 2	DLG 12	DLG 16
2.345	GT power plant, low speed CP propeller and reduction gears, with special arrangements as in SWATH	FFG7 VSS	MCM SWA4	MONO3	PF 109	SWATH MCM	SWATH DE
3.280	GT power plant with complex drives	ACVC1 SESCVN	LCAC	SESCV	JEFF A		
3.436	Nuclear steam pressurized water reactor power plant, low speed FP propellers, straight drive train	SWACVN			DLGN 25 DLGN 38	DLGN 35	DLGN 36

CASES NOT USED

DE 1037	DE 1040	DE 1053
DLG 26	PG 93	PGG 1 (P)
AGEH 1	JEFF B	ARCTIC SEV

PROPULSION (SWBS 200) GROUP K_N VALUES

K_N VALUE	INTERPRETATION	SUGGESTED APPLICABILITY IN ANVCE			DATA BASE CASES USED FOR K_N		
1.000	Conventional 60 HZ power, steam or diesel generator drive	CPIC MONO3	FFG7 SWACVN	MCM	DE 1037 PF 109 DLG 16 PG 92 DLGN 25 DLGN 38	DE 1040 DDG 2 DLG 26 PGG 1(T) DLGN 35 SWATH MCM	DE 1053 DLG 12 CPIC PGG 1(P) DLGN 36 SWATH DE
2.036	Conventional 60 HZ power, light diesel or GT generator drive	HYD7 LCPC SESCVN	HOC PC1 VSS	LCAC SESCV	PGH 1 AGEH 1	PGH 2 DBH	PCH 1 2K SES (R)
3.719	Very low 60 HZ or mixed 60/400 HZ, GT generator drive	SES3	SWA4				
12.684	All 400 HZ, GT generator drive	ACV1	PHM		PHM 1	JEFF B	

CASES NOT USED

PG 93 JEFF A

ELECTRIC PLANT (SWBS 300) GROUP K_N FACTORS

K_N VALUE	INTERPRETATION	SUGGESTED APPLICABILITY IN ANVCE			DATA BASE CASES USED FOR K_N		
1.000	Simple control systems, minimal electronics	CPICX	LCPC	PC1	DE 1037 DLG 12 CPIC	DE 1040 DLG 16 PG 92	DE 1053 DLG 26 PG 93
3.153	Modest control systems, sophisticated electronics	FFG7 SWA4	MCM SWACVN	MONO3 VSS	PF 109 DLGN 35 SWATH MCM	PGG 1(P) DLGN 36 SWATH DE	DLGN 25 DLGN 38
6.906	Complex control systems, sophisticated electronics weight critical ships	ACV1 HYD7 LSES SESCV	ACV3 HOC PHM SESCVN	HYD2 LCAC SES3	PGH 1 PHM 1 JEFF A	PGH 2 AGEH 1 JEFF B	PCH 1 DBH ARCTIC SEV

CASES NOT USED

DDG 2	PGG 1(T)	2K SES(R)
2K SES(B)		

COMMAND AND SURVEILLANCE (SWBS 400) GROUP K_N FACTORS

K_N VALUE	INTERPRETATION	SUGGESTED APPLICABILITY IN ANVCE			DATA BASE CASES USED FOR K_N		
1.000	Steam propelled displacement ship				DE 1037 DG 2 DLG 26	DE 1040 DLG 12	DE 1053 DLG 16
1.528	GT propelled displacement ship	CPICX MCM SWA4	FFG7 MONO3 WACVN	LCPC PC1 VSS	PF 109 PG 92 DLGN 25	CPIC PGG 1(T) DLGN 35	PG 93 PGG 1(P) DLGN 36
4.161	Fully submerged hydrofoils	HYD2	HYD7	HOC	PCH 1	AGEH 1	DBH
5.370	Air cushion vehicles	ACV1 LSES	ACV3 SES3	LCAC SESCV	JEFF A 2KSES(B)	ARCTIC SEV	2K SES(R)
					CASES NOT USED		
					PGH 1 JEFF B	PGH 2	PHM 1

AUXILIARY SYSTEMS (SWBS 500) GROUP K_N FACTORS

K_N VALUE	INTERPRETATION	SUGGESTED APPLICABILITY IN ANVCE			DATA BASE CASES USED FOR K_N		
1.000	Conventional displacement ship	CPICX	FFG7	LCPC	DE 1037	DE 1040	DE 1053
		MCM	MONO3	PC1	PF 109	DDG 2	DLG 12
		SWA4	SWACVN	VSS	DLG 16	DLG 26	CPIC
					PGG 1(T)	PGG 1(P)	DLGN 25
					DOGN 35	DLGN 36	DLGN 38
					SWATH DE		
1.857	Weight critical ship	ACV1	ACV3	HYD2	PGH 1	PGH 2	PCH 1
		HYD7	HOC	LCAC	PHM 1	AGEH 1	ARCTIC SEV
		LSES	PHM	SES3	2K SES(R)	2KSES(B)	
		SESCV	SESCVN				

CASES NOT USED

PG 93	PG 92	SWATH MCM
DBH	JEFF A	JEFF B

OUTFIT AND FURNISHINGS (SWBS 600) GROUP K_N FACTORS

K_N VALUE	INTERPRETATION	SUGGESTED APPLICABILITY IN ANVCE			DATA BASE CASES USED FOR K_N		
1.000	Conventional displacement ship	CPIC	FFG7	LCPC	DE 1037	DE 1053	PF 109
		MCM	MONO3	PC1	DDG 2	DLG 12	DLG 16
		SWA4	SWACVN	VSS	DLG 26	CPIC	PG 92
					PGG 1(T)	DLGN 35	DLGN 38
3.401	Weight critical ship, light armament	ACV1	ACVC3	HYD2	SWATH MCM	SWATH DE	PGH 1
		HYD7	HOC	LCAC	PGH 2	PCH 1	PHM 1
		LSES	PHM	SES3	DBH	2KSES(B)	
		SESCV	SESCVN				

CASES NOT USED

DE 1040	PG 93	PGG 1(P)
DLGN 25	DLGN 36	AGEH 1
JEFF A	JEFF B	ARCTIC SEV
2K SES(R)		

ARMAMENT (SWBS 700) GROUP K_N FACTORS

K_N VALUE	INTERPRETATION	SUGGESTED APPLICABILITY IN ANVCE			DATA BASE CASES USED FOR K_N		
1.000	Follow ship before 1970				DE 1037	DE 1040	DE 1053
					DDG 2	DLG 12	DLG 16
					PG 93	PG 92	DLGN 25
2.881	Follow ship, 1970 and after				SWATH MCM		
12.888	Lead ship, unsophisticated weapons	CPICX	LCAC	LCPC	PGG 1(T)	PGG 1(P)	SWATH DE
		MCM			PGH 1	PGH 2	PCH 1
					AGEH 1	DBH	JEFF A
					JEFF B	ARCTIC SEV	2K SES(R)
					2D SES(B)		
26.064	Lead ship, sophisticated weapons	ACV1	ACV3	FFG7	PF 109	PHM 1	
		HYD2	HYD7	HOC			
		LESES	MONO3	PC1			
		PHM	SES3	SESCV			
		SESCVN	SWA4	SWACVN			
		VSG					

CASES NOT USED

DLG 26	CPIC	DLGN 35
DLGN 38		

INTEGRATION/ENGINEERING (SWBS 800) GROUP K_N FACTORS

K_N VALUE	INTERPRETATION	SUGGESTED APPLICABILITY IN ANVCE	DATA BASE CASES USED FOR K_N
1.000	Simple tooling, limited trials	CPICX LCPC DE 1037	DE 2040 DDG 2 DLG 12 DLG 16 DLG 26 CPIC PG 93 PGG 1(T) PGG 1(P) AGEH 1
4.254	Complex tooling, extensive trials	ACVC1 ACVC3 FFG7 HYD2 HYD7 HOC LCAC LSES MCM MONO3 PC1 PHM SES3 SESCV SESCVN SWA4 SWACVN VSS	PF 109 DLGN 25 DLGN 35 DLGN 36 DLGN 38 SWATH DE PHM 1 DBH JEFF A JEFF B 2K SES(B)

CASES NOT USED

DE 1053	PG 92	SWATH MCM
PGH 1	PGH 2	PCH 1
ARCTIC SEV	2K SES (R)	

SHIP ASSEMBLY AND SUPPORT SERVICES (SWBS 900) GROUP K_N FACTORS

APPENDIX C

COST ESTIMATING SURVEY

The survey is designed to examine the perceived needs of any individual who must answer the question; "How much will this cost?" This is meant to include all levels of management involved in any type of ship acquisition program, from concept design through to production, and into operations and support, as well as official cost estimators.

I hope to accomplish two tasks with this survey. The first is to develop an awareness of the different cost estimating needs that occur throughout the various phases of a ship's life. The second is to attempt to match these needs with the characteristics of different cost estimating techniques. In other words, to improve the responsiveness of cost estimating models to user expressed needs.

The questionnaire is divided into two columns. The right hand column is for any individual who perceives a need for ship costing information and the left hand column is for people who have used any sort of cost estimating technique.

NEW SHIP COST ESTIMATING SURVEY

NAME .... RANK .... PHONE ....

POSITION .... DEPARTMENT ....

PLACE OF EMPLOYMENT .... YOUR FUNCTION ....

....

COST MODEL PERFORMANCE	USER IMPORTANCE
Name of cost model (e.g., ASSET, RCA PRICE,...)	
Under the following headings, indicate the cost-related information that is incorporated into your cost model and how this is done.	Under the following headings, indicate the cost-related information you feel should be incorporated into a cost model and any ideas of how this can be accomplished.

Technology
(e.g., technology available, state-of-the-art design influences,...)

....	....
....	....

Design
(e.g., weight, margins, design standards & practices, ship configuration, component/subsystem selections,...)

....	....
....	....

Manufacturing
(e.g., construction method, degree of automation, tooling, learning,...)

....	....
....	....

Programmatic
(e.g., type of contract, competitions, scheduling, cost of change orders,...)

....	....
....	....

COST MODEL PERFORMANCE		USER IMPORTANCE

Economic
(e.g., escalation, inflation rates, discounting,...)

....|.......................................

....|.......................................

Cost Breakdown
(e.g., nonrecurring, direct,...)

....|.......................................

....|.......................................

Operations & Support
(e.g., maintenance scheduling, reliability, modularity,...)

....|.......................................

....|.......................................

Other

....|.......................................

....|.......................................

For the following features, use performance ratings from 1 to 10 (1 for total disagreement; 10 for extremely important)

For the following features, use importance ratings from 1 to 10 (1 for "nice to have"; 10 for extremely important)

Performance	Feature	Importance
.....	Minimal training is required to use the model	.....
.....	The model can be calibrated using return data	.....
.....	The model is based on data reflecting the latest technology	.....
	The model is able to	
.....	(a) generate internal cost targets	.....
.....	(b) prepare planning/budgetary estimates	.....
.....	(c) perform trade-off studies	.....
.....	(d) validate outside industry bids	.....
.....	The model is able to provide estimates starting in the conceptual design phase	.....
.....	The model is easily accessible at reasonable cost	.....
.....	The model is developed in-house and can be easily modified	.....
	The model gives an accurate estimate of	
.....	(a) construction costs	.....
.....	(b) programmatic costs	.....
.....	(c) life cycle costs	.....
.....	The model is available to agencies/individuals with a need to know	.....
.....	Other	.....

COST MODEL
PERFORMANCE

Indicate an approximate accuracy (as a percentage) for your cost model during concept/preliminary design for

(a) construction costs ......
(b) programmatic costs ......
(c) life cycle costs ......
(d) other
....

Is there an area where the model performs especially well?

....

....

What is your definition of well?

....

Is there an area where the model performs poorly?

....

....

What is your definition of poorly?

....

For what phase(s) of a ship acquisition program is this model applicable?

....

....

....

USER
IMPORTANCE

Indicate your required accuracy (as a percentage) during concept/ perliminary design for

(a) construction costs ......
(b) programmatic costs ......
(c) life cycle costs ......
(d) other
....

Is there an area of cost estimating that you feel needs particular attention?

....

....

....

What is the reason(s) that this is so important?

....

....

....

For what phase(s) of a ship acquisition program are you most interested in receiving costs for?

....

....

....

....

APPENDIX D

SWBS GROUP BREAKDOWN FOR THE NCA TWO-DIGIT COST MODEL

(Ref. 1)

COST GROUP: 1A

SWBS NO.	DESCRIPTION
111	SHELL PLATING, SURF. SHIP AND SUBMARINE PRESS. HULL
113	INNER BOTTOM
114	SHELL APPENDAGES
115	STANCHIONS
116	LONGIT. FRAMING, SURF. SHIP AND SUBMARINE PRESS. HULL
117	TRANSV. FRAMING, SURF. SHIP AND SUBMARINE PRESS. HULL
121	LONGITUDINAL STRUCTURAL BULKHEADS
122	TRANSVERSE STRUCTURAL BULKHEADS
123	TRUNKS AND ENCLOSURES
124	BULKHEADS IN TORPEDO PROTECTION SYSTEM
131	MAIN DECK
132	2ND DECK
133	3RD DECK
134	4TH DECK
135	5TH DECK AND DECKS BELOW
141	1ST PLATFORM
142	2ND PLATFORM
143	3RD PLATFORM
144	4TH PLATFORM
145	5TH PLATFORM
149	FLATS
166	SPONSONS

COST GROUP: 1B

SWBS NO.	DESCRIPTION
151	DECKHOUSE STRUCTURE TO FIRST LEVEL
152	1ST DECKHOUSE LEVEL
153	2ND DECKHOUSE LEVEL
154	3RD DECKHOUSE LEVEL
155	4TH DECKHOUSE LEVEL
156	5TH DECKHOUSE LEVEL
157	6TH DECKHOUSE LEVEL
158	7TH DECKHOUSE LEVEL
159	8TH DECKHOUSE LEVEL AND ABOVE
164	BALLISTIC PLATING

COST GROUP: 1C

SWBS NO.	DESCRIPTION
182	PROPULSION PLANT FOUNDATIONS
183	ELECTRIC PLANT FOUNDATIONS
184	COMMAND AND SURVEILLANCE FOUNDATIONS
185	AUXILIARY SYSTEMS FOUNDATIONS
186	OUTFIT AND FURNISHINGS FOUNDATIONS
187	ARMAMENT FOUNDATIONS

COST GROUP: 1D

SWBS NO.	DESCRIPTION
161	STRUCTURAL CASTINGS, FORGINGS, AND EQUIV. WELDMENTS
162	STACKS AND MACKS (COMBINED STACK AND MAST)
163	SEA CHESTS
165	SONAR DOMES
167	HULL STRUCTURAL CLOSURES
168	DECKHOUSE STRUCTURAL CLOSURES
169	SPECIAL PURPOSE CLOSURES AND STRUCTURES
171	MASTS, TOWERS, TETRAPODS
172	KINGPOSTS AND SUPPORT FRAMES

COST GROUP: 2A

SWBS NO.	DESCRIPTION
221	PROPULSION BOILERS
222	GAS GENERATORS
223	MAIN PROPULSION BATTERIES
224	MAIN PROPULSION FUEL CELLS
231	PROPULSION STEAM TURBINES
232	PROPULSION STEAM ENGINES
233	PROPULSION INTERNAL COMBUSTION ENGINES
234	PROPULSION GAS TURBINES
235	ELECTRIC PROPULSION
236	SELF-CONTAINED PROPULSION SYSTEMS
237	AUXILIARY PROPULSION DEVICES
241	PROPULSION REDUCTION GEARS
242	PROPULSION CLUTCHES AND COUPLINGS
253	MAIN STEAM PIPING SYSTEM
254	CONDENSERS AND AIR EJECTORS
255	FEED AND CONDENSATE SYSTEM

COST GROUP: 2B

SWBS NO.	DESCRIPTION
243	PROPULSION SHAFTING
244	PROPULSION SHAFT BEARINGS
245	PROPULSORS
246	PROPULSOR SHROUDS AND DUCTS

COST GROUP: 2C

SWBS NO.	DESCRIPTION
251	COMBUSTION AIR SYSTEM
259	UPTAKES (INNER CASING)

COST GROUP: 2D

SWBS NO.	DESCRIPTION
252	PROPULSION CONTROL SYSTEM
256	CIRCULATING AND COOLING SEA WATER SYSTEM
258	H.P. STEAM DRAIN SYSTEM
261	FUEL SERVICE SYSTEM
262	MAIN PROPULSION LUBE OIL SYSTEM
264	LUBE OIL FILL, TRANSFER, AND PURIFICATION

COST GROUP: 3A

SWBS NO.	DESCRIPTION
311	SHIP SERVICE POWER GENERATION
312	EMERGENCY GENERATORS
314	POWER CONVERSION EQUIPMENT
341	SSTG LUBE OIL
342	DIESEL SUPPORT SYSTEMS
343	TURBINE SUPPORT SYSTEMS

COST GROUP: 3B

SWBS NO.	DESCRIPTION
313	BATTERIES AND SERVICE FACILITIES
321	SHIP SERVICE POWER CABLE
322	EMERGENCY POWER CABLE SYSTEM
323	CASUALTY POWER CABLE SYSTEM
324	SWITCHGEAR AND PANELS
331	LIGHTING DISTRIBUTION
332	LIGHTING FIXTURES

COST GROUP: 4A

SWBS NO.	DESCRIPTION
421	NON-ELECTRICAL/ELECTRONIC NAVIGATION AIDS
422	ELECTRICAL NAVIGATION AIDS (INCL NAVIG. LIGHTS)
423	ELECTRONIC NAVIGATION SYSTEMS, RADIO
424	ELECTRONIC NAVIGATION SYSTEMS, ACOUSTICAL
426	ELECTRICAL NAVIGATION SYSTEMS
427	INERTIAL NAVIGATION SYSTEMS
428	NAVIGATION CONTROL MONITORING
431	SWITCHBOARDS FOR I.C. SYSTEMS
432	TELEPHONE SYSTEMS
433	ANNOUNCING SYSTEMS
434	ENTERTAINMENT AND TRAINING SYSTEMS
435	VOICE TUBES AND MESSAGE PASSING SYSTEMS
436	ALARM, SAFETY, AND WARNING SYSTEMS
437	INDICATING, ORDER, AND METERING SYSTEMS
438	INTEGRATED CONTROL SYSTEMS
439	RECORDING AND TELEVISION SYSTEMS
443	VISUAL AND AUDIBLE SYSTEMS
473	TORPEDO DECOYS
474	DECOYS (OTHER)
475	DEGAUSSING
476	MINE COUNTERMEASURES
491	ELECTRONIC TEST, CHECKOUT, AND MONITORING EQUIPMENT
492	FLIGHT CONTROL AND INSTRUMENT LANDING SYSTEMS
493	NON COMBAT DATA PROCESSING SYSTEMS
494	METEOROLOGICAL SYSTEMS
495	SPECIAL PURPOSE INTELLIGENCE SYSTEMS

COST GROUP: 4B

SWBS NO.	DESCRIPTION
411	DATA DISPLAY GROUP
412	DATA PROCESSING GROUP
413	DIGITAL DATA SWITCHBOARDS
414	INTERFACE EQUIPMENT
415	DIGITAL DATA COMMUNICATIONS
417	COMMAND AND CONTROL ANALOG SWITCHBOARDS
441	RADIO SYSTEMS
442	UNDERWATER SYSTEMS
444	TELEMETRY SYSTEMS
445	TTY AND FACSIMILE SYSTEMS
446	SECURITY EQUIPMENT SYSTEMS
451	SURFACE SEARCH RADAR
452	AIR SEARCH RADAR (2D)
453	AIR SEARCH RADAR (3D)
454	AIRCRAFT CONTROL APPROACH RADAR
455	IDENTIFICATION SYSTEMS (IFF)
456	MULTIPLE MODE RADAR
459	SPACE VEHICLE ELECTRONIC TRACKING
461	ACTIVE SONAR
462	PASSIVE SONAR
463	MULTIPLE MODE SONAR
464	CLASSIFICATION SONAR
465	BATHYTHERMOGRAPH
471	ACTIVE ECM (INCL COMBINATION ACTIVE/PASSIVE)
472	PASSIVE ECM
481	GUN FIRE CONTROL SYSTEMS
482	MISSILE FIRE CONTROL SYSTEMS
483	UNDERWATER FIRE CONTROL SYSTEMS
484	INTEGRATED FIRE CONTROL SYSTEMS
489	WEAPON SYSTEMS SWITCHBOARDS

COST GROUP: 5A

SWBS NO.	DESCRIPTION
511	COMPARTMENT HEATING SYSTEM
512	VENTILATION SYSTEM
513	MACHINERY SPACE VENTILATION SYSTEM
514	AIR CONDITIONING SYSTEM
516	REFRIGERATION SYSTEM
517	AUXILIARY BOILERS AND OTHER HEAT SOURCES

COST GROUP: 5B

SWBS NO.	DESCRIPTION
521	FIREMAIN AND FLUSHING (SEA WATER) SYSTEM
522	SPRINKLER SYSTEM
523	WASHDOWN SYSTEM
524	AUXILIARY SEA WATER SYSTEM
526	SCUPPERS AND DECK DRAINS
527	FIREMAIN ACTUATED SERVICES - OTHER
528	PLUMBING DRAINAGE
529	DRAINAGE AND BALLASTING SYSTEM
531	DISTILLING PLANT
532	COOLING WATER
533	POTABLE WATER
534	AUX. STEAM AND DRAINS WITHIN MACHINERY BOX
535	AUX. STEAM AND DRAINS OUTSIDE MACHINERY BOX
536	AUXILIARY FRESH WATER COOLING
541	SHIP FUEL AND FUEL COMPENSATING SYSTEM
542	AVIATION AND GENERAL PURPOSE FUELS
543	AVIATION AND GENERAL PURPOSE LUBRICATING OIL
544	LIQUID CARGO
545	TANK HEATING
549	SPECIAL FUEL AND LUBRICANTS, HANDLING AND STOWAGE
551	COMPRESSED AIR SYSTEMS
552	COMPRESSED GASES
553	O_2N_2 SYSTEM
554	LP BLOW
555	FIRE EXTINGUISHING SYSTEMS
556	HYDRAULIC FLUID SYSTEM
557	LIQUID GASES, CARGO
558	SPECIAL PIPING SYSTEMS
565	TRIM AND HEEL SYSTEMS (SURFACE SHIPS)
593	ENVIRONMENTAL POLLUTION CONTROL SYSTEMS
594	SUBMARINE RESCUE, SALVAGE, AND SURVIVAL SYSTEMS

COST GROUP: 5C

SWBS NO.	DESCRIPTION
561	STEERING AND DIVING CONTROL SYSTEMS
562	RUDDER
568	MANEUVERING SYSTEMS

COST GROUP: 5D

SWBS NO.	DESCRIPTION
571	REPLENISHMENT-AT-SEA SYSTEMS
572	SHIP STORES AND EQUIPMENT HANDLING SYSTEMS
573	CARGO HANDLING SYSTEMS
574	VERTICAL REPLENISHMENT SYSTEMS
581	ANCHOR HANDLING AND STOWAGE SYSTEMS
582	MOORING AND TOWING SYSTEMS
583	BOATS, BOAT HANDLING AND STOWAGE SYSTEMS
584	MECHANICALLY OPERATED DOOR, GATE, RAMP, TURNTABLE SYSTEM
585	ELEVATING AND RETRACTING GEAR
588	AIRCRAFT HANDLING, SERVICING AND STOWAGE
589	MISCELLANEOUS MECHANICAL HANDLING SYSTEMS
592	SWIMMER AND DIVER SUPPORT AND PROTECTION SYSTEMS
595	TOWING, LAUNCHING AND HANDLING FOR UNDERWATER SYSTEMS
596	HANDLING SYSTEMS FOR DIVER AND SUBMERSIBLE VEHICLES
597	SALVAGE SUPPORT SYSTEMS

COST GROUP: 6A

SWBS NO.	DESCRIPTION
605	RODENT AND VERMIN PROOFING
611	HULL FITTINGS
612	RAILS, STANCHIONS, AND LIFELINES
613	RIGGING AND CANVAS
625	AIRPORTS, FIXED PORTLIGHTS, AND WINDOWS

COST GROUP: 6B

SWBS NO.	DESCRIPTION
621	NON-STRUCTURAL BULKHEADS
622	FLOOR PLATES AND GRATINGS
623	LADDERS
624	NON-STRUCTURAL CLOSURES
637	SHEATHING

COST GROUP: 6C

SWBS NO.	DESCRIPTION
602	HULL DESIGNATING AND MARKING
603	DRAFT MARKS
604	LOCKS, KEYS, AND TAGS
631	PAINTING
632	ZINC COATING
633	CATHODIC PROTECTION
634	DECK COVERING
635	HULL INSULATION
636	HULL DAMPING
639	RADIATION SHIELDING

COST GROUP: 6D

SWBS NO.	DESCRIPTION
654	UTILITY SPACES
655	LAUNDRY SPACES
656	TRASH DISPOSAL SPACES
664	DAMAGE CONTROL STATIONS
665	WORKSHOPS, LABS, TEST AREAS (INCLUDING PORTABLE TOOLS, EQUIPMENT)
671	LOCKERS AND SPECIAL STOWAGE
672	STOREROOMS AND ISSUE ROOMS

COST GROUP: 6E

SWBS NO.	DESCRIPTION
638	REFRIGERATED SPACES
641	OFFICER BERTHING AND MESSING SPACES
642	NONCOMMISSIONED OFFICER BERTHING AND MESSING SPACES
643	ENLISTED PERSONNEL BERTHING AND MESSING SPACES
644	SANITARY SPACES AND FIXTURES
645	LEISURE AND COMMUNITY SPACES
651	COMMISSARY SPACES
652	MEDICAL SPACES
653	DENTAL SPACES
661	OFFICES
662	MACHINERY CONTROL CENTERS FURNISHINGS
663	ELECTRONICS CONTROL CENTERS FURNISHINGS

COST GROUP: 7

SWBS NO.	DESCRIPTION
701	GENERAL ARRANGEMENT - WEAPONRY SYSTEMS
711	GUNS
712	AMMUNITION HANDLING
713	AMMUNITION STOWAGE
721	LAUNCHING DEVICES (MISSILES AND ROCKETS)
722	MISSILE, ROCKET, AND GUIDANCE CAPSULE HANDLING SYSTEM
723	MISSILE AND ROCKET STOWAGE
724	MISSILE HYDRAULICS
725	MISSILE GAS
726	MISSILE COMPENSATING
727	MISSILE LAUNCHER CONTROL
728	MISSILE HEATING, COOLING, TEMPERATURE CONTROL
729	MISSILE MONITORING, TEST AND ALIGNMENT
731	MINE LAUNCHING DEVICES
732	MINE HANDLING
733	MINE STOWAGE
741	DEPTH CHARGE LAUNCHING DEVICES
742	DEPTH CHARGE HANDLING
743	DEPTH CHARGE STOWAGE
751	TORPEDO TUBES
752	TORPEDO HANDLING
753	TORPEDO STOWAGE
754	SUBMARINE TORPEDO EJECTION
761	SMALL ARMS AND PYROTECHNIC LAUNCHING DEVICES
762	SMALL ARMS AND PYROTECHNIC HANDLING
763	SMALL ARMS AND PYROTECHNIC STOWAGE
770	CARGO MUNITIONS
772	CARGO MUNITIONS HANDLING
773	CARGO MUNITIONS STOWAGE
782	AIRCRAFT RELATED WEAPONS HANDLING
783	AIRCRAFT RELATED WEAPONS STOWAGE
792	SPECIAL WEAPONS HANDLING
793	SPECIAL WEAPONS STOWAGE
797	MISCELLANEOUS ORDNANCE SPACES

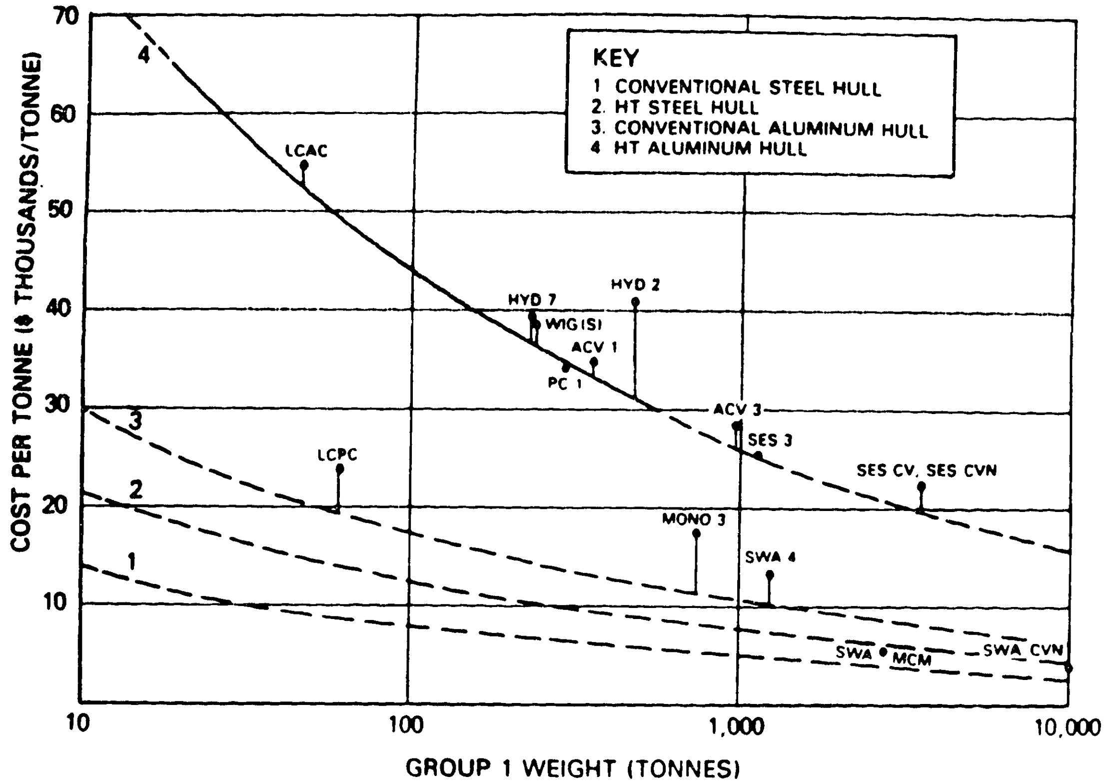
APPENDIX E

ANVCE SHIP SAMPLE AND SWBS GROUP CERS

(Ref. 54)

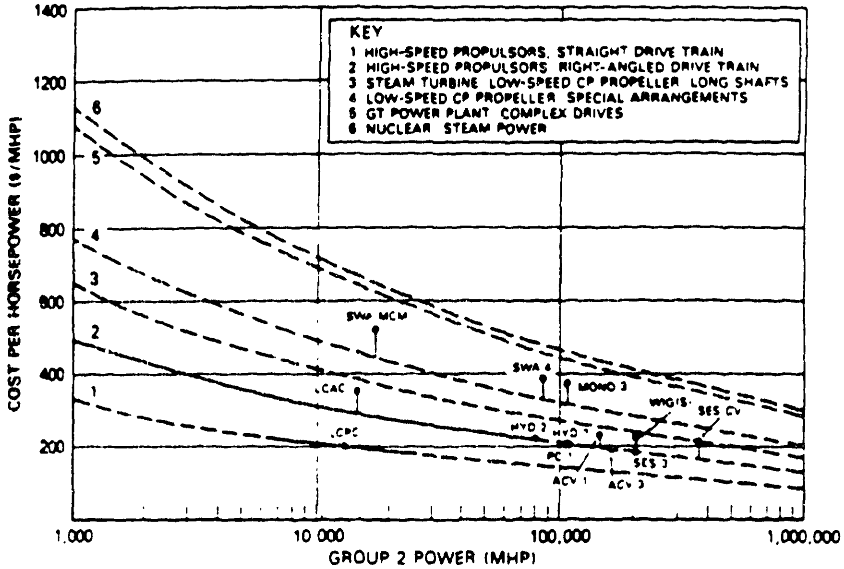
Vehicle	Definition	ANVCE Project Design	Baseline Design	Existing Design
ACV 1	Nominal 1000-tonne ACV	X		
ACV 3	Nominal 3000-tonne ACV	X		
A/L	Air loiter aircraft	X		
A/L(N)	Nuclear-powered, air loiter aircraft	X		
AVP	Advanced patrol aircraft		X	
CPIC	Coastal patrol interdiction craft			X
CXX	Long-range cargo aircraft (USAF)		X	
FAB	Fully air-buoyant LTA vehicle	X		
FFG 7	PERRY-class, guided-missile frigate			X
HYD 7	Nominal, 700-tonne, high-speed hydrofoil	X		
HYD 2	Nominal, 2000-tonne hydrofoil	X		
HOC	Hydrofoil, ocean combatant			X
LCAC	Landing craft, air cushion vehicle	X		
LCPC	Landing craft, planing craft	X		
LSES	Large SES			X
MONO 3	Nominal, 3000-tonne, advanced-technology monohull		X	
PC 1	Nominal, 1000-tonne planing craft	X		
PHM	Guided-missile, patrol hydrofoil			X
SAB	Semiair-buoyant LTA vehicle	X		
SES 3	Nominal, 3000-tonne SES	X		
SES CV	SES carrier	X		
SES CVN	Nuclear-powered SES carrier	X		
S/L(L)	Large, sea loiter aircraft	X		
S/L(S)	Small, sea loiter aircraft	X		
S/L(V)	Ship-based, V/STOL, sea loiter aircraft	X		
SWA 4	Nominal, 4000-tonne SWATH frigate	X		
SWA MCM	Mine-countermeasures SWATH ship	X		
SWA CVN	Nuclear-powered, SWATH carrier	X		
VSS	V/STOL, support ship		X	
WIG(H)	Hard-end-plate WIG vehicle	X		
WIG(O)	Out-of-ground-effect, WIG vehicle	X		
WIG(S)	Soft-end-plate, WIG vehicle	X		
ZPG X	Patrol, LTA vehicle			X

Surface Vehicle Groups			Air Vehicle Groups		Special-Purpose Vehicles
3000-Tonne Class	1000-Tonne Class	Aircraft Carriers	Large, Multi-Mission Aircraft	Small, ASW Aircraft	
ACV 3	ACV 1	SES CV	A/L	SAB	LCAC
HYD 2	HYD 7	SES CVN	A/L(N)	S/L(S)	LCPC
SES 3	PC 1	SWA CVN	FAB	S/L(V)	SWA MCM
SWA 4	WIG(S)		S/L(L)	AVP	WIG(H)
MONO 3			WIG(O)		

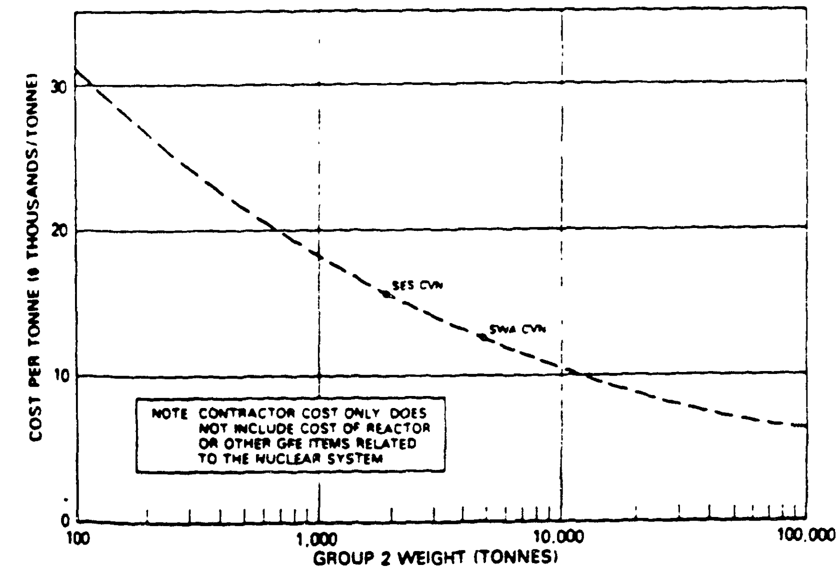


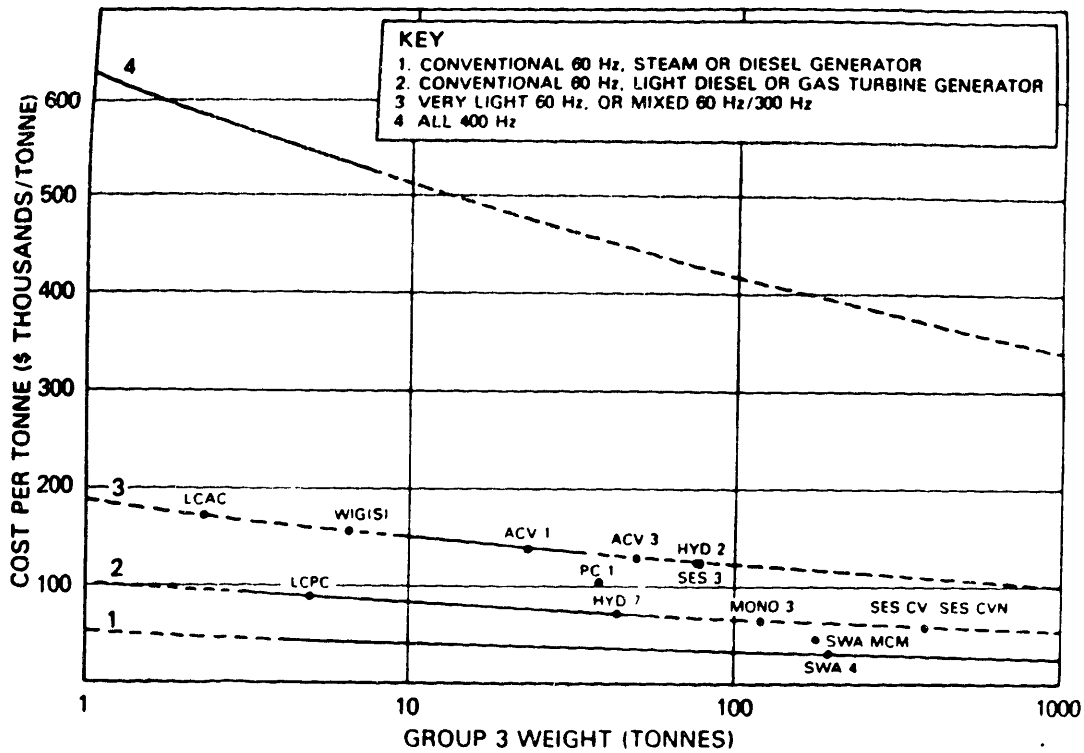
KEY
1 CONVENTIONAL STEEL HULL
2. HT STEEL HULL
3. CONVENTIONAL ALUMINUM HULL
4 HT ALUMINUM HULL
COST PER TONNE ($ THOUSANDS/TONNE)
GROUP 1 WEIGHT (TONNES)
70
60
50
40
30
20
10
10
100
1,000
10,000
LCAC
HYD 7
WIG (S)
HYD 2
ACV 1
PC 1
ACV 3
SES 3
SES CV, SES CVN
LCPC
MONO 3
SWA 4
SWA
MCM
SWA CVN
1
2
3
4

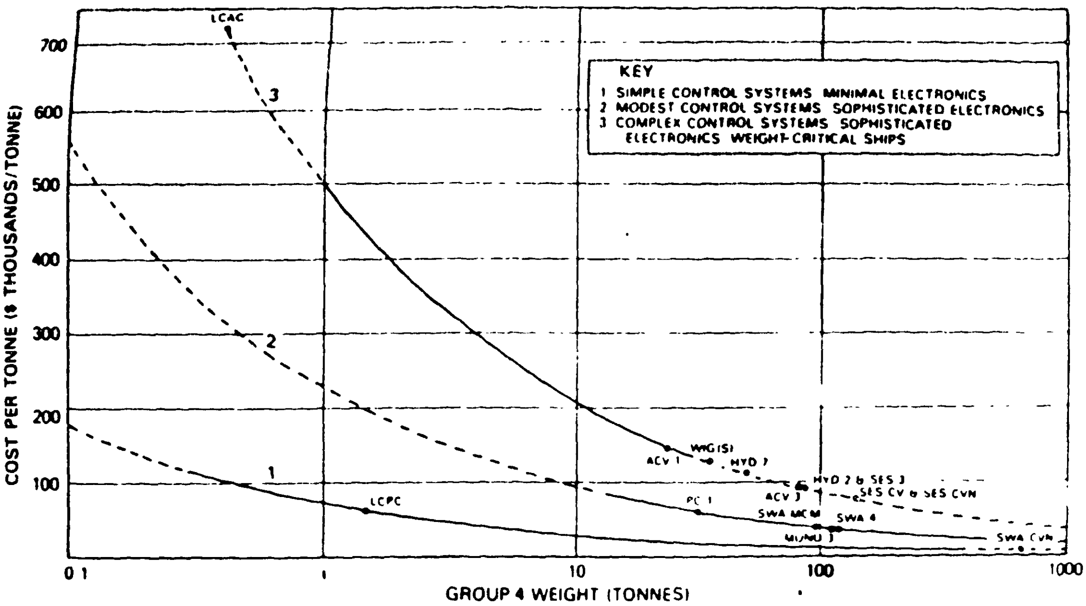
NONNUCLEAR PROPULSION

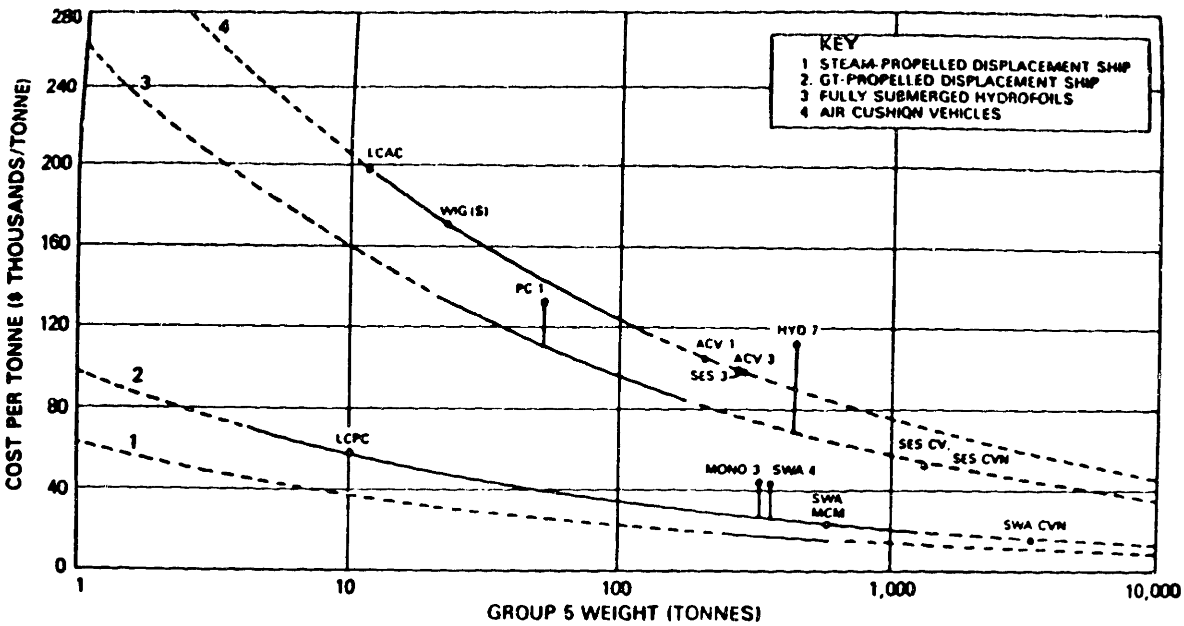


NUCLEAR PROPULSION

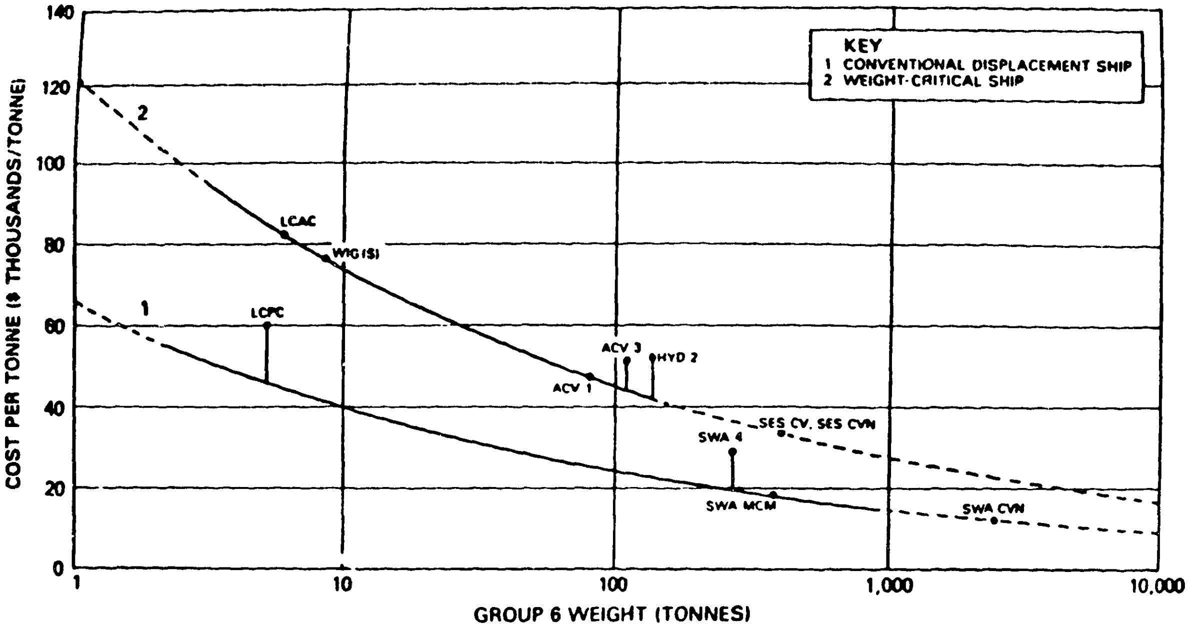


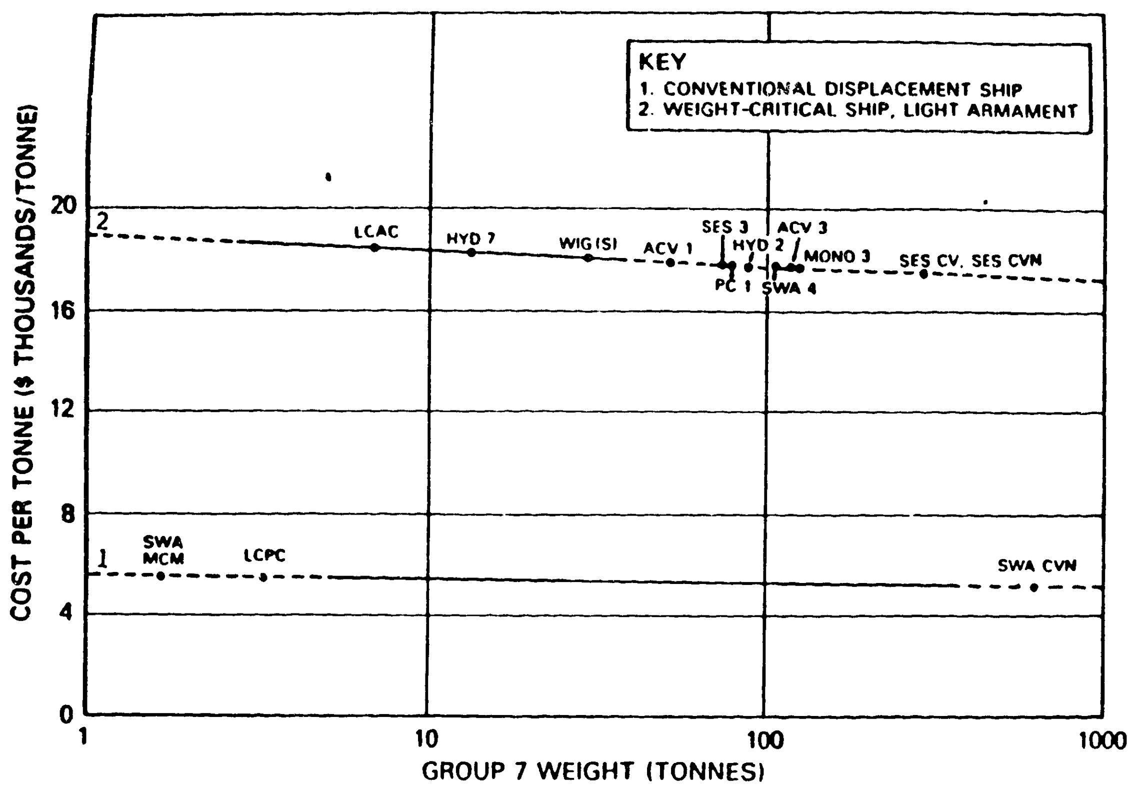

KEY
1. CONVENTIONAL 60 Hz, STEAM OR DIESEL GENERATOR
2. CONVENTIONAL 60 Hz, LIGHT DIESEL OR GAS TURBINE GENERATOR
3 VERY LIGHT 60 Hz, OR MIXED 60 Hz/300 Hz
4 ALL 400 Hz
COST PER TONNE ($ THOUSANDS/TONNE)
600
500
400
300
200
100
4
3
2
1
LCAC
WIG(S)
ACV 1
ACV 3
HYD 2
PC 1
SES 3
LCPC
HYD 7
MONO 3
SES CV
SES CVN
SWA MCM
SWA 4
1
10
100
1000
GROUP 3 WEIGHT (TONNES)


LCAC
700
600
500
400
300
200
100
COST PER TONNE ($ THOUSANDS/TONNE)
KEY
1 SIMPLE CONTROL SYSTEMS MINIMAL ELECTRONICS
2 MODEST CONTROL SYSTEMS SOPHISTICATED ELECTRONICS
3 COMPLEX CONTROL SYSTEMS SOPHISTICATED ELECTRONICS WEIGHT-CRITICAL SHIPS
3
2
1
LCPC
WIG(S)
ACV 1
HYD 2 & SES 3
ACV 3
SES CV & SES CVN
PC 1
SWA MCM
SWA 4
SWA CVN
0 1
1
10
100
1000
GROUP 4 WEIGHT (TONNES)

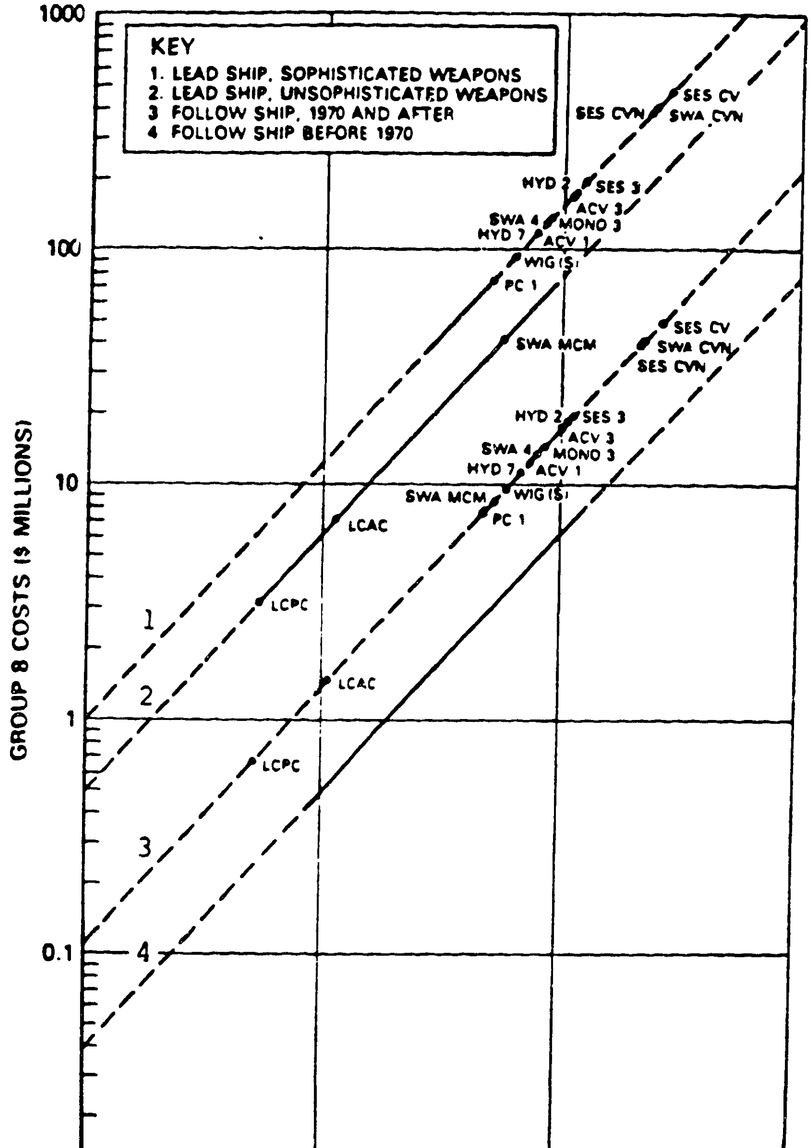


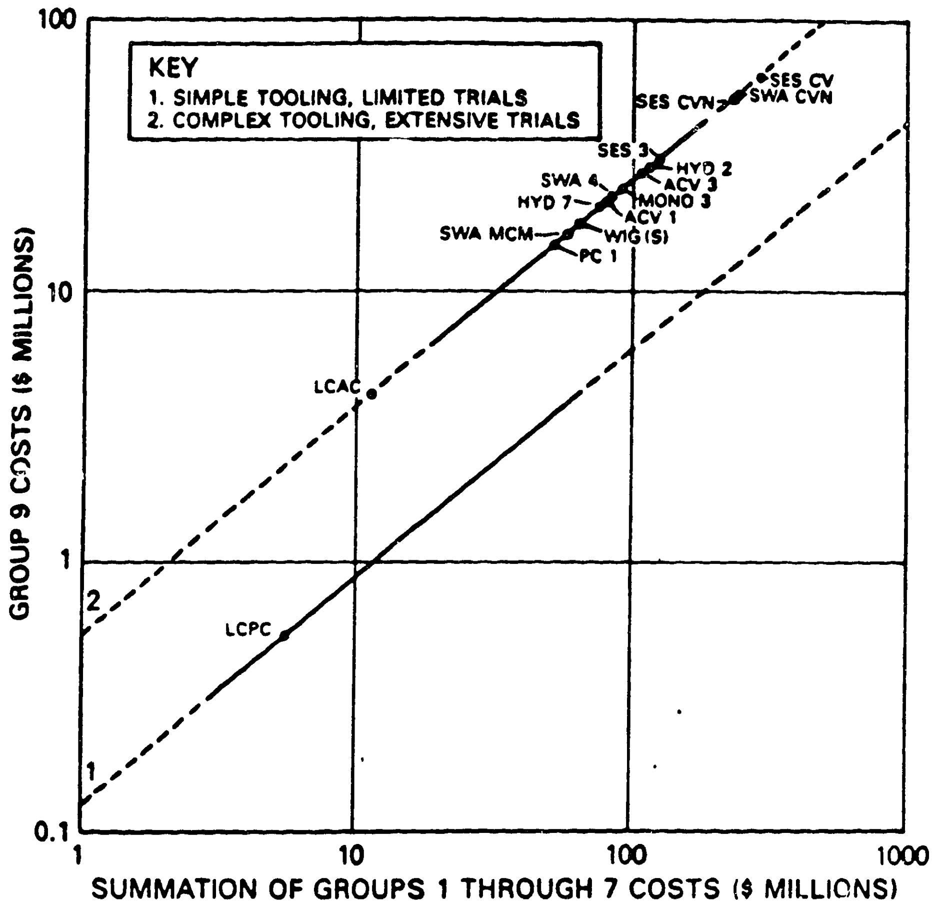
KEY
1 STEAM-PROPELLED DISPLACEMENT SHIP
2. GT-PROPELLED DISPLACEMENT SHIP
3 FULLY SUBMERGED HYDROFOILS
4 AIR CUSHION VEHICLES
COST PER TONNE ($ THOUSANDS/TONNE)
GROUP 5 WEIGHT (TONNES)
280
240
200
160
120
80
40
0
1
10
100
1,000
10,000
LCAC
WIG (S)
PC 1
ACV 1
ACV 3
SES 3
HYD 7
LCPC
MONO 3
SWA 4
SWA MCM
SES CV
SES CVN
SWA CVN


KEY
1 CONVENTIONAL DISPLACEMENT SHIP
2 WEIGHT-CRITICAL SHIP
140
120
100
80
60
40
20
0
COST PER TONNE ($ THOUSANDS/TONNE)
2
1
LCAC
WIG (S)
LCPC
ACV 3
HYD 2
ACV 1
SES CV, SES CVN
SWA 4
SWA MCM
SWA CVN
1
10
100
1,000
10,000
GROUP 6 WEIGHT (TONNES)



KEY
1. CONVENTIONAL DISPLACEMENT SHIP
2. WEIGHT-CRITICAL SHIP, LIGHT ARMAMENT
COST PER TONNE ($ THOUSANDS/TONNE)
20
16
12
8
4
0
2
LCAC
HYD 7
WIG (S)
ACV 1
SES 3
HYD 2
ACV 3
MONO 3
SES CV, SES CVN
PC 1
SWA 4
1
SWA MCM
LCPC
SWA CVN
1
10
100
1000
GROUP 7 WEIGHT (TONNES)


KEY
1. LEAD SHIP, SOPHISTICATED WEAPONS
2. LEAD SHIP, UNSOPHISTICATED WEAPONS
3 FOLLOW SHIP, 1970 AND AFTER
4 FOLLOW SHIP BEFORE 1970
GROUP 8 COSTS ($ MILLIONS)
SUMMATION OF GROUPS 1 THROUGH 7 COSTS ($ MILLIONS)
1000
100
10
1
0.1
.01
SES CVN
SES CV
SWA CVN
HYD 2
SES 3
ACV 3
SWA 4
MONO 3
HYD 7
ACV 1
WIG (S)
PC 1
SWA MCM
LCAC
LCPC



KEY
1. SIMPLE TOOLING, LIMITED TRIALS
2. COMPLEX TOOLING, EXTENSIVE TRIALS
100
10
1
0.1
1
10
100
1000
GROUP 9 COSTS ($ MILLIONS)
SUMMATION OF GROUPS 1 THROUGH 7 COSTS ($ MILLIONS)
SES CV
SES CVN
SWA CVN
SES 3
HYD 2
ACV 3
SWA 4
MONO 3
HYD 7
ACV 1
SWA MCM
WIG (S)
PC 1
LCAC
LCPC
2
1

APPENDIX F

PRICE H INPUT GLOSSARY AND DATA SHEET

(Ref. 20)

GLOSSARY OF PRICE H VARIABLES

BASIC INPUTS

AUCOST	Average recurring unit production cost (Historical Data).
CATGRY	Thru-put cost category.
CMPID	Equipment electronic classification.
COST	Purchased item cost.
CPF	Two, three, or five digit code for the manufacturing process used in production.
DCOST	Thru-put development cost.
DESRPE	Decimal fraction of electronic design repetition.
DESRPS	Decimal fraction of structural design repetition.
DFPRO	Month/Year of completion of first prototype (Not to include field tests).
DLPRO	Month/Year of completion of development.
DSTART	Month/Year of start of development.
DTCOST	Total development cost (Historical Data).
ECMPLX	Engineering complexity factor.
EREL	Electronic reliability adjustment factor.
INTEGE	Level of integration and test requirements applicable to electronics.
INTEGS	Level of integration and test requirements applicable to structural/mechanical areas.
MCPLXE	Empirical input of the electronics manufacturing complexity.
MCPLXS	Empirical input of the structural/mechanical manufacturing complexity.
MECID	Equipments mechanical/structural classification.
MODE	Numerical designation of PRICE input mode.
MREL	Mechanical reliability adjustment factor.
NEWEL	Decimal equivalent of unique new electronic design required.
NEWST	Decimal equivalent of unique new mechanical/structural design required.
PCOST	Thru-put production cost.
PEND	Month/Year of completion of production.
PFAD	Month/Year of production first article completion (Does not include field testing).
PLTFM	Equipments designed operating environment (Specification Level).
PRCOST	Prototype manufacturing cost, to include special tooling and test equipment (Historical Data).
PROSUP	Prototype support empirical factor.
PROTOS	Number of prototypes to be developed from DSTART to DLPRO.
PSTART	Month/Year of release to production - start of production cycle.
PTCOST	Total production cost (Historical Data).
QTY	Number of production units to be built from PSTART to PEND.
QTYNHA	Number of equipments required for integration to the next higher assembly level (System).
RATOOL	Average monthly production rate for which tooling is to be costed.
TARCST	Target design-to-unit-production-cost (Amortized over all production elements).
TCOST	Total thru-put cost.
USEVOL	Proportion of an equipments volume occupied by the electronics package.
VOL	Envelope volume of an equipment (Cubic feet).
WECF	Electronic packaging density (Weight of electronics per cubic foot).
WS	Weight of mechanical/structural elements (Pounds).
WSCF	Mechanical/structural density (Weight of structure per cubic foot).
WT	Weight of equipment (Pounds).
YRECON	Economic base year.
YRTECH	Technological base year.

GLOBAL INPUTS

COSTU	Units for cost measurements (e.g. dollars, thousands of dollars, etc.).
DDATA	Level of data requirements for the development phase.
DESIGN	Empirical factor controlling the level of engineering design.
DMULT	Development cost multiplier (for additions to manufacturing cost level).
DPROJ	Level of project management for the development phase.
DRAFT	Empirical factor controlling the level of drafting.
DTECIM	Level of technological improvement for development programs.
DTLGTS	Level of special tools and test equipment required for prototype manufacturing.
ECNE	Level of production engineering change activity for electronics sections.
ECNS	Level of production engineering change activity for structural sections.
ESC	Escalation control variable.
NFACS	Number of production facilities (Lines) to build QTY equipment.
NSHIFT	Number of production shifts used to build QTY equipment.
PDATA	Level of data/documentation requirements during the production phase.
PMULT	Production cost multiplier (For additions to manufacturing cost level).
PPROJ	Multiplier of production project management costs.
PSF	Prototype schedule factor (Defines the sequential manner in which the prototypes will be manufactured).
PTECIM	Level of technological improvement for production programs.
PTLGTS	Multiplier of special production tools and equipment costs.
RSRCE	Indicator of resources that are available for production.
SYSTEM	Multiplier of systems engineering costs in the development phase.
TECDEL	Number of years of technological delay (Lag).

PRICE Input Data Worksheet

Basic Modes

File name: ______
Sheet ___ of ____

Title: Date:

General A	Production Quantity QTY	Prototypes PROTOS	Weight (lbs) WT	Volume (ft^3) VOL	Mode, HW/SW Integration MODE . HSINT	
General B	Quantity/Next Higher Assembly QTYNHA	NHA Integration Factors Electronic INTEGE	Structural INTEGS	Specification Level PLTFM	Year of Economics YRECON	Year of Technology YRTECH
Mechanical/ Structural	Structure Weight WS	Manufacturing Complexity MCPLXS	New Structure NEWST	Design Repeat DESRPS	Mechanical Reliability MREL	
Electronics	WE Per Ft^3 WECF / Volume Fraction USEVOL	Manufacturing Complexity MCPLXE	New Electronics NEWEL	Design Repeat DESRPE	Electronic Reliability EREL	
Development	Development Start DSTART	1st Prototype Complete DFPRO	Development Complete DLPRO	Engineering Complexity ECMPLX	Tooling & Test Equip DTLGTS	Prototype Activity PROSUP
Production	Production Start PSTART	First Article Delivery PFAD	Production Complete PEND	PRICE-Improvement Factor PIF	Tooling & Test Equip PTLGTS	Rate/Month Tooling RATOOL
Actual Cost Data (Mode 7 only)	Average Unit AUCOST	Production Total PTCOST	Prototypes PRCOST	Development Total DTCOST		

Notes:

1 ELECTRONIC ITEM
2 MECHANICAL ITEM
6 MODIFIED ITEM
7 ECIRP

GC 1613 1/85

RCA