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REVISED FOLLOW SHIP AND FOLLOW YARD

CONSTRUCTION COST MODEL

DRAFT FINAL REPORT

Prepared by:
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GIBBS & COX, INC
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1.0 BACKGROUND

The objective of this study is to update the existing Follow Ship and Follow Yard Cost Model (1), which was prepared by Gibbs & Cox, Inc. for the Naval Center for Cost Analysis (NCA) in 1985. The existing model was a first attempt to identify the factors that contribute to the construction cost of follow ships built at a lead yard, and the construction cost of the lead ship and follow ships built at a follow yard. These factors were then combined into a set of algorithms to be used to predict follow ship and follow yard costs, based on lead ship costs, which are derived using existing cost models for U.S. Naval surface combatants (2) and U.S. Naval auxiliary and amphibious type ships (3).

The existing model provides a good modelling approach and a good attempt to identify factors that influence costs. However, it was felt that the model required further refinement and additional data analysis in order to make it a more useful cost model for NCA. This study is intended to provide such refinements and will supersede the existing model. This study will address the following topics:

CHAPTER 2: Evaluation of the Existing Model
CHAPTER 3: Description of the Revised Model
CHAPTER 4: Data Analysis
CHAPTER 5: Use of the Revised Model

2.0 EVALUATION OF THE EXISTING MODEL

In developing the existing model, Gibbs & Cox, Inc. performed an extensive literature survey of prior studies that related to the issue of follow ships and follow yards, as well as general issues related to experience with the concepts of the learning curve. A bibliography of the relevant studies identified in the literature survey (with additional references identified during the current update) is provided in Appendix A. This literature survey helped define the premise of the existing model, namely that shipyards experience a learning phenomenon, akin to that discovered in the aircraft industry, which lead to the development of the learning curve theory.

The object of the original study was then focused on an attempt to obtain input from shipyards that would augment the literature and assist in the development of a learning curve model specific to the current U.S. Naval surface combatant, and auxiliary and amphibious ship acquisition experience. To this end, a letter was drafted by Gibbs & Cox, Inc. and sent to the following shipyards: BIW, NASSCO, Avondale, Todd, General Dynamics, Newport News Shipbuilding and Tacoma Boatbuilding. Only two shipyards responded, BIW and Tacoma Boatbuilding. BIW provided both opinions concerning factors that influence follow ship and follow yard costs, as well as a breakdown of data based on its FFG 7 Class experience. Tacoma provided opinions concerning factors that influence follow ship and follow yard costs based on their engineering judgement. Copies of the Gibbs & Cox, Inc. letter and the shipyards' responses are included in Appendix B.

The model that evolved attempts to do two basic things. The first is to identify factors that affect the slope of the learning curve for follow ships in a lead yard and from this and with additional cost information, to determine follow ship costs for the lead yard. The second is to determine factors that identify the cost of the lead ship in a follow yard, as well as the slope of the learning curve for the follow yard. From these and with additional cost information, a determination of lead and follow ship costs for the follow yard is made. In both cases the model differentiates between material and labor costs. Also in both cases the costs are separated between those for SWBS Groups 100-700, which are considered subject to learning, and SWBS Groups 800 and 900, where the costs for these two groups are considered to be a percentage (25%) of the SWBS Groups 800 and 900 costs for the lead ship. A flow chart for the existing model is shown in Figure 1.

The equations for determining the learning curve are of the typical form for evaluating unit costs or cumulative average cost, which have been normalized to allow their being used as multipliers against lead ship costs. The equations are presented in the following forms:

$$LC = [i^{b+1} - (i-1)^{b+1}] \qquad (1)$$

for individual ship cost and

$$LC = (i)^{b} \qquad (2)$$

for cumulative average cost where

$$b = \frac{\log SL}{\log 2}$$

and

- o LC is the learning curve factor, which is the value of the cost of the i^{th} ship divided by the cost of the lead ship.
- o i is the number of the ship to be estimated
- o b is a parameter related to the "Slope" of a learning curve (it is the geometric slope of the learning curve line plotted on logarithmic grid paper)
- o SL is the "Slope" of the learning curve and is defined as the ratio of the cost per 2X units of the cost X units, where X is any number in the series of construction.

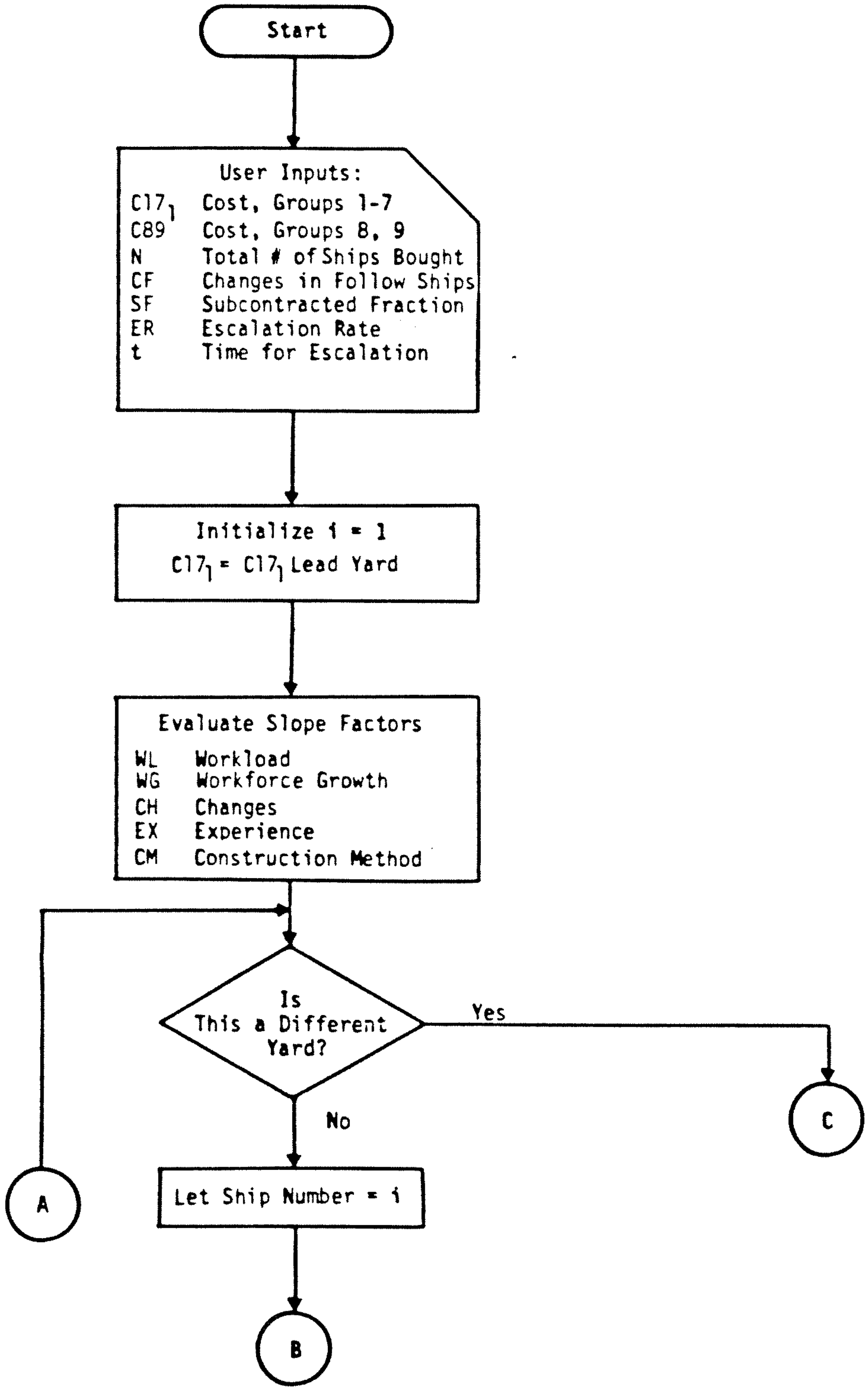


FIGURE 1

COST MODEL FLOW CHART

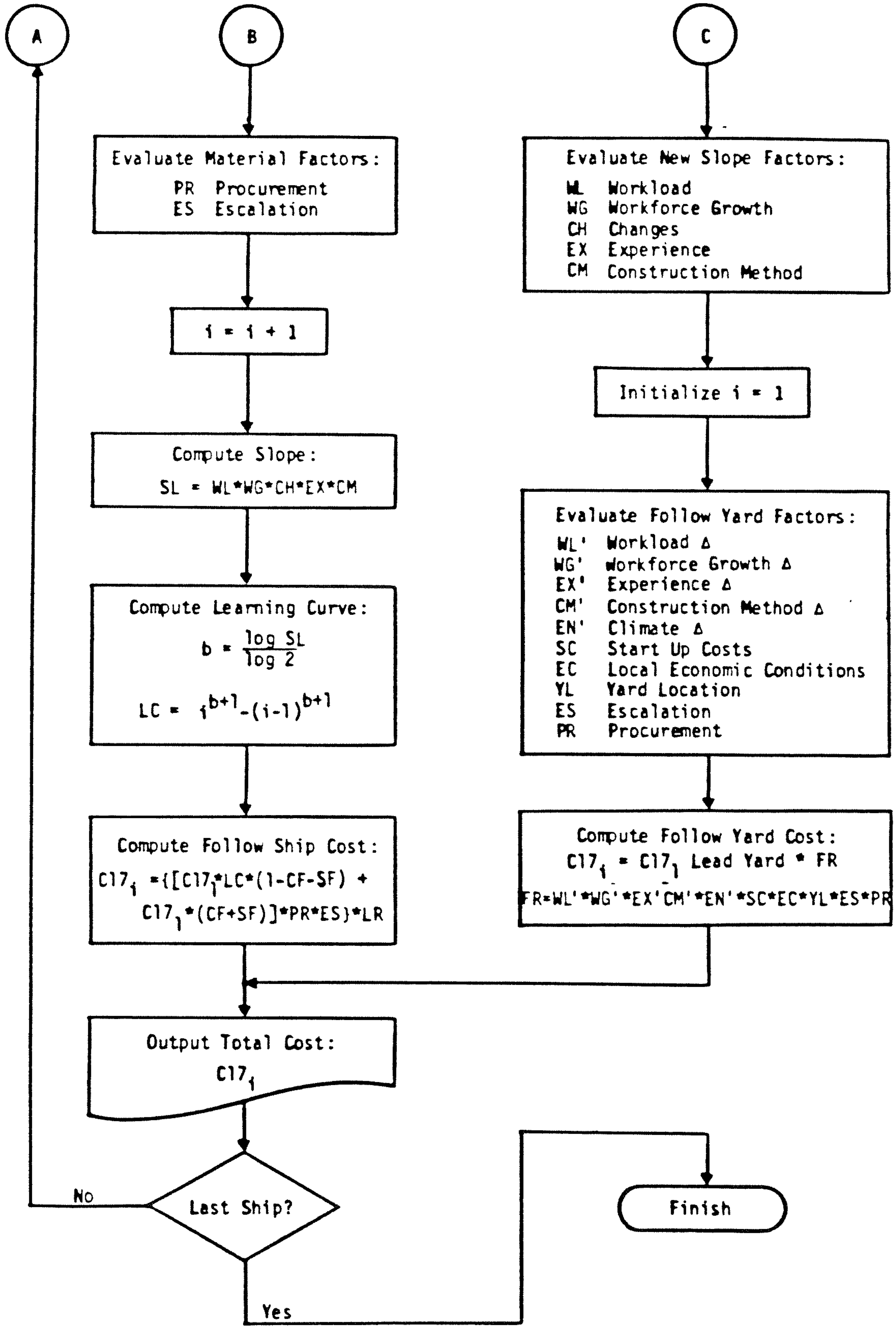


FIGURE 1 (continued)

Where the existing model differs from the learning curve application identified in the literature survey is in the determination of "Slope". Whereas the typical approach to determination of "Slope" has been through evaluation of historical data, the existing model identifies certain "Slope" factors, which when multiplied together, estimate a value for "Slope" for a specific shipyard. These represent the factors identified by the shipyards that would influence the intensity of learning and include factors for a shipyard's workload, work force growth, amount of change that occurred during lead ship construction, experience and construction method.

The resulting algorithms developed to estimate lead yard follow ship cost in the existing model are as follows:

$$C17_{iL} = C17_{1L} * LC_L * (1-CF_L-SF_L) + C17_{1L} *(CF_L+ SF_L)$$

$$C17_{iM} = [C17_{1M}* LC_M* (1-CF_M-SF_M) + C17_{1M}* (CF_M+SF_M)] * PR * ES$$

$$C_{iTOT} = (C17_{iL} + .25\ C89_{1L}) * LR + (C17_{iM}+ .25 *C89_1$$

where

- o SUBSET L = labor costs in manhours
- o SUBSET M = material costs in dollars
- o CiTOT = total costs of i^{th} ship in yard
- o C17i = cost of SWBS Groups 100-700 of i^{th} ship in lead yard
- o $C89_1$ = cost of SWBS Groups 800 and 900 of lead ship in lead yard
- o $C17(_1)$ = cost of SWBS Groups 100-700 of lead ship in lead yard
- o LC = learning curve factor
- o CF = changes to follow ship
- o SF = subcontracted fraction
- o PR = procurement factor
- o ES = escalation rate
- o LR = labor rate

The resulting algorithms developed to determine follow yard lead ship construction costs are as follows:

$C17_{1L}$ = ($C17_{1L}$ lead yard)*WL'*WG'*EX'*CM'*EN'*SC*EC*YL

$C17_{1M}$ = ($C17_{1M}$ lead yard *EX' *SC *EC *YL *ES *PR)

C_{1TOT} = ($C17_{1L}$ + $C89_{1L}$) *LR + ($C17_{1M}$ + $C89_{1M}$)

where

SUBSET L	=	labor costs in manhours
SUBSET M	=	material costs in dollars
C1TOT	=	total cost of lead ship in follow yard
C89	=	cost of SWBS Groups 800 and 900 of lead ship in lead yard
C17(1)	=	cost of SWBS Groups 100 - 700 of lead ship in lead yard
WL'	=	follow yard workload
WC'	=	follow yard workload growth
EX'	=	follow yard experience
CM'	=	follow yard construction method
EN'	=	follow yard climate factor
SC	=	startup costs
EC	=	local economic conditions
PR	=	procurement factor
YL	=	yard location
ES	=	expected escalation
LR	=	labor rate

For follow ship construction costs in a follow yard, the same algorithms developed for the lead yard follow ship construction costs are used, but with factors for the follow yard.

The basic problem with the existing model is that there are far too many variables to quantify with the available data base. Although an effort is made to assume quantitative values for the various parameters, and then to check them against the data, in reality, there is no confidence that the assumed values have any real meaning. In addition, given the number of parameters, the value of any single parameter is in the noise level, and differences between two values of the same parameter are well beyond the accuracy of the model. On the other hand, the various parameters are derived from the engineering judgement of the responding shipyard estimators and should not be discounted. Instead, given the lack of data, these parameters should be qualitatively assessed as a group in order to determine a trend that could be used to assign a value for learning.

A second problem with the model is that it goes beyond the scope of the lead yard models. In the lead yard models, the shipyard is assumed to be representative of U.S. industry, as opposed to a specific shipyard. In the existing follow ship/follow yard model, choices are made between individual yards. Also in the lead yard models, labor is determined as numbers of manhours, and NCA then translates these manhours into costs using other algorithms. In the existing follow ship and follow yard model there are values for labor rates.

A third problem is that SWBS Groups 800 and 900 costs for a follow ship were assumed to be 25% of the lead ship SWBS Groups 800 and 900 costs. This value was derived from historical trends experienced by BIW in the FFG 7 Class shipbuilding program. However, NCA has noted that it is significantly undervalued compared to recent information that they have access to, in particular, in the AEGIS shipbuilding program. Subsequent experience by BIW in the AEGIS shipbuilding program bore out NCA's concern, where, for example, the groups 800 labor costs for the CG 51 (lead ship in a follow yard) were 131% of those for the CG 47 (lead ship in the lead yard). The trend for SWBS Group 800 labor costs for the CG 47 Class is shown in Figure 2.

FIGURE 2

Comparison of SWBS Group 800 Labor Costs for CG 47 Class

Ship No.	Ship	SWBS Group 800 labor costs in thousands of man-hours	% Lead Ship
	Ingalls Shipbuilding		
1	CG 47	2537.9	--
2	CG 48	925.6	36
3-6	Average CG 49,50,52,53	1029.4	41
7-9	Average CG 54,55,56	432.9	17
	BIW		
1	CG 51	3452.0	131

References (4) & (5)

Material cost data is not available in sufficient detail to determine similar trends for material costs.

These problems with the existing model are addressed in the revised model. In addition, recent data acquired by NCA and BIW was made available for the revised model and provides additional data from which to determine values for the slope of the learning curve.

3.0 DESCRIPTION OF REVISED MODEL

3.1 Introduction

The revised model attempts to retain the good aspects of the existing model, while addressing the problems noted in Chapter 2. The revision does not involve a repetition of the previous effort, i.e., canvassing yards or extensive literature search, as much as a reinterpretation of the input and a reassessment of the data. A major improvement in the data base was provided for this effort and consists of recent CG 47 Class return cost data provided by NCA (Reference (4)) and BIW (Reference (5)). This data and others will be assessed in Chapter 4.

The revised model reduces the number of parameters that require quantification to the minimum necessary to establish a learning curve. It then attempts to bound the problem by identifying different scenarios that would affect the "Slope" of the learning curve, and presents representative values for "Slope" for these different scenarios. The model attempts to be consistent with the lead yard models by limiting the output to labor manhours and material costs. It also attempts not to individualize shipyards, but to differentiate between relative capabilities of shipyards with recent similar shipbuilding experience versus those without recent experience. The model is consistent with the lead yard model by differentiating between the labor costs and material costs, in the use of the SWBS breakdown developed for the lead ship models, and in the use of the lead ship costs derived from the lead yard models as a starting point for the follow ship and follow yard models.

3.2 Revised Follow Ship Cost Model

In theory, and given sufficient data, a learning curve model for follow ships at a shipyard should differentiate between labor and material costs, recurring and non-recurring costs, and costs that are and are not subject to learning. Only those recurring labor and material costs that are subject to learning should experience a learning phenomenon and the learning should be at a rate specific to the nature of the various labor and material elements. The cost of a follow ship should then be the sum of the estimated recurring labor and material costs subject to learning, added to the recurring costs not subject to learning. The cost of the class of ships built at the yard would then be the summation of the lead ship costs and the individual follow ship costs.

Figure 3 is a flow chart for the idealized model for estimating the costs of a follow ship in a shipyard. The first step is to separate the costs of the lead ship into the following:

- Material costs - all SWBS Groups

- Labor costs for:

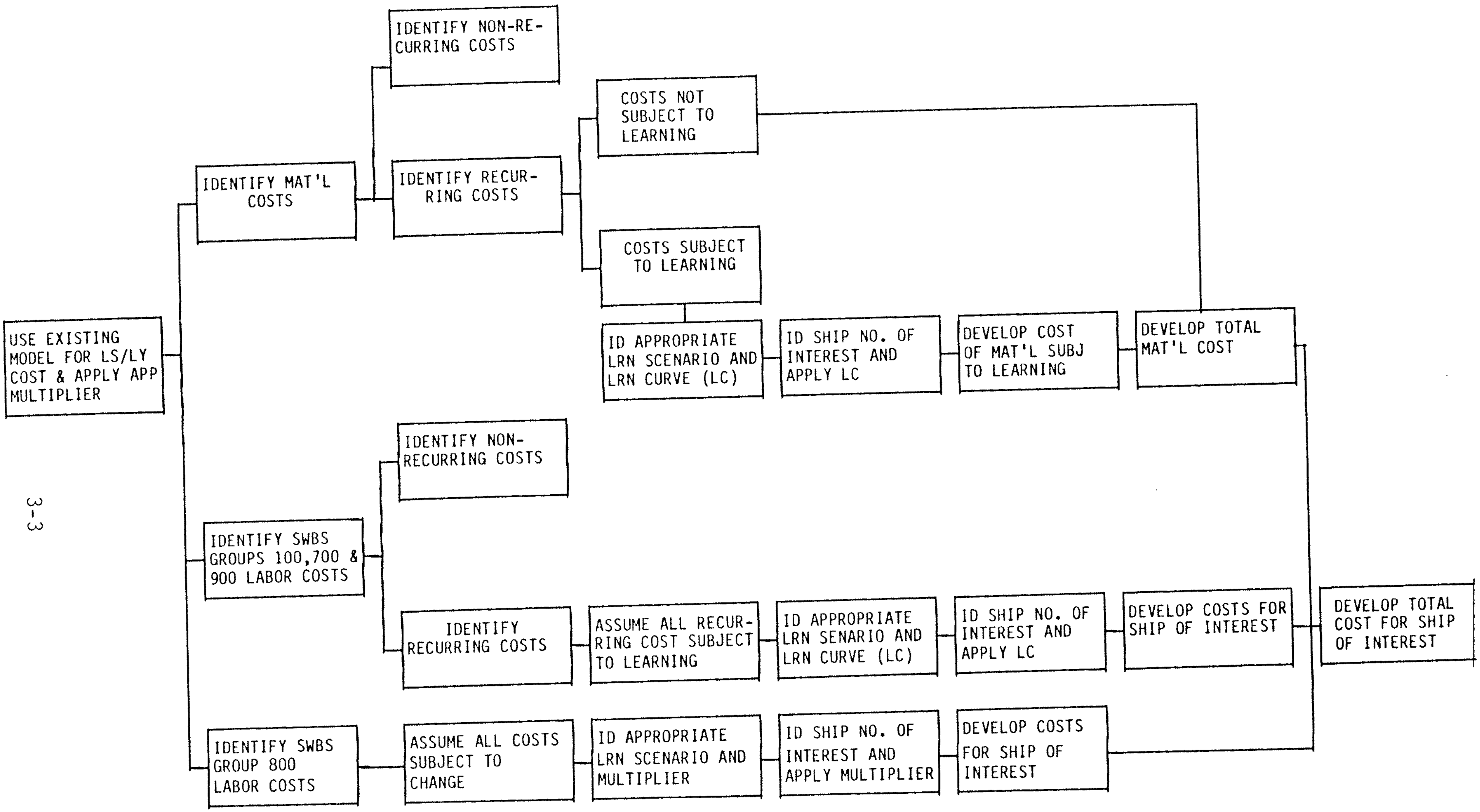
  -SWBS Group 100 - Hull Structure
  -SWBS Group 200 - Propulsion Systems
  -SWBS Group 300 - Electrical Systems
  -SWBS Group 400 - Command and Control
  -SWBS Group 500 - Auxiliary Systems
  -SWBS Group 600 - Outfit and Furnishings
  -SWBS Group 700 - Armament
  -SWBS Group 900 - Construction Services

- Labor Costs for:

  -SWBS Group 800 - Design and Engineering Services

The rationale for the breakdown is the assumption that all material costs will exhibit the same learning rate, that the basic construction labor, SWBS Group 100-700 and 900, will exhibit the same learning rate, and that the design and engineering services, SWBS Group 800, will exhibit its own expenditure rate.

The second step is to differentiate between recurring and non-recurring costs for the three groups, since non-recurring costs incurred by the lead ship will not be passed on to the follow ships.


USE EXISTING MODEL FOR LS/LY COST & APPLY APP MULTIPLIER
IDENTIFY MAT'L COSTS
IDENTIFY NON-RECURRING COSTS
IDENTIFY RECURRING COSTS
COSTS NOT SUBJECT TO LEARNING
COSTS SUBJECT TO LEARNING
ID APPROPRIATE LRN SCENARIO AND LRN CURVE (LC)
ID SHIP NO. OF INTEREST AND APPLY LC
DEVELOP COST OF MAT'L SUBJ TO LEARNING
DEVELOP TOTAL MAT'L COST
IDENTIFY SWBS GROUPS 100,700 & 900 LABOR COSTS
IDENTIFY NON-RECURRING COSTS
IDENTIFY RECURRING COSTS
ASSUME ALL RECURRING COST SUBJECT TO LEARNING
ID APPROPRIATE LRN SENARIO AND LRN CURVE (LC)
ID SHIP NO. OF INTEREST AND APPLY LC
DEVELOP COSTS FOR SHIP OF INTEREST
DEVELOP TOTAL COST FOR SHIP OF INTEREST
IDENTIFY SWBS GROUP 800 LABOR COSTS
ASSUME ALL COSTS SUBJECT TO CHANGE
ID APPROPRIATE LRN SCENARIO AND MULTIPLIER
ID SHIP NO. OF INTEREST AND APPLY MULTIPLIER
DEVELOP COSTS FOR SHIP OF INTEREST

The third step is to differentiate between the recurring costs that are and are not subject to learning. The revised model assumes that all construction related labor costs are subject to learning, whereas much of the material costs, where you may be buying a vendor's millionth product, will not exhibit appreciable learning for the numbers of items bought. Follow ship labor costs related to the design and engineering services (Group 800) are assumed to be a straight percentage of the lead ship costs. This percentage has been selected as 40% based on Reference (4).

The fourth step is to select the learning scenario that applies to the shipyard in question. These scenarios are described in detail in the following section. Learning factors for each cost group are determined from this selection of the appropriate scenario.

The fifth step is to apply the selected "Slope" to the learning curves using the following learning curve formulas:

$$FS_{\alpha} = LS_{\alpha}[i^{(b+1)_{\alpha}} - (i-1)^{(b+1)_{\alpha}}]$$

for the Individual Ship Cost, where

$$FS_{\alpha} = LS_{\alpha}(i)^{b_{\alpha}}$$

for the Cumulative Average Cost, or

$$b = \frac{\log SL_{\alpha}}{\log 2}$$

and

α - is the cost element under consideration (i.e., material costs, Group 100 - 700 and 900 labor costs, or SWBS Group 800 costs)

FS- follow ship cost

LS- lead ship cost

i - the number of the ship built in the yard to be estimated

SL- is the "Slope" selected

From this the cost estimates for the various recurring cost elements subject to learning are developed.

The sixth step is to sum all the recurring cost elements (including the material costs not subject to learning) in order to develop an estimate of the total cost for the follow ship in question.

The cumulative total costs of (i) ships built in a yard would be derived using the following formula:

$$TC_{\alpha} = LS_{\alpha}(i)^{1+b}$$

where TC - Cumulative total costs

i - is the total number of ships built in the yard

The different cost elements would be added together as before, taking care to account for material and labor costs not subject to learning. Thus, the total cost would be derived using the following formula:

Total cost for ships in yard = (Cumulative total material and labor costs) +
(Non-recurring material and labor costs) +
(1+0.4(i-1)(lead ship SWBS Group 800 costs)

3.3 Follow Ship Learning Scenarios

The rate of learning is a function of a number of factors. Early learning curve theory was developed from the experience of the aircraft and ship construction industries during World War II, where to meet defense needs large numbers of identical aircraft or ships were built in a number of different plants or yards by relatively inexperienced people. Dramatic drops in man-hour rates were observed with each doubling of the number of units produced. For example, for Liberty Ships built in World War II, declines in man-hours per vessel with each doubling of output of 12-24%, with an average 19%, (or "Slopes" of 88-76% and 81%, respectively) were experienced (Reference 6)). The dramatic declines were attributable to the fact that the designs were the same, the pace of construction steady and continuous over a large number of ships, and that the expanding workforce was relatively inexperienced to begin with, thus having a great capacity to learn.

The World War II experience was unique and not representative of the current shipbuilding environment. In the current environment, there are a limited number of shipyards that handle a majority of Naval construction. These yards typically have recent experience with similar types of ships. They also have workforces that are experienced, especially at the senior technical and management levels. Thus, the absolute capacity to learn is less than that of yards in World War II. Secondly, modern Naval ships are built in smaller numbers and there are considerable numbers of design changes between each ship. For example, BIW estimates that there were over 9000 design changes between the CG 47 (lead ship in lead yard) and CG 51 (lead ship in follow yard). These design changes have a negative effect on learning since they present new production situations. Thirdly, scheduling of ship production does not always allow for maximizing of learning. An accelerated schedule will result in follow ships beginning construction before the full learning on the lead ship is realized. On the other hand, long hiatuses between construction of follow ships results in loss of learning. As the absolute numbers of ships of a class that any single yard builds is small, the impact of these inefficiencies is large compared to a building program with a large number of units to amortize. Fourthly, the SWBS Group 800 design and engineering services portion of a ship construction program tends to be a variable that is independent of learning. As shown in Figure 2, these costs ranged from a low of 17% to a high of 131% of lead ship costs. This SWBS group encompasses a large volume of work in support of the Navy's ship acquisition office management and administrative requirements. As such, this work changes as programmatic requirements change. It is also work that is more subject to cost cutting measures since a large portion of it is not absolutely necessary to build a ship.

Typical ranges of learning curve "Slopes" for the construction labor (e.g., SWBS Groups 100-700 and 900) for post war shipyards constructing multiple Naval ships of the same class range in value from 88-90% (Reference 4 and 9, respectively). Although hard data was unavailable for material costs, "Slopes" for material costs are reported in the literature to be on the order of 97% (References 7 and 8). This high percentage is attributable to the fact that much of the material cost represents items that have already experienced the bulk of their individual learning. However, there will be learning in the form of more efficient use of the material in the shipyard as follow ships are built.

For the purposes of the revised follow ship model, the following scenarios are provided in order to estimate the factors to be used for the model:

Scenario (1)

For an experienced shipyard historically involved in Naval construction similar to that anticipated, where there are a number of ships to be built in the yard, there are changes anticipated between ships, and there is a good production schedule, the following factors should be used.

- Material Costs: "Slope" = 97%
- SWBS Group 100-700, and 900 Labor Costs: "Slope" = 88-90%
- SWBS Group 800: Multiply lead ship costs by 0.40

Choice of "Slopes" from SWBS Groups 100-700 and 900 labor costs should be 90% for a ship that it is anticipated will experience considerable change or have major schedule perturbations. The 88% range should be used for a ship that it is anticipated will not experience significant changes or schedule perturbations. If material and labor costs cannot be separated, a combined "Slope" of 93% should be used.

Scenario (2)

For a yard that is less experienced in the type of construction anticipated, and where conditions are similar to the above, two steps are required. Since this type of condition was not anticipated by the lead ship model, the lead ship labor costs must be multiplied by a factor of 1.2 to account for the inexperience of the new yard. The rationale for this is presented in Section 4.5. Material costs would remain the same. Then the following factors should be applied:

- Material Costs: "Slope" = 97%
- SWBS Groups 100-700 and 900 Labor Costs: "Slope" = 85-87%
- SWBS Group 800 Labor Costs: Multiply lead ship costs by 0.40

Selection of the "Slope" value for SWBS Groups 100-700 and 900 should be similar to that of the first scenario. Again for combined labor and material costs use a "Slope" of 88%, when necessary.

Scenario (3)

For a situation analogous to World War II, where national defense needs require opening new yards and construction of many identical ships, then the following factors should be applied:

- Material Costs: "Slope" 97%
- SWBS Groups 100-700 and 900 Labor Costs = "Slope" = 80%
- SWBS Group 800 Labor Costs: Multiply lead ship costs by 0.4

As with scenario 2, lead yard labor costs must be multiplied by a factor of 1.35 to account for the inexperience of the yards. This scenario should be viewed as a lower bound to the learning curve.

Scenario (4)

For a situation where there are radical design changes anticipated between individual ships, or there will be a very erratic schedule, a situation could arise where there would be no appreciable learning. Under this condition lead ship labor costs should be multiplied by either 1.0, 1.2 or 1.35, depending on the experience level of the yard (i.e., scenario 1, 2, or 3). Then there would be no learning factors assigned for follow ships in the class. This should be viewed as an upper bound to the learning curve.

3.4 Revised Lead Ship in a Follow Yard Model

Determining the costs of a lead ship in a follow yard is a difficult problem to conceptualize. Given the assumption that the lead ship models estimate costs for constructing lead ships in typical experienced yards, there is no reason for the cost of a lead ship in a follow yard to be different than the lead ship in a lead yard. This is particularly true for SWBS Groups 100 to 700 and 900 labor and material costs, which relate to the construction of the ship. However, both historical data and CG 47 Class data show costs are higher, with historical data ranging from 6% to 28% higher, and with CG 47 class data being 17% higher. On the other hand recent DDG 51 Class bidding experience would indicate significantly less effort for the lead ship in the follow yard (even less than the first follow ship in the lead yard). The follow yard bid is on the order of 65% of lead ship bid. Naturally, these are bid values and not return costs; however, they are fixed price bids. The likelihood of the follow yard costs growing by 50% to match the CG 47 experience seems small. Thus, given the inclusiveness of the data, the revised model will assume that there is no difference between lead yard costs for experienced yards for SWBS Groups 100 to 700 and 900, and for material costs.

Group 800 costs also present a problem. It would be assumed that the bulk of the non-recurring design and engineering services costs would be assigned to the lead ship and that the follow yard would experience SWBS Group 800 costs similar to that of the follow ships in the lead yard. Again, data is inconclusive. For the CG 47 Class experience (the only recent data available), the follow yard lead ship (CG-51) SWBS Group 800 costs were 36% higher than the lead ship SWBS 800 costs. Cost estimators at BIW advised that these costs represented an unrealistically high data point. However, the likelihood of the normal situation being nearly 100% less than the CG 47 experience in order to match the lead yard follow ship data is small. Therefore, for the purposes of the revised model, the follow yard, lead ship SWBS Group 800 costs will be considered to also be the same as the lead yard, lead ship SWBS Group 800 costs.

The final factor to consider is the experience of the shipyards in question. If the follow yard is typical of those described in scenario 2 and 3 in Section 3.3, then the lead ship labor costs should be multiplied by the appropriate factor to account for experience.

Once the appropriate costs have been estimated then they can be summed to determine a lead ship in a follow yard cost. As an alternative, the recurring costs elements can be used as input into step three of the revised follow ship cost model and, along with the proper learning factors for the follow yard, be used to estimate follow ship costs in a follow yard.

3.5 Multi-Year and Multi-Ship Procurement

The impact of multi-year or multi-ship procurement was briefly addressed in the original model. Both BIW and Tacoma Boatbuilding provided assessments as to the potential cost savings that might result from quantity ship buys. The values of these savings were estimated at between 5 and 10 percent.

As part of this study this issue was again investigated, and it was determined that learning in the new model structure already encompasses the effects of multi-year or multi-ship buys on costs for surface combatants and most auxiliary or amphibious ships that are produced in series. Additionally the lead ship models are based on data from multi-ship programs. The reason for this is the fact that, particularly for destroyer-type surface combatants, the ships are normally procured in quantity in a continuous fashion over a relatively well-defined period of time; therefore, the number of ships procured and the experience of a particular shipyard with the ship type of interest become the primary variables. The result is that this model allows for multi-year/ship procurements, which is normal for the ship types of interest. In the event a single-ship buy is contemplated, then the original shipyard estimates of a 5 to 10 percent cost difference should be added to the value obtained for SWBS groups 100-700 and 900 from the lead ship models.

Multi-ship or multi-year procurement savings in the context in which it is most commonly discussed is really applicable to ships that are procured in limited numbers or in an unpredictable manner, e.g., aircraft carriers. This situation differs significantly from that associated with the ship types addressed by the lead ship and the Follow Ship and Follow Yard models and has not been addressed.

4.0 DATA ANALYSIS

4.1 Introduction

The data used for this modeling effort consists of three types of data: (1) historical, (2) data provided in the original model, and (3) data developed for the revised model. The historical data consists of data identified during the literature search and includes data related to the World War II experience, as well as some post war military and commercial shipbuilding programs. The data provided in the original model consists of input from BIW on the FFG 7 Class shipbuilding program. The data developed for the revised model consists of data for the CG 47 Class shipbuilding program provided by NCA and BIW. The remaining sections of this chapter will address each of these data sets.

The major difficulty in the data analysis for this effort concerns the availability of data in sufficient detail to be of use in quantifying the various parameters in the model. In order to develop a sufficiently large database, detailed return costs are required from a number of yards, over a number of ships, even to assess a single ship class. This problem is compounded if there is a desire to compare multiple ship classes.

Typically, return cost data is not the type of information a shipyard likes to divulge, since this database is what they use to develop their competitive bids. In the initial modeling effort, only BIW, out of seven major shipyards, was willing to provide such data.

A second source of return cost data is the data reported to the Navy by the shipyard. This data varies in detail depending on the nature of the contract and on the programmatic requirements imposed upon the shipyard by the Navy. For example, a shipyard with a fixed price contract may only have to report percentage complete, whereas a shipyard with costs plus fixed fee award will be required to bill the Navy by labor category and direct expense. In either case, the data is usually proprietary and must be sanitized before it can be assessed by non-Navy personnel. In addition, the data analysis will not reflect shipyard estimator's judgement, which has been a valuable source of information in the lead ship models.

Another issue related to the availability and quality of the data is the use of the SWBS breakdown. None of the shipyards account for costs internally using the SWBS breakdown. Instead, they use their own functional breakdown to account for costs internally, then allocate costs to a SWBS number for reporting and bidding purposes. As ships are increasingly being built using zone construction and extensive preoutfitting, the visibility, for accounting purposes, of individual systems is becoming less. As such, the reliability of data in the SWBS format is less since there are elements of subjectivity in the determination and assignment of the data into the SWBS format.

An issue related to the completeness of the available data is various funding sources for costs reported and the impact on the data. In the CG 47 Class, for example, much of the material purchases are handled either as government furnished material or class common equipment. These procurement methods allow various sources of funding to be used and allow for cost savings through bulk purchases. The problem is that these costs are reported separately and are often amortized over a series of ships in the class. Similarly, certain labor costs are spread out through multiple ships or are split between the ship construction activities and the planning yard services type contracts.

The issue of competitiveness between shipyards also affects the data. The model reflects the "cost" of a ship in return costs, as opposed to the "price" of a ship in competitive bid prices. The price of a ship is the primary issue related to competitiveness since it reflects the business decisions a shipyard makes in determining their bid, whereas return costs reflect the actual effort required to construct the ship. However, during periods of slow construction, when competition is strong or shipyards are bidding against known budgetary limits, bids are very low and affect the return costs through cost cutting measures. These impacts are difficult to identify, since they relate to how a shipyard structures its bid and conducts its business. It is also an issue that is beyond the scope of the present effort, since it reflects economic conditions and business decisions that are not accounted for in the lead ship models.

4.2 Historical Data

Four sources (References 6, 7, 8, 9,) were identified in the literature that relate to cost savings for multiple ships. The relevant portions of these four papers are presented in Appendix D and their results will be summarized in this section.

Reference (6) is an excellent summary of the World War II experience. To meet defense needs, ship production during World War II was 50 times that of pre-war levels. To accommodate this production, a number of standard designs were introduced that lent themselves to mass production methods, including prefabrication of components outside the yard. The Liberty Ship is the outstanding example of this method, although this method was applied to Victory Ships, other commercial ships and even destroyer-escorts with similar results. Regarding the Liberty Ships, over 2400 were built during the war, and as many as 14 shipyards were in production at one time. As shown in Figure 4 the rate of drop was highest early in the program, and began to level off with time. In subsequent ship construction programs the initial drop is higher, partially through learning gained from the Liberty Ship program.

Figure 5 presents data for the reduction of man-hours per vessel with increasing production. As can be seen, the data plotted on log-log paper gives a straight line and shows a decrease of approximately 20% with each doubling of production. This 20% drop is the genesis of the 80% "Slope" for the learning curve for the wartime experience.

The report concludes by noting that although some production methods and practices developed during the war would have postwar utility, it would not be possible during peacetime to use uniform plans or mass-production methods to the extent practiced in the war.

Reference (7) is a report that presents data from World War II, and post World War II MARAD data and circa 1966 Naval/ship procurement data.

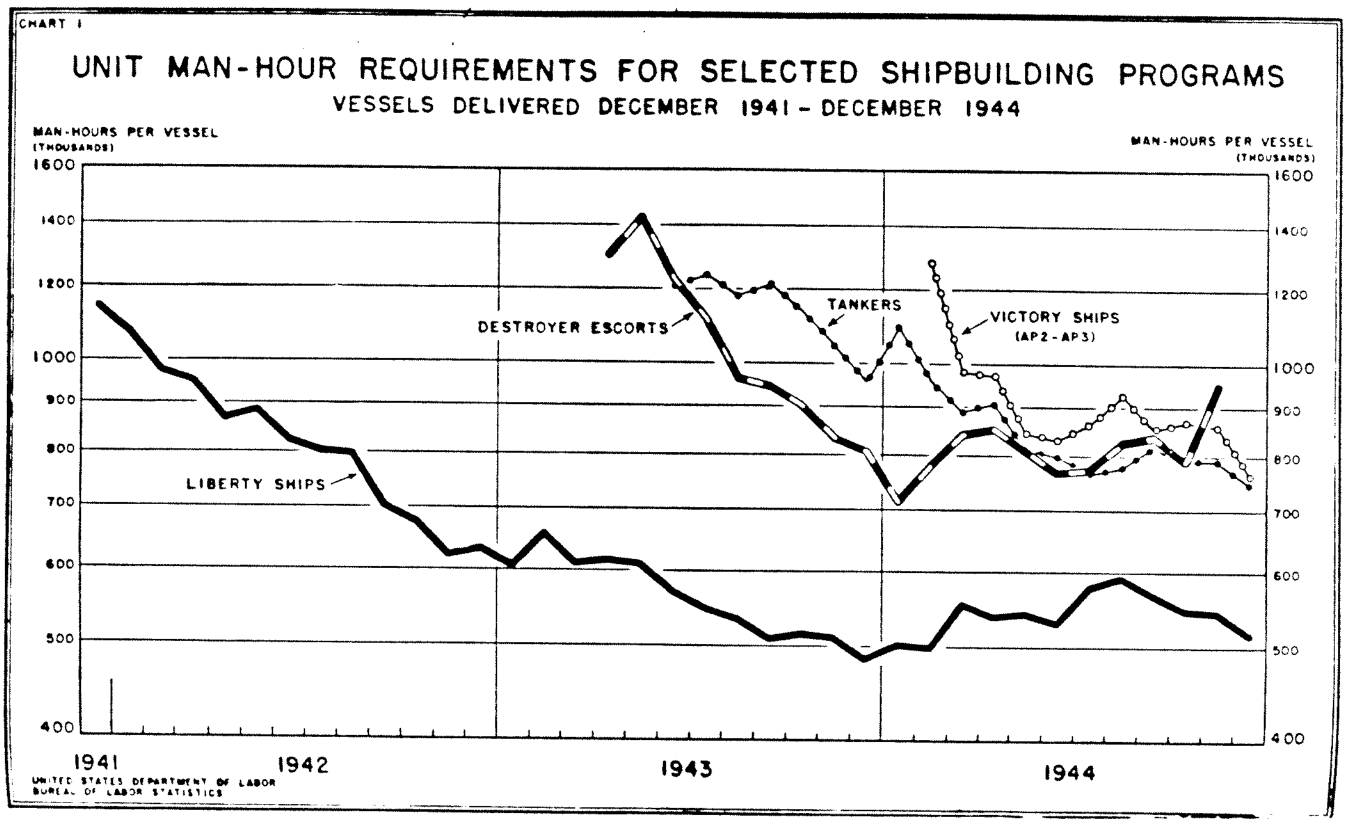


FIGURE 4
Unit Man-hour Reductions for Selected World War II Shipbuilding Programs

Source: Monthly Labor Review, December 1945.

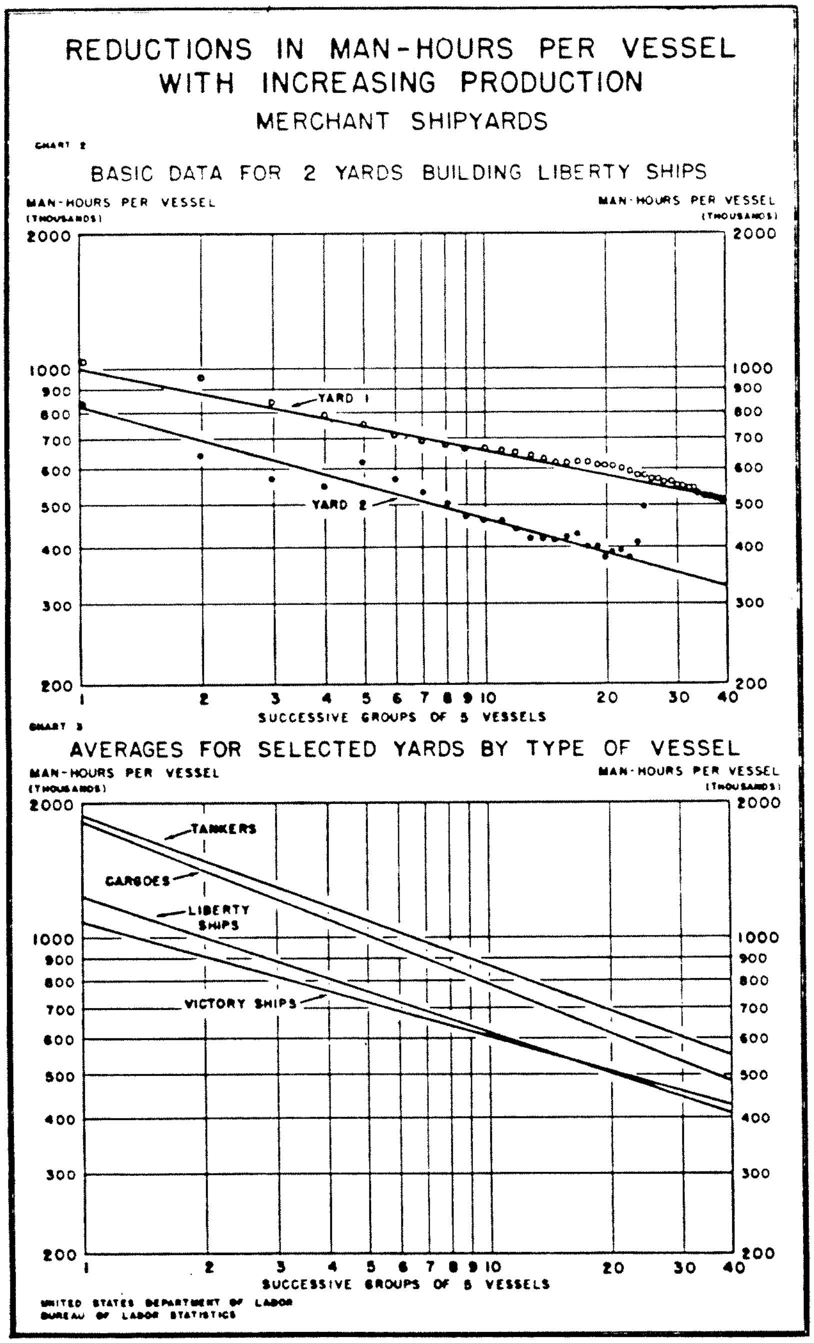


FIGURE 5

Reductions in Man-hours per Vessel
with Increasing Production

Source: Monthly Labor Review, December 1945.

Figures 6-9 present a summary of the progress curves for the U.S. built ships discussed in the paper. The Liberty Ship and destroyer escort data shown in Figures 6 and 7 are consistent with Reference (6).

The post-war MARAD data shown in Figure 8 indicates progress curve rates ranging from a 75 percent slope to a 95 percent slope, with the majority between 85 and 95 percent based on percent of lead ship man-hours. The author concluded that the data showed a rough correlation of "Slope" coefficients with that of the World War II experience.

The circa 1966 Naval ship procurement data shown in Figure 9 indicates progress curves on the order of 90 to 95 percent slopes based on percent of lead ship costs.

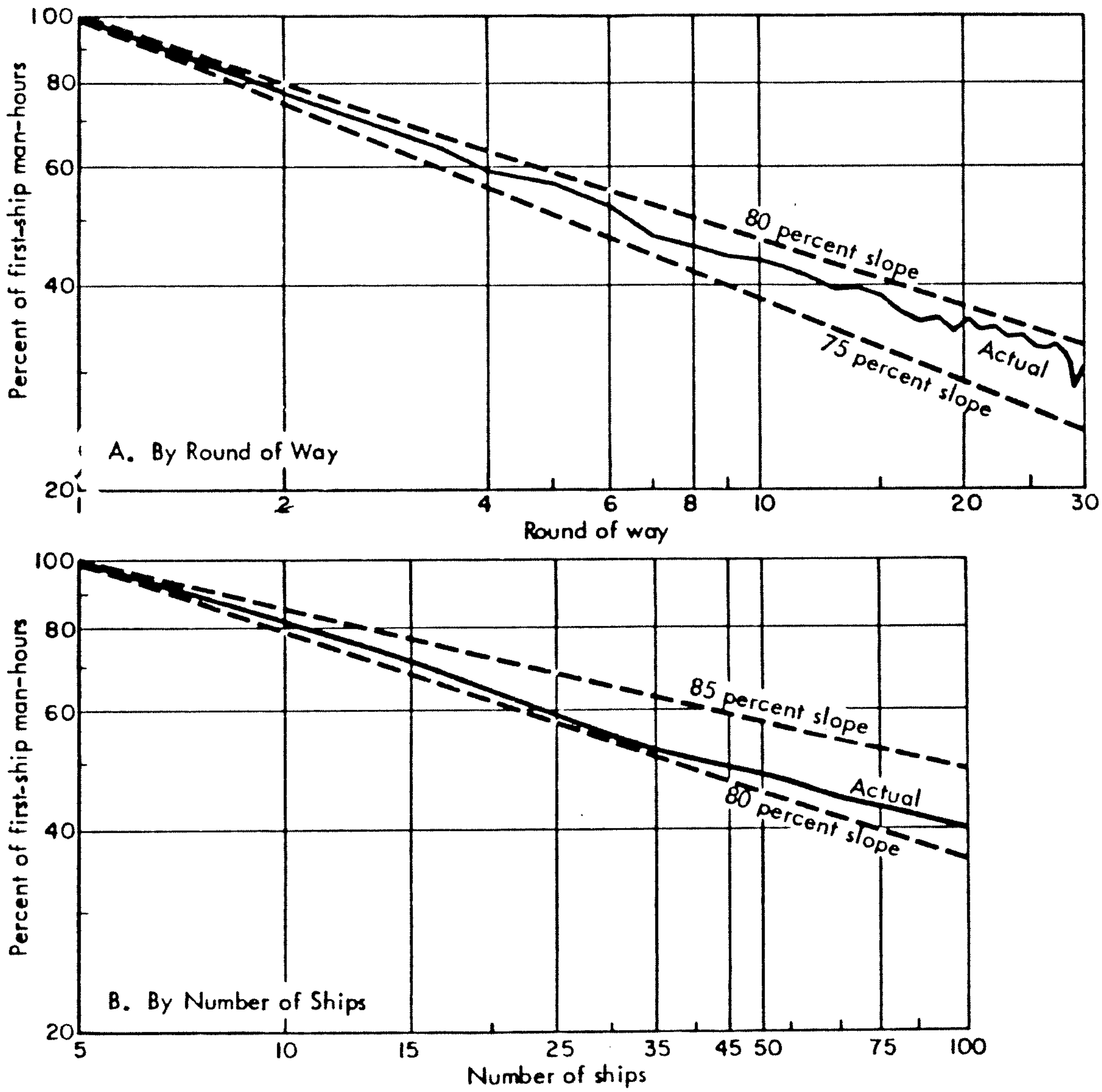
Also of interest in the circa 1966 Naval Ship procurement data are the relative costs of lead ships in different yards. Follow yard lead ship costs were consistently higher than lead yard lead ship costs and ranged, in percent, from 114% to 128% for two follow yards constructing destroyer escorts, and 106% to 117% for four follow yards constructing LST's. The average increase for the LST data was 110%.

Reference (8) is a summary of lecture notes by Joseph Fetchko and based on MARAD studies. It reports an average "Slope" for material of 97% and for labor of 88%. These factors were used for a combined labor and material "Slope" of 93%.

Reference (9) is a paper by John Couch which differentiates ship costs into five components: labor, material, non-recurring costs, overhead and profit. Of concern for the current model are the recommended "Slope" for labor and material, which are quoted at 90% and 97%, respectively.

4.3 FFG 7 Class Data

In the original modeling effort, BIW provided data from their FFG 7 Class construction experience. This input is contained in Appendix B. BIW



Source: Monthly Labor Review, December 1945.

FIGURE 6

Progress Curves for Liberty Ships
During World II

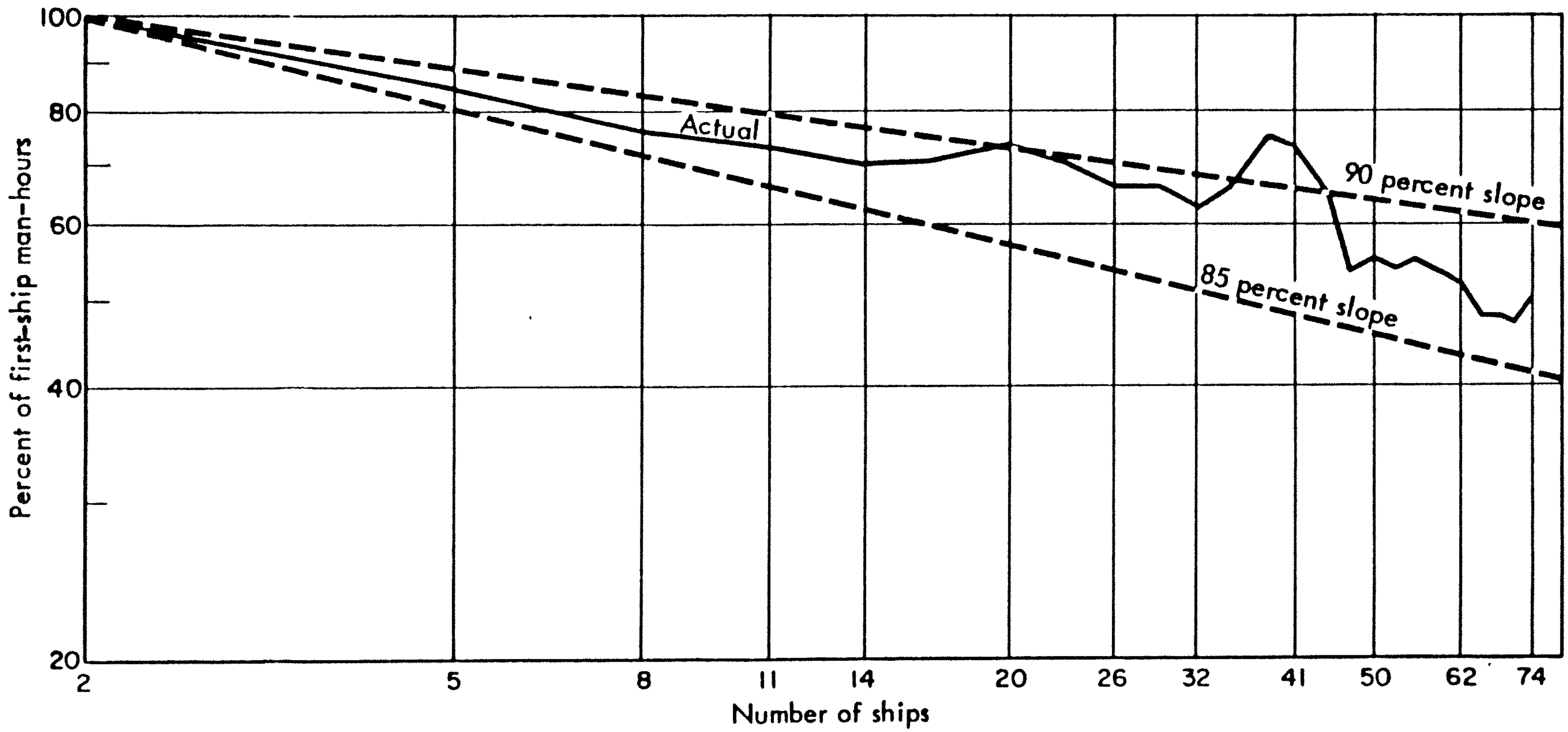


FIGURE 7

Progress' Curves for Destroyer Escorts
During World War II

Source: Monthly Labor Review, December 1945.

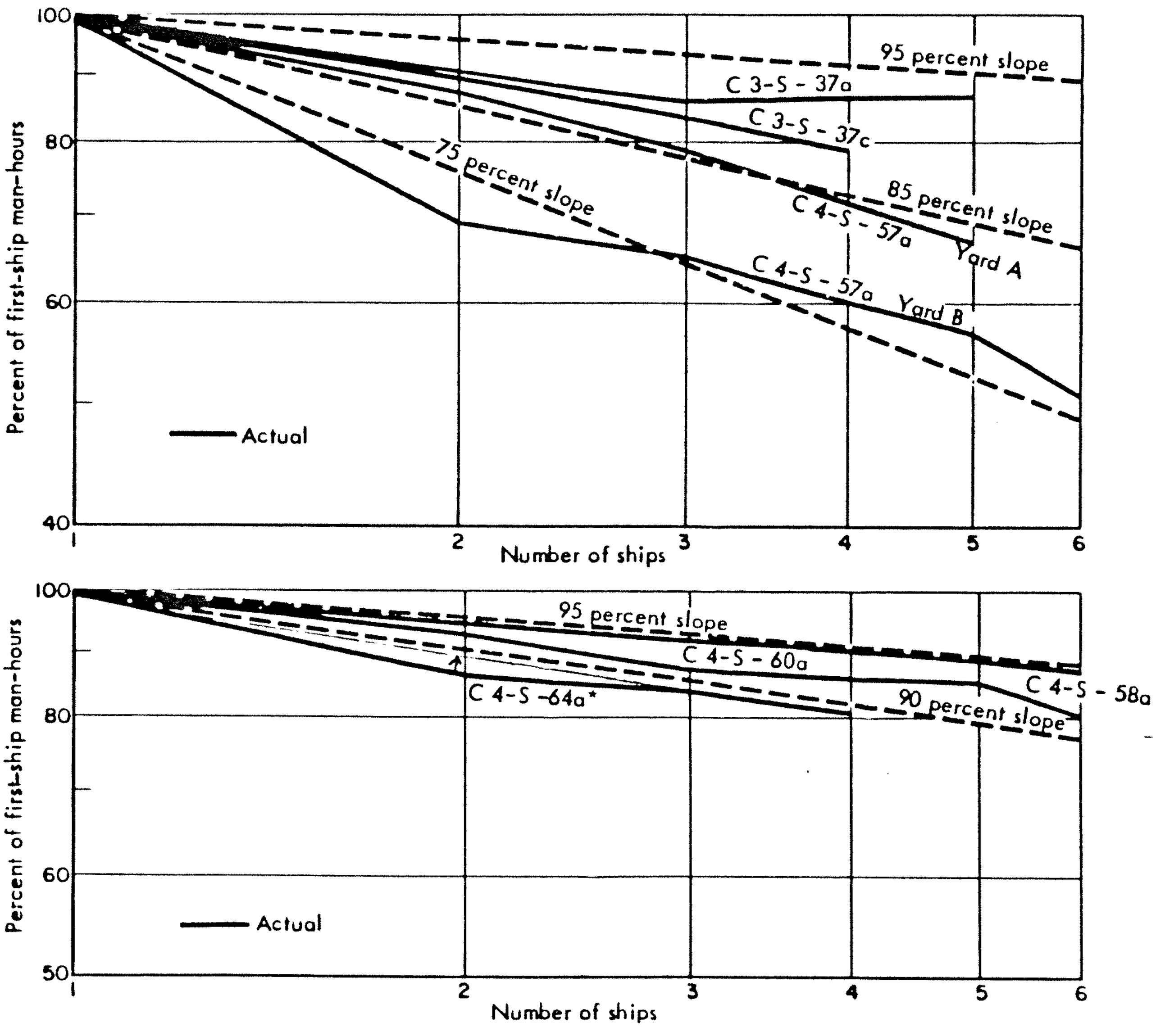
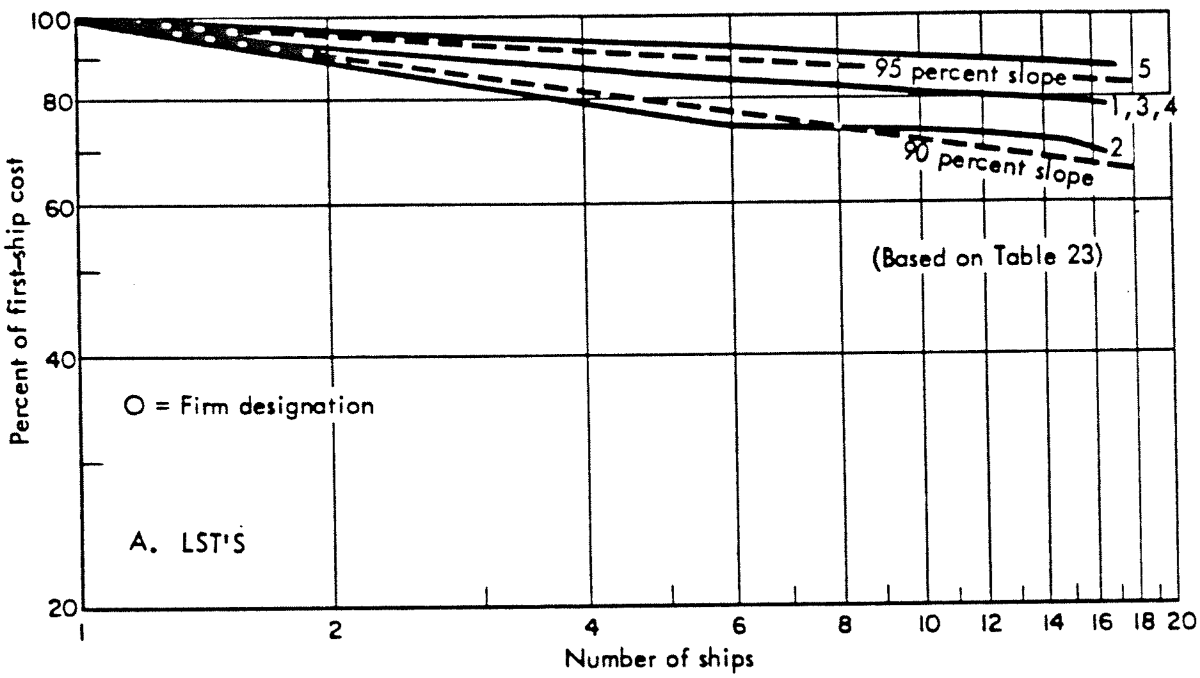


FIGURE 8

Progress Curves for MARAD Construction
Post-World War II



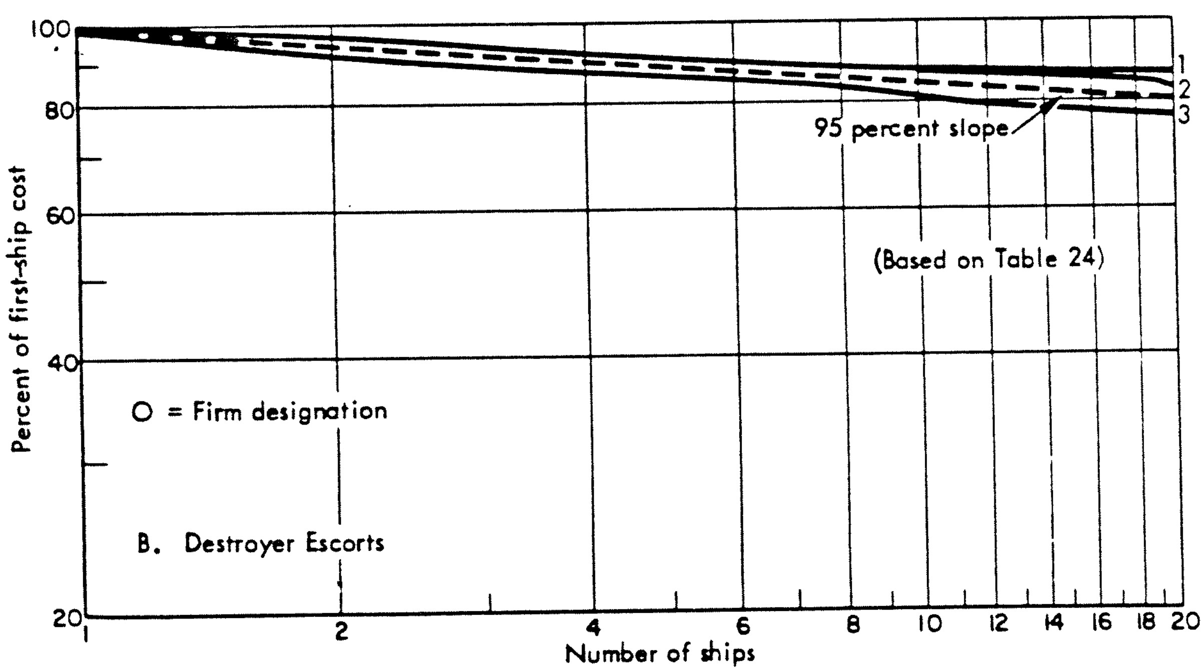


FIGURE 9
Cumulative Average Cost of LST's and
Destroyer Escorts for Several Firms

reported that their combined learning curve "Slope" is 93% and believed this represented a program with minor changes and minimal production problems. They also reported that the SWBS Groups primarily subject to learning are 100 through 700 and 900.

Figure 10 provides a summary of the FFG 7 Class data provided in the original model. Since SWBS Groups 800 and 900 were considered to be a percentage of lead ship costs, they are not provided in this summary. For SWBS Group 100-700, the "Slopes" derived for the labor costs are 82% between ships 1 and 2 and 90% between ships 2 and 4. Material costs "Slopes" are 78% between ships 1 and 2 and 95% for ships 2 and 4.

FIGURE 10

FFG 7 Return Costs Data

(i)	Ship	Labor Costs (SWBS 100-700) (k) man-hours	Material costs (SWBS 100-700) $k
1	FFG 7	1487	39349
2	8	1226	30470
3	11	1176	29578
4	13	1097	28998
12	34	896	29021

The data indicates significant reductions in manhours between ships 1 and 2 that cannot be explained using pure learning curve theory. The "Slope" values for ships 2 and 4 are more in line with those in the literature; however, it should be noted that the material costs do not show a consistent decline throughout the class. Using the FFG 8 costs as representative of lead ship costs, the labor costs for the FFG 12 (ship number 11 for this example) represents a learning curve "Slope" of 91%, which is again consistent with the literature.

4.4 CG 47 Class Data

The most recent data available for this study is on the CG 47 Class. The full data set is provided in Appendix E and a summary of the data is provided in Figure 11. Visibility of material cost is lost in this data set due to material costs being accounted for in a separate manner after CG 48. Therefore, the data set is primarily useful for assessing labor man-hours. The data set is further limited by the fact that costs are reported for groups of ships after the CG 47. Fortunately, the ships of interest in these groups are in the middle of the grouping and average costs for the group should be representative of these ships.

Figure 12 is a summary of the learning curve "Slopes" for the CG 47 Class ship built in the lead yard. Within each SWBS Group there are large variations between ships; however, on average they fall within the 85% to 93% range for SWBS Group 100-700 and 900. The average "Slope" for these SWBS Groups is 88%. SWBS Group 800 shows, as anticipated, no consistent "Slope". Given the limitations of the data, it is not possible to discern individual differences between SWBS Groups on ships; however, the accumulated average "Slope" of 88% for SWBS Groups 100-700 and 900 is consistent with the historical literature.

One final aspect of the data presented in Figure 13 is the relative costs of the lead ships in both the lead and follow yards, using man-hours as an indicator. For SWBS Groups 100-700 and 900 the lead ship in the follow yard was 117% that of the lead yard. For SWBS Group 800, the follow yard was 136% of the lead yard. For all SWBS groups this percentage was 123%. Of note, the BIW estimators believe the CG 51 Group 800 costs are abnormally high.

4.5 Values Selected for Use in Model

Based on the data reviewed in sections 4.1 through 4.4, the following values for "Slopes" and other factors elected for use in the model are as shown in Figure 13.

FIGURE 11

Summary of CG 47 Class Return Costs

Data for Labor Man-Hours (kmhrs)

SWBS Group	CG 47 (i=1)	CG 48 (i=2)	AVE CG 49/50/52/53 (Includes i=4)	CG 54/55/56 (Includes i=8)	CG 51 Lead ship in follow yard
100	808.9	735	717.5	662.6	885.6
200	186.1	149.1	127.3	114.8	145.1
300	760.4	589.2	541.0	461.0	432.7
400	205.0	142.4	143.9	129.1	328.7
500	868.2	765.6	719.0	656.0	689.2
600	749.3	646.2	608.4	530.0	744.7
700	71.8	68.6	63.0	45.8	71.1
800	2537.9	925.6	1029.4	432.9	3,452.0
900	1480.7	1053.5	970.3	864.9	2,703.0
TOTAL	7668.3	5075.2	4920.3	3897.1	9459.1
SWBS Group 100-700 and 900	5130.4	4149.6	3890.9	3464.2	6007.1

FIGURE 12

Summary of Learning Curve "Slopes" for CG 47 Class Lead Yard Labor Man-Hours by Ship and SWBS Number

SWBS Group	i= 1 and 2	i= 2 and 4	i= 4 and 8	AVE
100	0.91	0.98	0.92	0.93
200	0.80	0.86	0.90	0.85
300	0.77	0.92	0.85	0.85
400	0.69	1.01	0.90	0.87
500	0.88	0.93	0.91	0.91
600	0.86	0.94	0.87	0.89
700	0.95	0.92	0.73	0.87
800	0.36	1.11	0.42	0.63
900	0.71	0.92	0.89	0.84
Total 100-700,900	0.81	0.93	0.89	0.88

FIGURE 13

Values Selected for Use in Model

Parameter	Historical Data	FFG-7 Data	CG47 Data	Value Selected
o Total Cost "Slope"				
- Scenario 1[1]		93%		93%
- Scenario 2				88%
- Scenario 3	80%			80%
o SWBS Group 100 to 700 and 900 Labor "Slope" (Scenario 1)	88-95	90%	88%	88-90
o SWBS Group 800 Labor "Slope" (Scenario 1)	-	.25 of lead ship	.2 to .136 at lead ship	0.4 of lead ship
o Material costs slope	97%	95%		97

(1) See Section 3.3

4.6 Derivation of Experience Multipliers for Different Yards

As noted, the lead ship models assume a capable and experienced shipyard is building the ship. For circumstances where a less capable, or, in the extreme, a new, inexperienced shipyard is building the ship, there will be both a greater amount of learning taking place (as shown by "Slopes" of 85% and 80%, respectively), as well as a higher cost for the lead ship in these yards. To obtain an estimate of how much higher the lead ship in these more inexperienced yards would be compared to the experienced lead yard, a factor was estimated using the cumulative average cost formula and assuming that between the 3rd and 6th ship the various yards begin to produce ships for roughly the same cost.

A factor for the i^{th} follow ship is obtained as follows:

$$FS = LS(i)^b$$

$$FS = 1.0(3)^{-.105}$$

$$FS = .829$$

Then a lead ship cost in an inexperienced yard is derived in the following manner:

$$FS = LS(i)^b$$

$$.829 = LS(3)^{-.234}$$

$$LS = 1.15$$

This was done for a number of conditions and a value for the model was selected. Figure 14 shows a summary of the values derived.

FIGURE 14

Summary of Experience Multipliers for Different Shipyards

Shipyard (1)	Total "Slope"	b	LS Factor 3rd Ship	LS Factor 6th Ship	Selected for Model
Scenario 1	.93	-.105	1.0	1.0	1.00
Scenario 2	.85	-.234	1.15	1.26	1.20
Scenario 3	.80	-.322	1.26	1.47	1.35

(1) See Section 3.3

5.0 USE OF THE REVISED MODEL

5.1 Introduction

The Revised Follow Ship and Lead Ship in a Follow Yard Cost Model is significantly different from the original model. Therefore, the worksheet and supporting data for the original model cannot be used for the revised models. In this chapter, new worksheets and data sheets are provided and these new sheets supersede those of the original model.

One of the goals of the current effort was to simplify the model, both to make it easier to use and to make it more consistent with the level of detail of the data available. As noted earlier in the report, the various "Slope" and shipyard factors identified in the orginal model were based on shipyard estimators' judgement of the factors which would impact follow ships or follow yard costs. Even though these factors are not included in a quantitative way in the revised model, they should be qualitatively considered when selecting between the various scenarios presented in the revised model. These factors are described in Appendix B in their original form.

5.2 Revised Follow Ship Cost Model

Figure 15 provides a summary of the inputs required for the revised follow ship cost model. The primary sources of the lead ship costs are lead ship models and the specific design information NCA is using for preparing the estimate. The information for the learning scenario information is contained in section 3.3 of this report. The follow ship information is based on the specific problem NCA is investigating. Values for labor rates and inflation rate are derived from other models used by NCA. It should be noted that the value of (i) is for the number of ships built in an individual shipyard, and that if a class of ships built at different yards is under consideration, the model user must develop estimates for each shipyard.

FIGURE 15
Required Inputs for
Revised Follow Ship Cost Model

Project Title: ____________________

____

Lead Ship Costs

Material Costs(All SWBS Groups)	
Recurring costs	$ ______
Non-recurring costs	$ ______
Total	$ ______
SWBS Groups 100-700 and 900 Labor Costs	
Recurring costs	______ MHRS
Non-recurring costs	______ MHRS
Total	______ MHRS
SWBS Group 800 Labor Costs	
Recurring costs	______ MHRS
Non-recurring costs	______ MHRS
Total	______ MHRS
Total lead ship costs	
Material	$ ______
Labor	______ MHRS
Follow ship information	
Number of to be ships built in shipyard	______
Labor rate (LR)	______
Inflation rate(IR)	______
Fiscal year(FY)	______
Learning scenario information	
Scenario selected (1-4)	______
Material "Slope" selected	______
SWBS Group 100-700 and 900 "Slope" selected	______
SWBS Group 800 Labor Factor Selected	______
Combined Labor and Material Costs "Slope" selected (if appropriate)	______
Lead ship labor cost multiplier (1.0, 1.2, 1.35)	______

Figure 16 provides a worksheet for developing the follow ship costs. The worksheet is fairly straightforward and self explanatory. Explanations of the various factors are found in Chapter 3. The model attempts to provide flexibility in the estimating process based on the amount of data available, and the type of follow ship cost information desired. If all lead ship non-recurring material and labor costs can be estimated, then all three columns on the worksheet can be employed and follow ship costs for each group estimated, and then summed using appropriate inflation and labor rates. On the other hand, if only total material and labor costs can be identified, or if only total costs can be identified, the same procedure can be used, except that different "Slope" factors and multipliers should be used based on the discussion in Section 3.3. For the condition where only total lead ship material and labor costs are known, the first two columns should be used (i.e., Group 800 costs grouped with other SWBS Groups). If only a total lead ship combined material and cost is known, the second column should be used in order to assure that the lead ship multiplier is accounted for. In this case, all the costs would be identified in dollars and the worksheet should be marked up accordingly. It should be recognized that as lead ship cost data gets grouped together, the accuracy of the estimate is lessened. This is especially true when total material and labor costs are combined and the overall cost is multiplied by the lead ship multipliers.

Flexibility is also provided in the model for estimation of the individual ship cost, the cumulative average cost, or the cumulative total cost, depending upon the requirements of the problem NCA is investigating.

5.3 Revised Lead Ship in a Follow Yard

The revised ship in a follow yard does not require a separate worksheet, since it is essentially the lead ship costs, with labor costs multiplied by the lead ship cost multiplier. Thus, the first three rows of Figure 16 can be used to derive an estimate of the cost of a lead ship in a follow yard, i.e. the sum of modified lead ship cost on Figure 16.

FIGU 16

Follow Ship in a Shipyard Cost Estimating Worksheet

Project Title:

	MATERIALS COSTS (ALL SWBS GROUPS) ($)	SWBS GROUP 100-700 AND 900 LABOR COSTS (OR TOTAL COSTS, IF APPROPRIATE) (MHR)	SWBS GROUP 800 LABOR COSTS MHR
1 Lead Ship non-recurring costs	______	N/A	______
2 Lead Ship recurring costs (or total costs, if appropriate)	______	______	______
3 Lead Ship labor cost multiplier (1.0,1.2,1.35)	N/A	______	______
4 Modified Lead Ship Recurring Cost (LS = #2 x #3)	______	______	______
5 Follow Ship Data			
i= ______			
Labor Rate ______	N/A	______	______
Inflation Rate ______	______	______	______
6 Learning Scenario Data Slope(SL)	______	______	N/A
Group 800 Multiplier	N/A	N/A	0.4
$b = \frac{\log SL}{\log 2}$	______	______	N/A
7 For individual ship cost $FS=LS(i^{b+1})-(i-)^{b+1}$,	______	______	N/A
Group 800=LS/0.4)	N/A	N/A	______
8 For cumulative average cost $FS=LS(i)^b$	______	______	N/A
Group 800=LS(.4)	N/A	N/A	______

FIGURE 16 (continued)

Follow Ship in A Shipyard Cost Estimating Worksheet

Project Title:

	MATERIALS COSTS (ALL SWBS GROUPS)	SWBS GROUP 100-700 AND 900 LABOR COSTS (OR TOTAL COSTS, IF APPROPRIATE)	SWBS GROUP 800 LABOR COSTS
9 For cumulative total cost $CT=LS(i)^{1+b}$ Group 800=(1+0.4(i-1)LS)	______ NA	______ NA	NA ______

Total follow ship cost = (Individual ship or cumulative average material costs) x (Inflation factor) + (Individual ship or cumulative average SWBS Group 100-700 and 900 labor costs + Individual ship or cumulative average SWBS Group 800 labor costs) x (Labor rate)

Total cost of ships in yard = Lead ship costs + Σ Follow ship costs

or

Total cost of ships in yard = (Cumulative total material and labor costs in dollars) + (Non-recurring material and labor costs in dollars) + [(1+0.4(i-1)] (Lead ship SWBS Group 800 costs in dollars)

Lead ship in follow yard costs = Summation of modified lead ship costs

=(Modified material costs) x (Inflation factor) + (Modified SWBS Group 100-700 and 900 labor costs + Modified SWBS Group 800 labor cost) x (Labor rate)

6.0 CONCLUSIONS AND RECOMMENDATIONS

This report presents a revised follow ship and follow yard model that attempts to address the shortcomings of the original model. The original model was a first attempt to identify the factors which influence follow ship and follow yard costs and to structure a model to estimate these costs. The model that was developed was too complex to be verified with the data available, went beyond the scope of the existing lead yard models, and predicted low costs for SWBS Group 800 costs.

The revised model reduces the number of variables to the minimum to establish a learning curve. It thus bounds the problem by identifying different scenarios that affect the "Slope" of the learning curve, and presents representative values for the "Slope" for these different scenarios. The revised model also provides an estimate of the impact on lead ship costs if the shipyard being evaluated is less experienced than that assumed in the lead yard models. The revised model also updates the SWBS Group 800 costs, based on recent CG47 Class return cost data.

The revised model is consistent with the lead ship models by limiting output to labor man-hours and material costs. It also does not individualize shipyards, but differentiates between relative capabilities of shipyards with varying degrees of relevant experience. The revised model is also consistent with the lead yard models by limiting output to labor man-hours and material costs. It also does not individualize shipyards of varying degree of relevant experience. The revised model is also consistent with the lead yard models by differentiating between labor costs and material costs, in the use of the SWBS breakdown and in the use of the lead ship costs as input to the revised model.

The revised lead ship in a follow yard cost portion provides an estimating method for developing a lead ship cost based on the relative experience of the follow yard, as compared to the lead ship cost model. Unfortunately, the data available was inconclusive concerning follow yard cost trends, and the assumption was made that given a lead follow yard of equal experience, lead ship costs in both yards would be the same.

This report also provides a summary of the data used for revising the models, which consisted of historical data derived from the literature, FFG 7 Class data provided by BIW during the original modeling effort, and CG 47 Class data provided by NCA and BIW for the current effort. The data represents shipbuilding experience over the last 45 years and the trends indicated by the data are relatively consistent with time. The major difference was the World War II experience, where new, inexperienced yards were established to meet the war demands. The availability of the CG 47 Class return cost data helped to improve the model greatly because it provided insight into a very recent U.S. Navy shipbuilding program.

The primary recommendation for further development of the models is to expand on the models as data becomes available. No attempt was made in this effort to differentiate between type of ships, such as surface combatants, auxiliaries or amphibious ships. Also, no attempt was made to identify trends among individual SWBS groups. Also, as mentioned, there was insufficient data available to rigorously assess lead ship costs in lead and follow yards. These would be the type of assessments that could be considered if further data were made available.

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APPENDIX A

LITERATURE SURVEY, ANNOTATED BIBLIOGRAPHY

APPENDIX A

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APPENDIX B

G&C INQUIRY TO SHIPYARDS, BIW AND TACOMA BOATBUILDING RESPONSE

Letter to Shipyards

MAIN OFFICE
119 WEST 31ST STREET
NEW YORK, N.Y. 10001
212-613-1300

NEWPORT NEWS, VIRGINIA 23605
804-380-5800

GIBBS & COX INC

NAVAL ARCHITECTS AND MARINE ENGINEERS
1235 JEFFERSON DAVIS HIGHWAY • ARLINGTON, VIRGINIA 22202
703-979-1240

19541 (4-0550) 9 May 1983

Mr. Frank Silva
Manager, Cost Engineering Department
Newport News Shipbuilding & Dry Dock Co.
4101-T Washington Avenue
Newport News, VA 23607

Subject: Request for Indication of Interest in Follow Ship Cost Impact Study

Enclosure:
(A) Information Required for Study

Gentlemen:

1. Gibbs & Cox, Inc., under contract to the U.S. Navy, has been and is involved in the development of Ship Cost Models for OPNAV (OP-96). The current development of cost models for destroyer-cruiser and auxiliary-amphibious type ships has resulted in useful preliminary cost-estimating tools; however, there are a number of limitations to these models. Five primary areas are currently in need of further development to enhance the value of the current models by extending their usage and increasing confidence in their accuracy. These areas include the following:

- The models now estimate only lead ship costs, whereas experience with past buys has been with an average of five ships in each of twenty-one auxiliary-amphibious classes and fifteen ships in each of eleven frigate-destroyer-cruiser classes. As a result, it is important to extend the models to accommodate follow ship costs and the effects of multiple ship buys.

- The identification of recurring and non-recurring costs in multi-ship buys is another feature that would be of use. This is a variation on the issue of lead and follow-ship costs in that specific costs unique to lead ship procurement would be identified with those associated with follow ships.

Appendix (A)

- Second source start-up costs is another variation that could be of interest. The costs associated with the lead ship at a follow yard have not been addressed to date, yet they affect the total costs associated with a class of ships. Given the procurement approach taken with the FFG-7 and CG-47 and the similar proposed approach with DDG-51, this may be an important issue.

- Closely associated with the above is the effect of multi-year buys on cost. Recent estimates from shipyards indicated significant savings in cost and time through multi-year procurements. Providing the ability to account for these savings in the existing models would be very worthwhile.

- Experience with the development of the auxiliary-amphibious ship cost model indicates a relatively high degree of spread associated with the data. Having return cost data from additional shipyards, especially for ship types such as PG and LCC would be very useful in increasing the confidence level associated with the model.

2. The same basic approach used in previous Gibbs & Cox, Inc. cost model programs is proposed for this effort, i.e., return cost data from shipyards participating in the study will be used to develop cost estimating relationships for materials ($/ton, $/SHP, etc.) and labor (manhours/ton, MH/SHP, etc.), which will then form the basis for the cost algorithms. In this case, it is proposed that the shipyard cost data be used to develop "correction factors" to be applied to the basic algorithms of the existing models. This is considered appropriate for follow ship, multi-ship and multi-year procurement costs. At the same time recurring and non-recurring costs may be identified and attributed to the lead ship and follow ships as appropriate.

3. In line with the above discussion, it is proposed to allocate approximately $10K to each of three participating shipyards for the purpose of obtaining return cost data and analyses of its implications on selected ship programs for which the shipbuilder can provide the required data. It is anticipated that this level of effort will be accomplished over a 2-month period. Enclosure (A) discusses type of data and other information to be furnished by the shipbuilder.

4. It is requested that the shipbuilder, after reviewing this letter and its enclosure, identify one or more programs for which requisite data can be provided within the cost and time frame identified herein. Assuming agreement can be reached on scope of effort and program(s) involved, a contract will be issued to cover this effort.

5. Your prompt attention to this matter will be greatly appreciated.

Very truly yours,

GIBBS & COX, INC.

A. W. Schmidt

A. W. Schmidt
Project Engineer

1. List of Candidate Programs to be Considered:

(For BIW)	DD931 (7)	FFG-1 (3)	FFG-7 (23)
(For NASSCO)	AFS (7)	AD (4)	LST (17)
(For Avondale)	FF 1052 (27)	AO (5)	WHEC (12)
(For Todd)	FF 1052 (14)	FFG-7 (29)	AOT (4)
(For G.D.)	AOR (7)	LSD (4)	
(For N.N.S.B.)	CGN 36/38 (6)	LKA (5)	
(For Tacoma)	PCG (4) PG (10)	WMEC (4)	T-AGOS (8)

2. Information/Data Desired:

a. Modelling cost factors will be developed for each of the basic nine (9) one-digit U.S. Navy SWBS cost groups. It is recognized that shipyard return costs may be more easily extracted in accordance with their own cost groupings. A cross reference matrix should be provided along with explanatory material.

b. Within each cost group the following data should be provided:

Total wgt. of cost group,
Amount of other independent variable (I.V.) if weight is not the best (SHP, KW, L/B/D, etc.),
Labor factor in Manhours/Ton (or other I.V.),
Material factor in $/Ton (or other I.V.), in actual year expended,
Identification and discussion of any factor which is considered to be either unique or distorts the labor/material factors.

c. Shipyard return costs should be developed as indicated above for:

(1) First ship of the class in the shipyard (i.e. lead ship in yard)

(2) A follow ship of the same class in the yard (preferably 3rd or 4th).

(3) A later ship also, if significantly different.

d. Opinions should be provided as to what effect (a) multi-year procurement may have on ship costs, and (b) multi-ship procurement had on ship costs. Provide rationale to support any opinions rendered.

e. Based on c. above, provide:

(1) Basic ship description

Length, Beam, Draft, Depth, Displ (Full Load), SHP and other I.V., Propulsion Plant type, no. of shafts and any unique installed systems which had impact on cost factors for given ship.

(2) Breakdown and identification of recurring and non-recurring costs between 1st and follow ship of class.

(3) Discussion of other factors which had impact or influence on cost differentials between lead and follow ships, such as:

(a) economic conditions,
(b) labor rates,
(c) overall work load,
(d) changes and/or differences in major systems (armament, propulsion, etc.)
(e) increased inspection or software requirements,
(f) major changes in "make or buy" decisions,
(g) extended building period,
(h) escalation, productivity, etc.

BIW Response

BATH IRON WORKS CORPORATION

COST MODEL

DEVELOPMENT STUDY

LEAD/FOLLOW SHIPS

NOVEMBER 1983

BATH IRON WORKS CORPORATION

COST MODEL

INTRODUCTION

The Bath Iron Works Corporation is pleased to assist Gibbs & Cox in the development of a cost model for U.S. Destroyer auxiliary and amphibious type ships. The text and charts that follow set forth the major cost factors which contribute to differences between lead and follow-ships of a class.

Data provided represents FFG-1 class (Previously DEG 4-6) and the FFG-7 class ships.

Specifically FFG 4 and 6 material is provided along with FFG 8 and 34 which is the 1st ship of flight #1 and the last ship (11th) of flight #2.

All cost data was developed at BIW's charge level representing return cost information. Biw has also converted/reconciled all data to the OPNAV ship work breakdown structure utilizing a computer system developed during the CG proposal period.

Exhibits __A__ thru __K__ have been developed to illustrate trends and comparisions.

The enclosed computer runs reflect manhours and material cost by BIW charge and SWBS.

Gibbs & Cox will note BIW's text and exhibits speak to a relatively smooth production run on both FFG 4-6 and FFG 8-34. Indeed a learning curve at 93% indicates programs with minor changes and with minimal production problems.

BIW is convinced multi-ship multi-fiscal year production is the most cost effective method of surface ship procurement.

Even with substantial configuration changes such as experienced on the 1st ship of the FFG 3rd flight a continuation of learning is maintained to the extent portions of the construction remain unchanged.

BIW welcomes task III and stands ready to provide specific answers to questions that may arise.

BATH IRON WORKS CORPORATION

TASK RESPONSE

TASK I:

Factors which contribute to lead ship and follow ship cost differences:

1) Learning: (labor only)

Learning between ships in a multi-ship contract at the BIW has historically been on a 93% unit progress curve. Return costs for the FFG 1 and FFG 7 class ships used in this study indicate that favorable conditions in the yard at the time of contract performance contributed to their falling within the acceptable range of this curve. Factors such as an unusual amount of change orders, design, material procurement problems and company/union labor disputes could adversely affect learning if they occurred during construction.
The SWBS groups primarily subject to learning are 100 thru 700 and 900.

2) Recurring vs non-recurring costs: (labor and material)

Most non-recurring costs are associated with SWBS groups 800 and 900 and include design/engineering, lofting and general and administration services. These are considered non-production costs and are generally charged to the first ship of a multi-ship contract and thereby result in a great disparity of costs between lead and follow ships in these groups. It follows therefore that non-recurring costs are minimized on a multi-ship/multi-year procurement.

3) Material procurement and inflation:

Pre-planning, scheduling and establishment of in-yard requirement dates for major material and components are of prime importance in maintaining a proper relationship between lead and follow ships. Failure to procure, prepare and deliver major components in accordance with a pre-established schedule could have a profound effect on labor and material costs due to delays in production and inflation. To avoid this situation and especially the cost impact on the last ships in a contract, it is highly desireable to procure as many shipsets of material at the same time as practicable. Multi-ship material procurement also has obvious cost advantages inherent in Quantity Buying. During construction of the FFG-1 class ships the rate of inflation was low enough to be practically insignificant. However, at the time the second flight of FFG-7 class ships were being built, the inflation rate was approximatly 11% per year and if not for multi-ship buying could have had a serious impact on follow ship costs.

4) Availability of skilled labor:

The over-all yard work load during the construction of ships under a multi-ship procurement contract could affect the availability of skilled labor on follow ships. Expertise gained by tradesmen on a series of similar ships would be lost if it was "drawn-off" to satisfy the requirements of concurrent contracts. It is apparent therefore that every effort should be made to maintain the skill level throughout a multi-ship construction contract.

COST MODEL DEVELOPMENT STUDY

LEAD & FOLLOW SHIPS

SWBS Group	WEIGHT (L/tons)	LABOR HOURS: Non-Recurring (1)	LABOR HOURS: Recurring (DPL)	(2)	Mhrs/ Ton	MATERIAL DOLLARS: Non-Recurring (1)	MATERIAL DOLLARS: Recurring (DPM)	(2)	Dollar/ Ton
FFG 8 :									
100	1,256.78		415,815		330.9		1,923,566		1,530.6
200	249.86		57,712		231.0		4,581,122		18,334.8
300	205.73		147,292		715.9		2,214,386		10,763.6
400	96.08		77,051		801.9		830,510		8,643.9
500	417.61		246,038		589.2		5,471,612		13,102.2
600	288.65		273,618		947.9		2,037,593		7,059.0
700	96.05		8,027		83.6		79,073		823.2
800		536,219 27.6%	958			473,155 2.5%	24		
900		203,740 10.5%	718,907			1,435,732 7.7%	1,612,698		
TOTAL	2,610.76	739,959 38.0%	1,945,428			1,908,887 10.2%	18,750,584		
FFG 34 :									
100	1,256.78		254,222	61%	202.3		2,024,547	105%	1,610.9
200	249.86		44,826	78%	179.4		6,487,651	142%	25,965.1
300	205.73		114,813	78%	558.1		2,434,850	110%	11,835.1
400	96.08		57,278	74%	596.1		925,536	111%	9,633.0
500	417.61		182,456	74%	436.9		6,190,270	113%	14,823.1
600	288.65		234,364	86%	811.9		2,167,610	106%	7,509.5
700	96.05		8,412	105%	87.6		88,063	111%	916.8
800		47,872 3.3%	4,617			4,391 .02%	6,383		
900		44,466 3.1%	549,274	76%		1,128,092 5.2%	1,225,982	76%	
TOTAL	2,610.76	92,338 6.4%	1,450,262	75%		1,132,483 5.3%	21,550,892	115%	

(1) Percent of total DPL/DPM
(2) Percent of 1st ship

COST MODEL DEVELOPMENT STUDY

LEAD & FOLLOW SHIPS

		LABOR HOURS					MATERIAL DOLLARS				
SWBS Group	WEIGHT (L/tons)	Non-Recurring	(1)	Recurring (DPL)	(2)	Mhrs/Ton	Non-Recurring	(1)	Recurring (DPM)	(2)	Dollar/Ton
FFG 4 :											
100	1,248.09			233,202		186.8			397,673		318.6
200	360.85			37,078		102.8			931,799		2,582.2
300	103.16			94,768		918.7			747,755		7,248.5
400	147.37			95,003		644.7			467,783		3,174.2
500	339.99			271,061		797.3			1,668,956		4,908.8
600	242.54			198,516		818.5			493,340		2,034.1
700	132.13			35,393		267.9			220,036		1,665.3
800		81,222	6.4%	994			192,317	3.6%	1,730		
900		8,291	.7%	308,946			36,533	.7%	368,300		
TOTAL	2,574.13	89,513	70.2%	1,274,961			228,850	4.3%	5,297,373		
FFG 6 :											
100	1,248.09			212,195	91%	170.0			408,623	103%	327.4
200	360.85			33,016	89%	91.5			928,629	100%	2,573.4
300	103.16			72,905	77%	706.7			732,878	98%	7,104.3
400	147.37			77,712	82%	527.3			463,462	99%	3,144.9
500	339.99			246,029	91%	723.6			1,609,843	97%	4,735.0
600	242.54			182,125	92%	750.9			471,019	96%	1,942.0
700	132.13			29,088	82%	220.1			146.145	66%	3,564.8
800		73,733	6.5%	691	70%		31,427	.6%	1,109	64%	
900		6,504	.6%	286,836	93%		100,065	2.0%	344,810	94%	
TOTAL	2,574.13	80,237	7.0%	1,140,607	90%		131,492	2.6%	5,106,518	97%	

(1) Percent of total DPL/DPM
(2) Percent of 1st ship

Tacoma Response

REPORT

COST MODEL DEVELOPMENT STUDY
LEAD AND FOLLOW-SHIPS

PREPARED FOR

GIBBS AND COX, INC.
ARLINGTON, VIRGINIA

UNDER

GIBBS & COX PURCHASE ORDER NO. 9541-2

DATE

28 November 1983

SUBMITTED BY

H. Streb
Director

TACOMA-ESCHER WYSS JOB NO. 34075

THIS STUDY IS NOT TO BE CONSTRUED AS A SPECIFIC SOURCE FOR DETERMINING LEAD AND FOLLOW-SHIP COST DIFFERENCES OR SHIP CONSTRUCTION COSTS. IT IS SOLELY INTENDED, BASED ON THE EXPERIENCE AND PROFESSIONAL JUDGEMENT OF THE PREPARER, THAT THIS STUDY OUTLINES ONLY THE VARIOUS FACTORS WHICH SIGNIFICANTLY AFFECT VESSEL COSTS AND EVALUATES EACH ON A QUALITATIVE AND/OR QUANTITATIVE BASIS.

COST MODEL DEVELOPMENT STUDY

I. INTRODUCTION

TACOMA-ESCHER WYSS, IN SUPPORT OF GIBBS AND COX, INC., HAS PREPARED THE FOLLOWING STUDY REGARDING THE DEVELOPMENT OF A FOLLOW-SHIP COST MODEL FOR U.S. PATROL, CORVETTE, FRIGATE, DESTROYER, AUXILIARY AND AMPHIBIOUS TYPE SHIPS. THIS STUDY, BASED ON EXPERIENCE AND PROFESSIONAL JUDGEMEMENT, PROVIDES INPUT, BOTH QUALITATIVE AND QUANTITATIVE, REGARDING THE EFFECTS ON SHIP CONSTRUCTION COSTS WHICH ARE DIFFERENT BETWEEN LEAD AND FOLLOW-SHIPS.

SINCE ACTUAL OR COMPLETE VESSEL COSTS ARE EITHER UNAVAILABLE OR DIFFICULT TO ASSESS ON A WHOLE-SHIP BASIS OR AT THE SYSTEMS LEVEL, IT WAS DETERMINED TO DEVELOP A MATRIX OF FACTORS WHICH AFFECT SHIP CONSTRUCTION AND TO FURTHER ANALYZE EACH OF THESE FACTORS ON A WHOLE-SHIP BASIS. THIS MATRIX WAS DEVELOPED FOR THREE HYPOTHETICAL SHIPYARDS, YARD A, EAST COAST; YARD B, GULF COAST; AND YARD C, WEST COAST. THE FACTORS WERE THEN COMPARED TO EACH YARD, AN ASSESSMENT MADE OF ANY RELEVANT IMPACT, AND WHERE POSSIBLE, A QUANTITATIVE VALUE ASSIGNED.

NUMEROUS FACTORS AFFECTING SHIP CONSTRUCTION WERE CONSIDERED, HOWEVER, ONLY THOSE WHICH WERE DETERMINED TO SIGNIFICANTLY AFFECT VESSEL COSTS WERE EVALUATED.

II. BASELINE RATIONALE

THE FACTORS THAT WERE ASSESSED WERE DIVIDED BETWEEN TWO CATEGORIES, THOSE CONSIDERED SPECIFIC BETWEEN SHIPYARDS, AND THOSE CONSIDERED COMMON BETWEEN SHIPYARDS.

THESE FACTORS ARE SHOWN ON FIGURE 1 AND ARE SUMMARIZED AS FOLLOWS:

A. COMMON FACTORS

1. MULTI-SHIP PROCUREMENT
2. MULTI-YEAR PROCUREMENT
3. MATERIALS
4. CONTRACT DESIGN CHANGES
5. CUSTOMER DESIGN CHANGES
6. MAKE OR BUY DECISIONS
7. CUSTOMER DIRECTED PURCHASE
8. METHOD OF CONSTRUCTION
9. EXPERIENCE
10. OVERALL WORKLOAD

B. SPECIFIC FACTORS

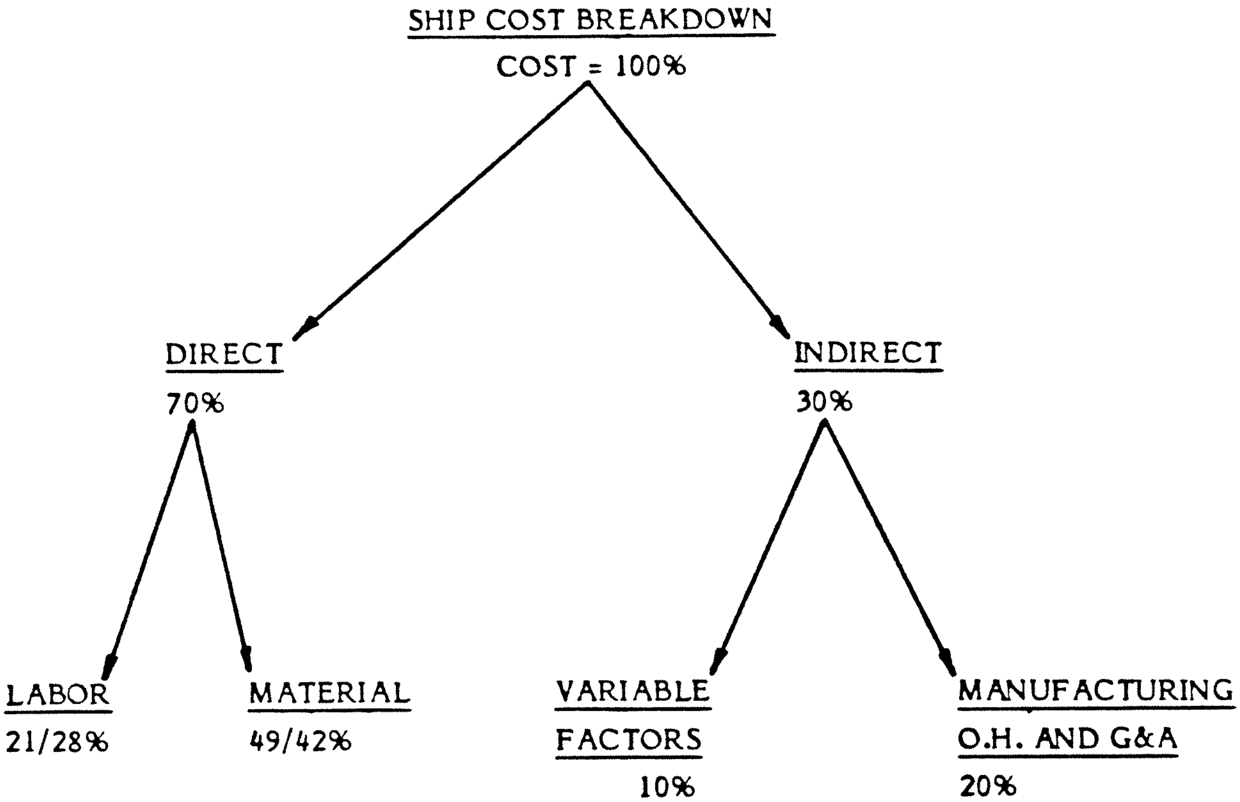
1. LABOR RATES
2. ESCALATION
3. INSPECTION/SOFTWARE/HARDWARE CHANGES
4. PRODUCTIVITY
5. YARD LOCATION
6. LOCAL ENVIRONMENT
7. ECONOMIC CONDITIONS
8. FACILITIES
9. START-UP COSTS
10. INDIRECT COSTS

IN ORDER TO ESTABLISH A COMMON BASELINE AND ASSESS THE COST IMPACT OF EACH FACTOR BASED ON THE THREE YARDS' LOCATIONS, IT WAS CONSIDERED REASONABLE TO ESTABLISH A MATRIX RELATING TO THE VARIOUS SHIP TYPES AGAINST WHICH EACH OF THE COST FACTORS COULD BE ASSESSED AND A REASONABLE VALUE ASSIGNED. THIS MATRIX WAS FURTHER EXPANDED TO ALLOW COMPARISON OF

BOTH LEAD SHIP/FOLLOW-SHIP AT LEAD YARD AND FOLLOW-YARDS FOR BOTH MULTI-SHIP AND MULTI-YEAR TYPE PROCUREMENTS.

A BASE FOR COMPARISON WAS THEREFORE ESTABLISHED SO THAT THE SUMMATION OF COST VALUES WOULD BE EQUAL TO 100 FOR THE LEAD SHIP AT THE LEAD YARD FOR BOTH MULTI-SHIP AND MULTI-YEAR TYPE PROCUREMENTS.

FOLLOW-SHIPS AT THE LEAD YARD AND FOLLOW-YARDS WOULD THEN BE ASSESSED AGAINST THIS BASE. THE CRITERIA FOR ESTABLISHING THE BASE FOR THE DIRECT/INDIRECT SHIP COST BREAKDOWN WAS THE RESULT OF THE FOLLOWING ANALYSIS. THESE VALUES ARE CONSIDERED REASONABLE WITHIN THE INDUSTRY AND ACCEPTABLE WITHIN THE SCOPE OF THIS STUDY.



LABOR/MATERIAL SPLIT

DIRECT COST FACTOR = 70%

SHIP TYPE	MATERIAL	LABOR
PATROL, CORVETTE FRIGATE, DESTROYER	70%	30%
AUXILIARY	60%	40%
AMPHIBIOUS	60%	40%

AS A FINAL CONSIDERATION IN THE DEVELOPMENT OF THIS STUDY, GUIDELINES WERE ESTABLISHED REGARDING ADDITIONAL FACTORS WHICH HAVE AN INFLUENCE ON THE COST MODEL STUDY AND WERE EVALUATED ACCORDINGLY:

* STUDY BASED ON WHOLE-SHIP BASIS.
* SHIP DESIGN NOT INCLUDED.
* GOVERNMENT FURNISHED EQUIPMENT AND MATERIAL NOT INCLUDED.
* STUDY BASED ON PROCUREMENT OF TWO OR MORE SHIPS.
* POLITICAL INFLUENCE NOT CONSIDERED.
* STUDY BASED ON COMPETITIVE TYPE PROCUREMENT.
* NEGOTIATED OR DIRECTED SOLE SOURCE TYPE PROCUREMENTS NOT CONSIDERED.

III. FACTOR ANALYSIS AND COST IMPACT

THE FOLLOWING FACTORS WERE EVALUATED ON THE BASIS OF THEIR IMPORTANCE, DEFINITION RATIONALE, AND COST IMPACT INFLUENCE. THOSE FACTORS WHICH WERE CONSIDERED SPECIFIC WERE EVALUATED BASED ON THEIR COST IMPACT AND FURTHER ASSIGNED AN APPROXIAMATE VALUE. FIGURE 2 IS A TABULATION OF THE FACTORS AND ASSOCIATED VALUES. THE SUMMATION OF THE VALUES WERE THEN COMPARED TO THE BASE OF 100 AND THE VARIANCES BETWEEN EACH CATEGORY DEFINED.

A. COMMON FACTORS

1. MULTI-SHIP PROCUREMENT - A FIRM FIXED PRICE PROCUREMENT OF TWO OR MORE SHIPS AWARDED TO A GIVEN YARD TO BE PERFORMED WITHIN A SPECIFIED TIME PERIOD. THIS TYPE OF PROCUREMENT COULD ALSO INCLUDE OPTION PROVISIONS FOR ONE OR MORE SHIPS, BASED ON A FIXED PRICE PLUS ESCALATION, TO BE EXERCISED IN FUTURE YEARS BASED ON BUDGET APPROPRIATIONS. THIS

TYPE OF PROCUREMENT WOULD BE LIMITED TO THE SUCCESSFUL YARD, AND AFTER COMPLETION OF LEAD SHIPS, AND OPTION SHIPS IF EXERCISED, OPENED FOR COMPETITIVE REBID FOR SAME DESIGN AND CLASS.

2. MULTI-YEAR PROCUREMENT - THIS TYPE WOULD BE A FIRM FIXED PROCUREMENT OF TWO OR MORE SHIPS WITHOUT OPTION PROVISIONS. FOLLOW-ON SHIPS WOULD BE KEYED TO APPROVED AUTHORIZATION FOR MULTI-YEAR PLANNED PROCUREMENT OF A GIVEN NUMBER OF SHIPS TO BE FUNDED OVER A SPECIFIED NUMBER OF YEARS. THIS TYPE OF MULTI-YEAR PROCUREMENT IS CONSIDERED TO HAVE COST SAVINGS ADVANTAGES OVER OTHER TYPES OF PROCUREMENT.

3. MATERIALS - BASED ON THE MATERIAL SPLIT AS PREVIOUSLY DEFINED, ALL MATERIALS ARE ASSUMED TO BE STANDARD ITEMS AND COMPONENTS USED IN SHIP CONSTRUCTION SUCH AS PLATES, SHAPES, MACHINERY, ELECTRONICS, FURNISHINGS AND WEAPON SYSTEMS. IT IS ASSUMED THAT MATERIAL COSTS COULD BE REDUCED FOR FOLLOW-ON SHIPS BY UP TO 5% FOR MULTI-SHIP PROCUREMENT AND UP TO 10% FOR MULTI-YEAR PROCUREMENT BASED ON QUANTITY PROCUREMENTS, IMPROVED MATERIAL HANDLING AND PRODUCTION CONTROL, EVEN WITH INFLATION TAKEN INTO CONSIDERATION.

4. CONTRACT DESIGN CHANGES - CHANGES MADE BY THE SHIPYARD IN THE DETAIL AND ASSEMBLY STAGE TO SOLVE UNFORESEEN PROBLEMS SUCH AS INTERFERENCES BETWEEN SYSTEMS. DEPENDING ON THE STAGE OF CONSTRUCTION COMPLETED, THESE CHANGES COULD HAVE A MAJOR IMPACT ON CONTRACT COST. THESE CHANGES COULD ALSO IMPACT THE LEARNING CURVE, START-UP COSTS, PRODUCTIVITY, AND OVERALL WORKLOAD. SINCE THIS FACTOR WOULD IMPACT BOTH LEAD YARD AND

FOLLOW-YARD EQUALLY, NO SPECIFIC COST VALUE WAS ASSESSED.

5. CUSTOMER DESIGN CHANGES - CHANGES MADE BY THE CUSTOMER TO ACCOMMODATE NEW EQUIPMENT, MACHINERY, ELECTRONICS OR WEAPON SYSTEMS. CHANGES COULD BE IMPOSED ON THE LEAD SHIP OR FOLLOW-SHIPS. THESE CHANGES COULD IMPACT COST THE SAME AS WOULD CONTRACT DESIGN CHANGES. HERE AGAIN, IMPACT TO YARDS WOULD BE CONSIDERED EQUAL, SO THEREFORE, NO SPECIFIC COST VALUE WAS ASSESSED.

6. MAKE OR BUY DECISIONS - SHIPYARD HAS OPTION TO DECIDE THE COST ADVANTAGE OF EITHER PURCHASING A COMPONENT OR MANUFACTURING IN-HOUSE. THIS DECISION AFFORDS THE SHIPYARD A COST ADVANTAGE IF THEY HAVE THE CAPABILITY TO MANUFACTURE MAJOR OR SUB-SYSTEMS AND/OR COMPONENTS WITHIN THEIR FACILITY. THIS FACTOR DOES NOT DIRECTLY AFFECT THE LEAD SHIP/FOLLOW-SHIP COST. IT DOES, HOWEVER, AFFORD A SHIPYARD A COST ADVANTAGE IN BIDDING NEW SHIP CONSTRUCTION CONTRACTS. SINCE ALL SHIPYARDS COULD BE CONSIDERED AS HAVING THIS SAME ADVANTAGE, NO SPECIFIC COST VALUE WAS ASSESSED.

7. CUSTOMER DIRECTED PURCHASE - CONTRACT SPECIFIES THAT SHIPYARD PURCHASE AND INSTALL SPECIFIC TYPES OF EQUIPMENT SUCH AS ENGINES, GEARBOXES, PROPELLER SYSTEMS, CONTROL SYSTEMS, ELECTRONIC SYSTEMS AND WEAPON SYSTEMS WITHOUT COMPETITIVE BIDDING. THIS FACTOR COULD INCREASE TOTAL SHIP CONTRACT COST BY BEING LOCKED INTO A HIGHER PRICED SYSTEM AND/OR HIGHER INSTALLATION COSTS OVER A COMPARABLE COMPETITIVE SYSTEM. IT COULD ALSO RESULT IN THE DIRECTED PURCHASE NOT FULLY CONFORMING TO THE SHIP'S SPECIFICATION RESULTING IN INCREASED COSTS,

DELAYS IN RENEGOTIATING THE CONTRACT, OR IMPOSING HIGHER COSTS ON THE SHIPYARD TO PERFORM WHATEVER TASKS ARE NECESSARY TO ASSURE THAT THE DIRECTED PURCHASE CONFORMS TO CONTRACT REQUIREMENTS. THIS FACTOR WOULD ALSO IMPACT EACH SHIPYARD EQUALLY SO NO SPECIFIC COST VALUE WAS ASSESSED.

8. <u>METHOD OF CONSTRUCTION</u> - THIS FACTOR WOULD REFLECT MODULAR CONSTRUCTION AND ZONE OUTFITTING VERSUS TRADITIONAL METHODS OF CONSTRUCTION. AS IN "MAKE OR BUY DECISIONS", THIS FACTOR ALSO DOES NOT DIRECTLY AFFECT LEAD SHIP/FOLLOW-SHIP COST BUT DOES AFFORD THE SHIPYARD A COST ADVANTAGE IN BIDDING NEW CONSTRUCTION AS MODULAR CONSTRUCTION IS MORE COST-EFFECTIVE. HOWEVER, SINCE THIS TYPE OF CONSTRUCTION PROGRESSES QUITE DIFFERENTLY THAN THE TRADITIONAL TYPE (AS MODULARS ARE CONSIDERABLY OUTFITTED) CUSTOMER DESIGN CHANGES OR CONTRACT DESIGN CHANGES COULD BE MORE COSTLY BASED ON THE STAGE OF COMPLETION OVER A TRADITIONAL BUILT HULL. CHANGES CAN IMPACT MATERIALS, PRODUCTIVITY, START-UP COSTS, MAKE/BUY DECISIONS, AND OVERALL WORKLOAD. NO SPECIFIC COST VALUE WAS ASSESSED AS THIS FACTOR WOULD EQUALLY IMPACT EACH SHIPYARD.

9. <u>EXPERIENCE</u> - THIS FACTOR WOULD REFLECT THE CAPABILITY OF A SHIPYARD TO BUILD A PARTICULAR CLASS OF VESSEL BASED ON PRIOR WORK. EXPERIENCE WOULD LEAD TO DEVELOPING A LEARNING CURVE AND WOULD INFLUENCE OTHER FACTORS SUCH AS START-UP COSTS, PRODUCTIVITY, MAKE/BUY DECISIONS, AND METHOD OF CONSTRUCTION. SINCE ALL SHIPYARDS WERE ASSUMED TO HAVE EQUAL EXPERIENCE IN THE CONSTRUCTION OF A GIVEN CLASS OF VESSEL, NO SPECIFIC COST VALUE WAS ASSESSED. SINCE PRODUCTIVITY IS RELATED TO

EXPERIENCE, THE PRODUCTIVITY FACTOR WAS EVALUATED SEPARATELY AND A COST VALUE ASSESSED.

10. OVERALL WORKLOAD - THIS FACTOR WOULD TAKE INTO CONSIDERATION THE SHIPYARD'S PRIOR OR CURRENT OBLIGATIONS THAT NEED TO BE COMPLETED PRIOR TO OR CONCURRENTLY WITH ANY NEW CONTRACT. THIS WILL INFLUENCE A SHIPYARD'S COST DUE TO AN OVERLOAD OF WORK WHICH WOULD CAUSE NON-COST EFFECTIVE UTILIZATION OF PLANNED FACILITIES, RESULTING IN AN IMPACT ON PRODUCTION SCHEDULING AND PROGRESS. ALL SHIPYARDS COULD BE INVOLVED IN SUCH A SITUATION, THEREFORE, NO SPECIFIC COST VALUE WAS ASSESSED.

B. SPECIFIC FACTORS

1. LABOR RATES - THIS FACTOR WAS EVALUATED ON THE BASIS OF UNION LABOR USED IN THE ACTUAL CONSTRUCTION OF A VESSEL SUCH AS BOILERMAKERS, PIPEFITTERS, ELECTRICIANS, SHEET METAL WORKERS, MACHINISTS, PAINTERS AND CARPENTERS. LABOR RATES WERE EVALUATED FROM 10 COASTAL SHIPYARDS, EAST COAST, GULF COAST, AND WEST COAST. THE RATES RANGED FROM A LOW OF $9.05/HOUR TO A HIGH OF $13.50/HOUR FOR AN AVERAGE U.S. WAGE RATE OF $10.29/HOUR, CURRENT AS OF NOVEMBER 1983. THE RATES WERE THEN AVERAGED BASED ON THEIR GEOGRAPHIC LOCATION AND COMPARED TO THE U.S. AVERAGE RATE.

EAST COAST = $9.89/HOUR = 96.1% OF U.S. AVERAGE
GULF COAST = $9.52/HOUR = 92.5% OF U.S. AVERAGE
WEST COAST = $12.26/HOUR = 119.0% OF U.S. AVERAGE

THESE PERCENTAGES WERE THEN APPLIED TO THE LABOR SPLIT, AS DEFINED UNDER SHIP COST BREAKDOWN FOR THE

VARIOUS TYPES OF SHIPS, AND THE RESULTS TABULATED ON FIGURE 2.

2. ESCALATION - THIS FACTOR WAS EVALUATED ON THE BASIS OF THE BUREAU OF LABOR STATISTICS (BLS) STEEL VESSEL INDEX WITH THE BASE 1967 = 100, AND APPLIED ONLY TO MATERIAL. FIGURE 3 IS A COMPILATION OF THE INDICES FROM 1967 THROUGH SEPTEMBER 1983. FIGURE 4 IS THE SAME COMPILATION WITH AN ADDITIONAL TABULATION SHOWING THE PERCENTAGE OF CHANGE FROM ANY BASE MONTH TO THE BASE MONTH OF THE PREVIOUS YEAR. SEVERAL OTHER ESCALATION FACTORS COULD BE IMPOSED ON GOVERNMENT CONTRACTS, HOWEVER, FOR THIS STUDY THE BLS WAS USED FOR THE BASE COMPARISON. SINCE THE INTENT OF THIS STUDY IS TO EVALUATE LEAD SHIP AND FOLLOW-SHOP COSTS, IT COULD BE ASSUMED THAT LEAD SHIP WOULD BE IN PRESENT YEAR DOLLARS AND FOLLOW-SHIPS IN FUTURE YEAR DOLLARS. FOR THIS REASON WE HAVE ASSUMED THAT ESCALATION HAS BEEN ACCOUNTED FOR IN THE LEAD SHIP COST OR HAD BEEN CONSIDERED AS PART OF THE CONTRACT. SINCE THE ANNUAL CHANGE IN 1983 ESCALATION AVERAGED OVER THE PREVIOUS FOUR YEARS HAS BEEN ON THE ORDER OF 6.5%, WE HAVE INCLUDED IT AS PART OF INDIRECT COST, THUS THE BASE OF 100 WOULD REMAIN VALID.

3. INSPECTION/SOFTWARE/HARDWARE CHANGES - CHANGES IN REQUIREMENTS IMPOSED BY THE CONTRACTING ACTIVITY OR LOCAL SUPSHIPS OFFICE FROM ONE LOCALE TO ANOTHER ON INSPECTION PROCEDURES, SOFTWARE REQUIREMENTS OR HARDWARE CHANGES CAN RESULT IN AN IMPACT ON PRODUCTIVITY, MATERIALS, MAKE/BUY DECISIONS, AND OVERALL WORKLOAD. IT WOULD NOT BE CONSIDERED UNUSUAL FOR THE LEAD YARD TO DEVELOP PROCEDURES WITH THE LOCAL CONTRACTING ACTIVITY AND FOR FOLLOW-ON YARDS TO PERFORM UNDER

DIFFERENT PROCEDURES WITH THEIR LOCAL CONTRACTING ACTIVITY. CHANGES IN PROCEDURES COULD NECESSITATE CHANGES IN INSPECTION PRACTICE AND REWRITING OF PROGRAMS AND DOCUMENTATION. THIS FACTOR WAS EVALUATED AND ASSESSED A 1.0 SPECIFIC COST VALUE FOR FOLLOW-ON SHIPS AT FOLLOW-YARDS.

4. PRODUCTIVITY - THIS FACTOR IS GAUGED TO OUTPUT RELATED TO INPUT - HOW MUCH IS ACCOMPLISHED WITHIN A SCHEDULED AMOUNT OF TIME WITH A BUDGETED AMOUNT OF LABOR HOURS AND MATERIAL DOLLARS. VARIOUS FACTORS IMPACT PRODUCTIVITY, SUCH AS, EXPERIENCE, METHOD OF CONSTRUCTION, LOCAL ENVIRONMENT, AND OVERALL WORKLOAD. EACH YARD IS CONSIDERED TO HAVE AN EQUAL ADVANTAGE TO INCREASE PRODUCTIVITY BY UTILIZATION OF SPECIAL TOOLING, ALLOWING PERSONNEL TO BECOME MORE PROFICIENT, IMPROVING PRODUCTION - LINE TECHNIQUES, AND TAKING ADVANTAGE OF QUANTITY PROCUREMENTS. PRODUCTIVITY WILL THEREFORE, BE EVALUATED SOLELY ON THE BASIS OF DEVELOPING A LEARNING CURVE. IT IS GENERALLY ESTABLISHED THAT THE LEAD YARD HAS AN ADVANTAGE OVER FOLLOW-SHIPYARDS REGARDING REDUCED COSTS DUE TO LEARNING EXPERIENCE. WE, THEREFORE, ASSUME THAT THERE IS APPROXIMATELY UP TO A 10% LABOR ADVANTAGE FOR THE LEAD YARD. BY APPLYING THIS AS A PERCENTAGE OF THE LABOR RATE THE SPECIFIC COST VALUE IS ASSESSED. ANOTHER MAJOR FACTOR IN PRODUCTIVITY, HOWEVER, ONE WHICH IS NOT USED AS A COST COMPARISON IN THIS STUDY, IS THAT OF UNION/NON-UNION OR MINIMUM TRADE UNION REPRESENTATION WITHIN SHIPYARDS. THERE COULD BE UP TO A 30% LABOR SAVINGS BY ALLOWING VARIOUS TRADES TO PERFORM JOBS WITHIN OTHER TRADES' JURISDICTION.

5. <u>YARD LOCATION</u> - THIS FACTOR RELATES TO THE GEOGRAPHICAL LOCATION OF THE SHIPYARD; EAST COAST, GULF COAST, OR WEST COAST. THERE ARE MANY FACTORS WHICH MAY HAVE AN IMPACT ON VESSEL COSTS DUE TO LOCATION, SUCH AS; LABOR RATES, START-UP COSTS, ESCALATION, PRODUCTIVITY, LOCAL ENVIRONMENT, ECONOMIC CONDITIONS, FACILITIES, METHOD OF CONSTRUCTION, COST OF IN-BOUND FREIGHT, AND TIME AND COST OF VESSEL DELIVERY TO ASSIGNED LOCATION. EVALUATION OF THIS FACTOR IS VERY DIFFICULT IN TERMS OF OVERALL COST IMPACT COMPARISON, THEREFORE, NO SPECIFIC COST VALUE IS ASSESSED.

6. <u>LOCAL ENVIRONMENT</u> - THIS FACTOR IS EVALUATED RELATIVE TO CLIMATIC CONDITIONS IN THE VARIOUS GEOGRAPHICAL LOCATIONS. IT IS ASSUMED THAT WEATHER CONDITIONS, SUCH AS, HARSH WINTERS, HEAVY RAINS, FLOODING, AND EXTREME HEAT HAVE AN IMPACT ON PRODUCTION, THUS RESULTING IN LOWER PRODUCTIVITY. EVALUATING THE THREE GEOGRAPHICAL LOCATIONS AND DETERMINING THE EFFECT OF WEATHER CONDITIONS, WE HAVE ASSIGNED FACTORS FOR LOWER PRODUCTIVITY AT 10% FOR THE EAST COAST, 5% FOR THE GULF COAST AND 2% FOR THE WEST COAST. BY APPLYING THESE FACTORS AS A PERCENTAGE OF THE LABOR RATES, THE SPECIFIC COST VALUE IS ASSESSED.

7. <u>ECONOMIC CONDITIONS</u> - THE GENERAL ECONOMY WILL VARY NATIONWIDE AFFECTING LOCAL CONDITIONS WHICH COULD HAVE AN IMPACT ON VESSEL CONSTRUCTION COSTS. FACTORS WHICH WOULD HAVE AN INFLUENCE INCLUDE UNEMPLOYMENT, LACK OF SKILLED PERSONNEL TO FILL POSITIONS, COST OF BORROWING MONEY, AND INDIRECT COSTS.

HERE AGAIN, EVALUATION OF THIS FACTOR IS ALSO VERY DIFFICULT IN TERMS OF OVERALL COST IMPACT COMPARISON, THEREFORE, NO SPECIFIC COST VALUE IS ASSESSED.

8. FACILITIES - THIS FACTOR GENERALLY ADDRESSES THE AVAILABILITY OF SHIPYARD FACILITIES TO CONSTRUCT A SPECIFIC CLASS OF SHIP WITHIN A GIVEN TIME PERIOD. EVEN THOUGH A SHIPYARD MAY HAVE CONSTRUCTED A SIMILAR TYPE VESSEL AND POSSESS THE EXPERIENCE AND CAPABILITY, DUE TO CURRENT WORKLOAD OR PARTICULAR CONTRACT REQUIREMENTS, A SHIPYARD WOULD HAVE TO ASSESS THE AVAILABILITY OF IT'S STEEL FABRICATION FACILITIES, MACHINE SHOP FACILITIES, LAUNCH FACILITIES, AND OTHER SUPPORT FACILITIES TO ASSURE THERE IS NO CONFLICT BETWEEN EXISTING AND NEW CONTRACTS. THIS FACTOR COULD, THEREFORE, IMPACT METHOD OF CONSTRUCTION, OVERALL WORKLOAD, PRODUCTIVITY, AND START-UP COSTS. SHIPYARD FACILITIES WOULD DEFINITELY INFLUENCE THIS FACTOR PRIOR TO ANY BID CONSIDERATIONS AND THEREFORE, FOR THIS STUDY, NO SPECIFIC COST VALUE IS ASSESSED.

9. START-UP COSTS - THIS FACTOR IS INFLUENCED BY FACILITIES AVAILABILITY, BUT IS DIRECTED MORE TOWARDS TOOLING, FIXTURES, MATERIALS ACQUISITION, EQUIPMENT, CAPITAL, AND LABOR AVAILABILITY. SINCE THE LEAD YARD MAY HAVE EXISTING EQUIPMENT WHICH COULD BE UTILIZED OR MODIFIED, OR HAS AMORTIZED START-UP COSTS IN THE INITIAL LEAD SHIP CONTRACT, IT IS ASSUMED THAT THE LEAD YARD HAS A COST ADVANTAGE OVER FOLLOW-YARDS FOR FOLLOW-SHIPS. THIS FACTOR WILL ALSO INFLUENCE MATERIALS, MAKE/BUY DECISIONS, METHOD OF CONSTRUCTION, PRODUCTIVITY, AND LABOR. FOR THE PURPOSE OF THIS STUDY WE HAVE ASSESSED AN IMPACT ON MATERIAL OF 5% AND LABOR 10%.

BY APPLYING THESE FACTORS, AS A PERCENTAGE OF THE MATERIAL AND LABOR FACTORS FOR FOLLOW-SHIP/FOLLOW-YARD CONTRACTS, THE SPECIFIC COST VALUE IS ASSESSED.

10. INDIRECT COSTS - BASED ON THE DIRECT/INDIRECT SPLIT RELATED TO SHIP COST BREAKDOWN AS PREVIOUSLY DEFINED, WE ASSUMED INDIRECT COSTS OF 30%, WHICH FOR THE PURPOSE OF THIS STUDY, SHOULD BE GENERALLY ACCEPTED WITHIN THE INDUSTRY. INDIRECT COSTS WOULD CONSIST OF MANUFACTURING OVERHEAD AND G&A REPRESENTING 20%, AND 10% FOR VARIABLE FACTORS. A FACTOR FOR PROFIT OR FEE WAS NOT CONSIDERED AND THEREFORE, NOT INCLUDED AS PART OF INDIRECT COSTS.

IV. SUMMARY

THE RESULTS OF THIS STUDY, BASED ON EXPERIENCE, PROFESSIONAL JUDGEMENT, OPINIONS, AND ASSESSMENTS, HAVE INDICATED A DEFINITE TREND AND REASONABLE COMPARISON OF COST FACTORS WHICH ARE DIFFERENT FOR LEAD SHIPS AS COMPARED TO FOLLOW-SHIPS. SUMMATION OF THE COST VALUES RESULTS IN THE LEAD YARD AS HAVING A DEFINITE COST ADVANTAGE OVER FOLLOW-YARDS FOR FOLLOW-SHIPS CONTRACTS. EVALUATION OF THE COST FACTORS/COST VALUES RELATING TO THE THREE YARDS, "A", "B", AND "C", DENOTE CERTAIN COST ADVANTAGES/COST DISADVANTAGES. IN ORDER TO ASSESS THIS MATRIX AND PUT IT IN PROPER PERSPECTIVE, THESE VALUES SHOULD BE EVALUATED BASED ON A SPECIFIC APPLICATION WITHIN A GIVEN PERFORMANCE PERIOD.

SHIP CONSTRUCTION COST FACTORS RELATED TO LEAD SHIP/FOLLOW SHIPS

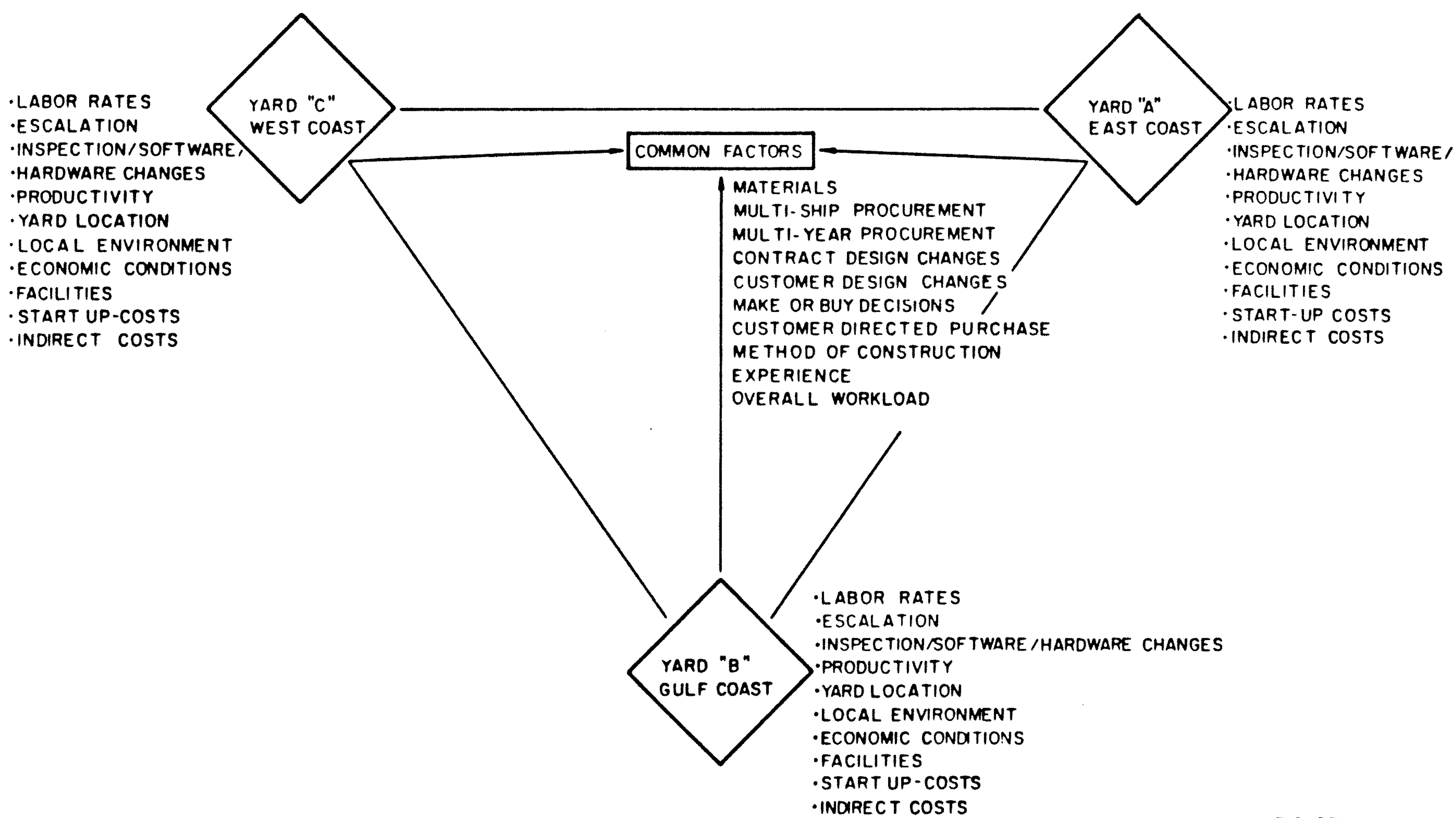


FIGURE I

SHIP CONSTRUCTION COST FACTORS/COST VALUES RELATED TO LEAD SHIP/FOLLOW-SHIPS

SHIP TYPE:	PATROL, CORVETTE, FRIGATE, OR DESTROYER									
	LEAD - SHIP		FOLLOW- SHIPS		LEAD-SHIP FOLLOW-YARDS (4)					
	LEAD YARD		LEAD YARD		YARD "A"		YARD "B"		YARD "C"	
CONTRACT TYPE:	MULTI-SHIP	MULTI-YEAR	MULTI-SHIP	MULTI-YEAR	MULTI-SHIP	MULTI-YEAR	MULTI-SHIP	MULTI-YEAR	MULTI-SHIP	MULTI-YEAR
COST FACTORS										
MATERIALS (STANDARDIZATION)	49.0	49.0	46.5	44.1	49.0	46.5	49.0	46.5	49.0	46.5
LABOR RATES	21.0	21.0	21.0	21.0	20.2	20.2	19.4	19.4	25.0	25.0
ESCALATION	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
CONTRACT DESIGN CHANGES	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
CUSTOMER DESIGN CHANGES	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
INSPECTION/ SOFTWARE/ HARDWARE CHANGES	-0-	-0-	-0-	-0-	1.0	1.0	1.0	1.0	1.0	1.0
MAKE OR BUY DECISIONS	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
CUSTOMER DIRECTED PURCHASE	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
METHOD OF CONSTRUCTION	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
EXPERIENCE	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
PRODUCTIVITY	(2)	(2)	(2)	(2)	2.0	2.0	1.9	1.9	2.5	2.5
YARD LOCATION	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)
LOCAL ENVIRONMENT	(2)	(2)	(2)	(2)	2.0	2.0	1.0	1.0	0.5	0.5
ECONOMIC CONDITIONS	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)
FACILITIES	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)
START-UP COSTS	(2)	(2)	(2)	(2)	4.5	4.3	4.4	4.3	5.0	4.8
OVERALL WORKLOAD	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
INDIRECT COSTS	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
TOTAL (5)	100.0	100.0	97.5	95.1	108.7	106.0	106.7	104.1	113.0	110.3

NOTES: (1) THESE FACTORS ARE CONSIDERED COMMON BETWEEN LEAD AND FOLLOW-YARDS AND ARE THEREFORE ASSESSED ON A QUALITATIVE BASIS.

(2) INCLUDED AS PART OF INDIRECT COSTS TO ESTABLISH THE BASE.

SHIP CONSTRUCTION COST FACTORS/COST VALUES RELATED TO LEAD SHIP/FOLLOW-SHIPS

SHIP TYPE:	AUXILIARY									
	LEAD-SHIP		FOLLOW-SHIPS		LEAD-SHIP FOLLOW-YARDS (4)					
	LEAD YARD		LEAD YARD		YARD "A"		YARD "B"		YARD "C"	
CONTRACT TYPE:	MULTI-SHIP	MULTI-YEAR	MULTI-SHIP	MULTI-YEAR	MULTI-SHIP	MULTI-YEAR	MULTI-SHIP	MULTI-YEAR	MULTI-SHIP	MULTI-YEAR
COST FACTORS	COST VALUES									
MATERIALS (STANDARDIZATION)	42.0	42.0	39.9	37.8	42.0	38.6	42.0	38.6	42.0	38.6
LABOR RATES	28.0	28.0	28.0	28.0	26.9	26.9	25.9	25.9	33.3	33.3
ESCALATION	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
CONTRACT DESIGN CHANGES	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
CUSTOMER DESIGN CHANGES	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
INSPECTION/SOFTWARE/ HARDWARE CHANGES	-0-	-0-	-0-	-0-	1.0	1.0	1.0	1.0	1.0	1.0
MAKE OR BUY DECISIONS	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
CUSTOMER DIRECTED PURCHASE	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
METHOD OF CONSTRUCTION	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
EXPERIENCE	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
PRODUCTIVITY	(2)	(2)	(2)	(2)	2.7	2.7	2.6	2.6	3.3	3.3
YARD LOCATION	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)
LOCAL ENVIRONMENT	(2)	(2)	(2)	(2)	2.7	2.7	1.3	1.3	0.7	0.7
ECONOMIC CONDITIONS	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)
FACILITIES	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)
START-UP COSTS	(2)	(2)	(2)	(2)	4.8	4.6	4.7	4.5	5.4	5.3
OVERALL WORKLOAD	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
INDIRECT COSTS	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
TOTAL (5)	100.0	100.0	97.9	95.8	110.1	106.5	107.5	103.9	115.7	112.2

(3) THESE FACTORS ARE CONSIDERED SPECIFIC BETWEEN LEAD AND FOLLOW-YARDS, BUT DUE TO THE NUMBER OF VARIABLES WHICH INFLUENCE THE COST FACTOR, NO COST VALUE WAS ASSESSED.

(4) THESE COLUMNS REPRESENT THE LEAD-SHIP OF A FOLLOW-SHIP CONTRACT.

SHIP CONSTRUCTION COST FACTORS/COST VALUES RELATED TO LEAD SHIP/FOLLOW-SHIPS

SHIP TYPE:	AMPHIBIOUS									
	LEAD-SHIP		FOLLOW-SHIPS		LEAD-SHIP FOLLOW-YARDS (4)					
	LEAD YARD		LEAD YARD		YARD "A"		YARD "B"		YARD "C"	
CONTRACT TYPE:	MULTI-SHIP	MULTI-YEAR	MULTI-SHIP	MULTI-YEAR	MULTI-SHIP	MULTI-YEAR	MULTI-SHIP	MULTI-YEAR	MULTI-SHIP	MULTI-YEAR
COST FACTORS										
MATERIALS (STANDARDIZATION)	42.0	42.0	39.9	37.8	42.0	38.6	42.0	38.6	42.0	38.6
LABOR RATES	28.0	28.0	28.0	28.0	26.9	26.9	25.9	25.9	33.3	33.3
ESCALATION	(2)	(2)	(2)	(2)	(2)	(2)	(2)	2	(2)	(2)
CONTRACT DESIGN CHANGES	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
CUSTOMER DESIGN CHANGES	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
INSPECTION/SOFTWARE/ HARDWARE CHANGES	-0-	-0-	-0-	-0-	1.0	1.0	1.0	1.0	1.0	1.0
MAKE OR BUY DECISIONS	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
CUSTOMER DIRECTED PURCHASE	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
METHOD OF CONSTRUCTION	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
EXPERIENCE	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
PRODUCTIVITY	(2)	(2)	(2)	(2)	2.7	2.7	2.6	2.6	3.3	3.3
YARD LOCATION	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)
LOCAL ENVIRONMENT	(2)	(2)	(2)	(2)	2.7	2.7	1.3	1.3	0.7	0.7
ECONOMIC CONDITIONS	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)
FACILITIES	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)
START-UP COSTS	(2)	(2)	(2)	(2)	4.8	4.6	4.7	4.5	5.4	5.3
OVERALL WORKLOAD	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
INDIRECT COSTS	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
TOTAL (5)	100.0	100.0	97.9	95.8	110.1	106.5	107.5	103.9	115.7	112.2

(5) FACTOR'S TOTAL COST VALUES WHICH REFLECT REDUCED FOLLOW-SHIPS ARE ON A TWO SHIP FOLLOW PROCUREMENT.

November 1983

BLS Steel Vessel Index

SHIPBUILDING INDEX
STEEL MATERIAL
1967 = 100

1976

August	197.1
September	197.6
October	198.4
November	198.4
December	200.5

1977

January	201.9
February	202.6
March	204.1
April	204.9
May	205.7
June	205.8
July	208.7
August	209.6
September	211.4
October	211.3
November	211.5
December	212.7

1978

January	214.6
February	218.3
March	220.2
April	222.8
May	223.7
June	224.7
July	226.0
August	228.5
September	229.2
October	230.7
November	232.7
December	234.1

1979

January	238.8
February	240.7
March	244.2
April	245.4
May	245.9
June	248.0
July	250.9
August	251.2
September	251.9
October	254.9
November	256.8
December	258.8

1980

January	262.8
February	265.6
March	268.0
April	272.5
May	272.3
June	272.7
July	271.9
August	273.8
September	275.9
October	279.8
November	281.6
December	284.0

1981

January	288.5
February	289.6
March	293.0
April	295.4
May	295.7
June	296.2
July	301.9
August	303.3
September	304.1
October	305.4
November	305.4
December	306.2

1982

January	308.7
February	309.3
March	309.3
April	310.1
May	309.8
June	308.4
July	308.5
August	308.4
September	308.2
October	309.4
November	308.7
December	307.6

1983

January	308.2
February	311.7
March	312.5
April	312.5
May	312.6
June	312.3
July	313.1
August	313.7
September	315.9
October	
November	
December	

FIGURE 3.

November 1983

BUREAU OF LABOR ATISTICAL INDEXES

MATERIAL INDEX FOR STEEL VESSEL CONTRACTS
BASE: AVERAGE FOR 1967=100

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1975	179.5 32.6%	180.6 31.1%	181.1 26.7%	181.9 23.2%	182.3 19.9%	182.1 15.1%	181.7 9.5%	182.5 7.0%	184.0 6.1%	186.2 5.9%	186.4 4.9%	186.9 5.4%
1976	188.0* 4.7%	190.1* 5.3%	191.2* 5.6%	192.6 5.9%	193.0 5.9%	195.8 7.5%	196.9 8.4%	197.1 8.0%	197.6 7.4%	198.4 6.6%	198.4 6.4%	200.5 7.3%
1977	201.9 7.4%	202.6* 6.6%	204.1* 6.7%	204.9* 6.4%	205.7* 6.6%	205.8* 5.1%	208.7* 6.0%	209.6* 6.3%	211.4* 7.0%	211.3* 6.5%	211.5* 6.6%	212.7* 6.1%
1978	214.6* 6.3%	218.3* 7.7%	220.2* 7.9%	222.8* 8.7%	223.7* 8.8%	224.7* 9.2%	226.0* 8.3%	228.5* 9.0%	229.2* 8.4%	230.7* 9.2%	232.7* 10.0%	234.1* 10.1%
1979	238.8* 11.3%	240.7* 10.3%	244.2* 10.9%	245.4* 10.1%	245.9* 9.9%	248.0* 10.4%	250.9* 11.0%	251.2* 9.9%	251.9* 9.9%	254.9* 10.5%	256.8* 10.4%	258.8* 10.6%
1980	262.8* 10.1%	265.6* 10.3%	268.0* 9.7%	272.5* 11.0%	272.3* 10.7%	272.7* 10.0%	271.9* 8.4%	273.8* 9.0%	275.9* 9.5%	279.8* 9.8%	281.6* 9.7%	284.0* 9.7%
1981	288.5* 9.8%	289.6* 9.0%	293.0* 9.3%	295.4* 8.4%	295.7* 8.6%	296.2* 8.6%	301.9* 11.0%	303.3* 10.8%	304.1* 10.2%	305.4* 10.7%	305.4* 8.5%	306.2* 7.8%
1982	308.7* 7.0%	309.3* 6.8%	309.3* 5.6%	310.1 5.0%	309.8* 4.8%	308.4* 4.1%	308.5* 2.2%	308.4 1.7%	308.2 1.3%	309.4 1.3%	308.7 1.1%	307.6 Ø.5%
1983	308.2 -0.2%	311.7 0.8%	312.5 1.0%	312.5 0.8%	312.6* 0.9%	312.3 1.3%	313.1 1.5%	313.7 1.7%	315.9 2.5%			

THE PERCENT OF INCREASE REPRESENTS THE CHANGE FROM THE MONTH TO THE PREVIOUS YEAR

* REVISED BY BLS

FIGURE 4.

APPENDIX C

HISTORICAL PAPERS RELATED TO COST SAVINGS OF MULTIPLE SHIP PRODUCTION

APPENDIX C

HISTORICAL PAPERS RELATED TO COST SAVINGS OF MULTIPLE SHIP PRODUCTION

SWBS 041-65

METHODS OF ESTIMATING INVESTMENT COSTS OF SHIPS

Joseph A. Fetchko
Naval Architect--Cost Estimator
Maritime Administration
Department of Commerce

Lecture Notes for Intensive Course
in Economics in Ship Design and Operation

University of Michigan
Engineering Summer Conferences

June 1968

APPENDIX D

MULTIPLE SHIP REDUCTION

The reduction in the selling price or cost for multiple ships in a contract is illustrated by Figure 33, showing material, labor and overhead costs for general cargo ships, as a percentage of the cost for the first ship. The first ship is assumed to be a new design and includes "full shipyard engineering."

The Maritime Administration has over the years developed average multiple ship reduction factors based on empirical data from over 100 bids. Since the data are based on actual bids, they are limited to 10 ships, maximum. However, with the use of theoretical progress curves, the reduction factors can be extended.

The theoretical progress curves (inappropriately called learning curves) are based on the theory whereby it is assumed that as a total quantity doubles, the cost per unit declines by some constant percentage. The theory was originally developed in the aircraft industry for estimating mass production of airframes. For a more detail discussion, the paper by Couch (5) is recommended.

It is convenient to express the multiple ship reductions or progress curves as a log-linear slope even though the actual bids seldom plot on a straight log line for all the ships in a contract. These relationships are reasonably consistent with that indicated by the Couch (5) and the recent large-lot naval bidders.

In conventional shipbuilding practice, when the total construction time for a large number of ships is long, there is often an increase in material and labor costs due to escalation that tends in a slight way to offset part of the gains of increasing the number of ships in one contract. This was especially noted in some material quotations from vendors of costly equipment for a recent large fixed-price MarAd ship procurement. While the cumulative average price continued to decrease by a very small amount, the unit price actually increased after the fifth and sixth unit. This was due to the later deliveries being in either a period of higher wage agreements or the expected cost increase for materials such as we are presently experiencing.

Tables 42 thru 44 show quantity reduction values for various slopes. Values up to 49 units are shown.

Figure 33

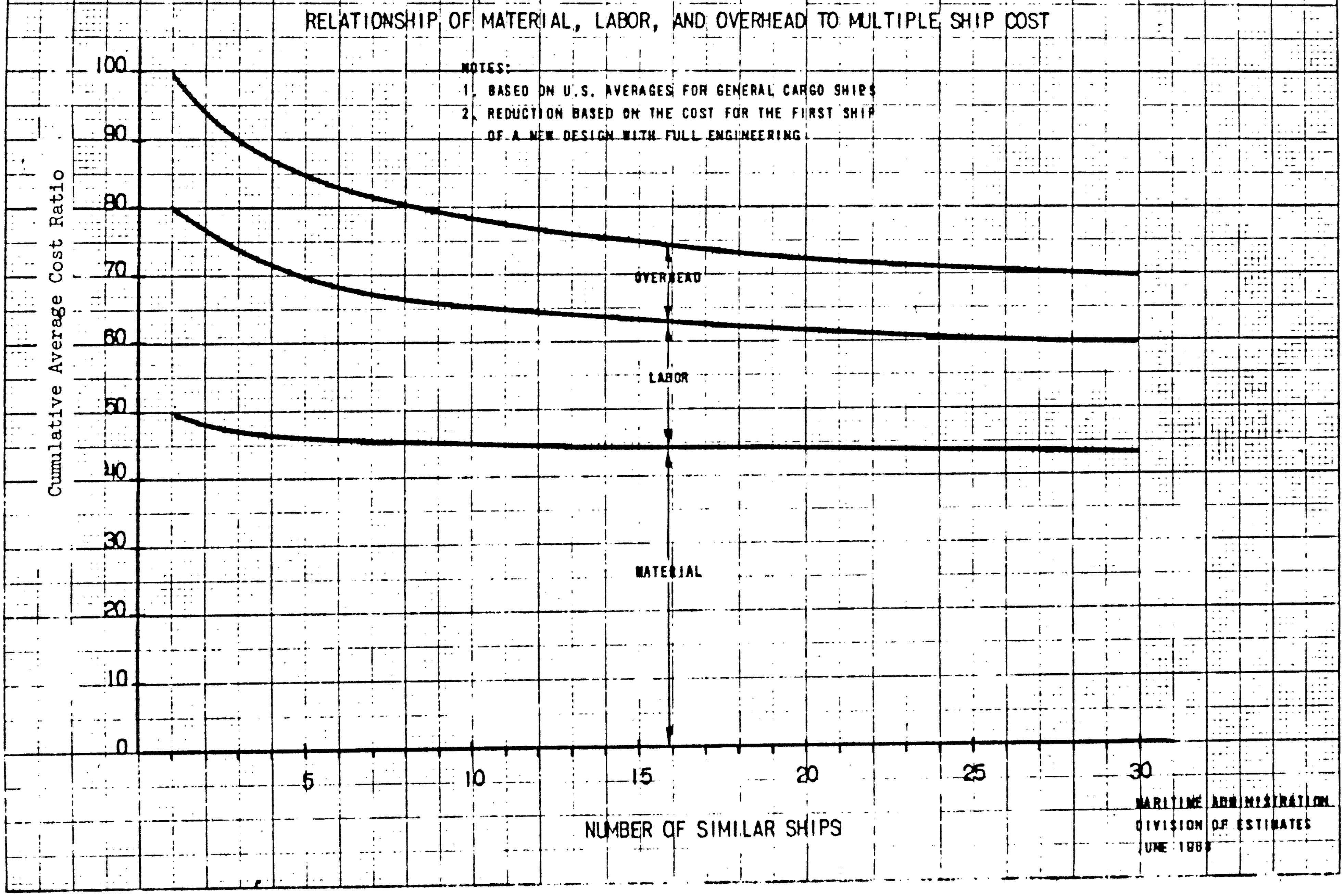

RELATIONSHIP OF MATERIAL, LABOR, AND OVERHEAD TO MULTIPLE SHIP COST
NOTES:
1. BASED ON U.S. AVERAGES FOR GENERAL CARGO SHIPS
2. REDUCTION BASED ON THE COST FOR THE FIRST SHIP OF A NEW DESIGN WITH FULL ENGINEERING
Cumulative Average Cost Ratio
100
90
80
70
60
50
40
30
20
10
0
OVERHEAD
LABOR
MATERIAL
5
10
15
20
25
30
NUMBER OF SIMILAR SHIPS
MARITIME ADMINISTRATION
DIVISION OF ESTIMATES

Table 42

PROGRESS CURVE VALUES
(For slopes of .80 to .86 for 1 thru 49 units)

80% 59A

	0	1	2	3	4	5	6	7	8	9	
		1.00000000	.80000000	.70210400	.64000000	.59563700	.56168300	.53450000	.51200000	.49295000	
1	.47651000	.46211100	.44934600	.43791600	.42759200	.41819900	.40960000	.40168300	.39436000	.38755500	1
2	.38120800	.37526700	.36968900	.36443600	.35947700	.35478400	.35033200	.34612200	.34207300	.33823100	2
3	.33455900	.33104600	.32768000	.32445000	.32134700	.31835200	.31548800	.31271700	.31004400	.30746200	3
4	.30496600	.30255200	.30021400	.29794800	.29575100	.29361900	.29154900	.28953700	.28758200	.28567900	4

81% 61A

	0	1	2	3	4	5	6	7	8	9	
		1.00000000	.81000000	.71606500	.65610000	.61306800	.58001200	.55345800	.53144100	.51274800	
1	.49658500	.48240300	.46981000	.45851600	.44830100	.43899600	.43046700	.42260600	.41532600	.40855500	1
2	.40223400	.39631200	.39074700	.38550200	.38054600	.37585300	.37139800	.36716100	.36312400	.35927100	2
3	.35558700	.35206000	.34867800	.34543200	.34231100	.33930800	.33641400	.33362400	.33093000	.32832700	3
4	.32581000	.32337300	.32101300	.31872500	.31650500	.31435000	.31225600	.31022200	.30824200	.30631600	4

82% 63A

	0	1	2	3	4	5	6	7	8	9	
		1.00000000	.82000000	.73012700	.67240000	.63076600	.59870400	.57285500	.55136800	.53308500	
1	.51724400	.50332100	.49093700	.47981400	.46974100	.46055400	.45212200	.44434200	.43714000	.43041500	1
2	.42414000	.41825700	.41272300	.40750400	.40256800	.39789100	.39344800	.38921900	.38518800	.38133700	2
3	.37765400	.37412500	.37074000	.36748800	.36436000	.36134900	.35844600	.35564500	.35294000	.35032500	3
4	.34779500	.34534500	.34297100	.34066800	.33843300	.33626200	.33415300	.33210200	.33010600	.32816300	4

83% 65A

	0	1	2	3	4	5	6	7	8	9	
		1.00000000	.83000000	.74428900	.68890000	.64870100	.61776000	.59268400	.57178700	.55394700	
1	.53849700	.52487500	.51274100	.50182600	.49192800	.48288900	.47458300	.46691200	.45979200	.45315800	1
2	.44695200	.44112900	.43564700	.43047200	.42557500	.42093000	.41651600	.41231100	.40830000	.40446700	2
3	.40079800	.39728000	.39390400	.39065900	.38753700	.38452900	.38162800	.37882700	.37612100	.37390400	3
4	.37097100	.36851600	.36613700	.36382800	.36158700	.35940900	.35729200	.35523200	.35322700	.35127500	4

84% 67A

	0	1	2	3	4	5	6	7	8	9	
		1.00000000	.84000000	.75855200	.70560000	.66708600	.63718400	.61295000	.59270400	.57540[illegible]	
1	.56035200	.54707800	.53523400	52456600	.51487800	.50601000	.49787100	.49033700	.48333700	.4768[illegible]	1
2	.47069600	.46495500	.45954600	.45443600	.44959700	.44500400	.44063500	.43647200	.43249600	.42869700	2
3	.42505700	.42156500	.41821200	.41498700	.41188300	.40889000	.40600300	.40321500	.40051900	.39791100	3
4	.39538500	.39293600	.39056200	.38825700	.38601800	.38384200	.38172600	.37966700	.37766100	.37570900	4

85% 69A

	0	1	2	3	4	5	6	7	8	9	
		1.00000000	.85000000	.77291500	.72250000	.68567100	.65697800	.63365600	.61412500	.59739700	
1	.58282000	.56994100	.55843100	.54804800	.53860800	.52996500	.52200600	.51463900	.50778800	.50139100	1
2	.49539700	.48976300	.48445000	.47942700	.47466600	.47014500	.46584100	.46173700	.45781700	.45406500	2
3	.45047100	.44702100	.44370500	.44051600	.43744300	.43448000	.43162000	.42885600	.42618300	.42359500	3
4	.42108800	.41865700	.41629800	.41400800	.41178200	.40961800	.40751300	.40546300	.40346600	.40152100	4

86% 71A

	0	1	2	3	4	5	6	7	8	9	
		1.00000000	.86000000	.78737700	.73960000	.70454700	.67714400	.65480800	.63605600	.61996200	
1	.60591100	.59347400	.58234400	.57228900	.56313500	.55474400	.54700800	.53984000	.53316700	.52693100	1
2	.52108300	.51558000	.51038800	.50547500	.50081600	.49638700	.49216900	.48814300	.48429600	.48061200	2
3	.47708000	.47368800	.47042700	.46728800	.46426200	.46134300	.45852400	.45579800	.45316100	.45060700	3
4	.44813100	.44573000	.44339900	.44113500	.43893400	.43679200	.43470800	.43267900	.43070100	.42877300	4

Table 43

PROGRESS CURVE VALUES

(For slopes of .87 to .93 for 1 thru 49 units)

87% 73A

	0	1	2	3	4	5	6	7	8	9
		1.00000000	.87000000	.80193700	.75690000	.72371600	.69768500	.67640900	.65850300	.64310300
1	.62963300	.61769100	.60698600	.59730300	.58847500	.58037500	.57289900	.56596200	.55950000	.55345500
2	.54778000	.54243700	.53739100	.53261300	.52807800	.52376500	.51965400	.51572800	.51197400	.50837700
3	.50492600	.50161000	.49842100	.49534900	.49238700	.48952000	.48676500	.48409300	.48150600	.47899900
4	.47656900	.47421100	.47192000	.46969400	.46753000	.46542400	.46337300	.46137500	.45942800	.45752800

88% 75A

	0	1	2	3	4	5	6	7	8	9
		1.00000000	.88000000	.81659600	.77440000	.74317800	.71860400	.69846300	.68147200	.66682900
1	.65399700	.64260100	.63237200	.62310500	.61464700	.60687600	.59969500	.59302800	.58680900	.58098700
2	.57551700	.57036200	.56548900	.56087200	.55648700	.55231300	.54833300	.54452900	.54088900	.53740000
3	.53405100	.53083100	.52773200	.52474600	.52186400	.51908200	.51639200	.51378900	.51126900	.50882500
4	.50645500	.50415400	.50191800	.49974500	.49763000	.49557200	.49356800	.49161400	.48970900	.48785000

89% 77A

	0	1	2	3	4	5	6	7	8	9
		1.00000000	.89000000	.83135200	.79210000	.76293400	.73990300	.72097400	.70496900	.69114700
1	.67901200	.66821800	.65851400	.64971200	.64166700	.63426700	.62742200	.62106000	.61512000	.60955400
2	.60432000	.59938400	.59471400	.59028600	.58607800	.58206900	.57824400	.57458600	.57108400	.56772400
3	.56449800	.56139500	.55840600	.55552500	.55274300	.55005600	.54745700	.54494100	.54250300	.54013900
4	.53784500	.53561700	.53345100	.53134500	.52929600	.52730000	.52535500	.52345900	.52160900	.51980400

90% 79A

	0	1	2	3	4	5	6	7	8	9
		1.00000000	.90000000	.84620600	.81000000	.78298700	.76158500	.74394800	.72900000	.71606500
1	.70468800	.69455300	.68542700	.67713800	.66955300	.66256800	.65610000	.65008200	.64445800	.63918300
2	.63421900	.62953300	.62509700	.62088800	.61688400	.61306800	.60942400	.60593800	.60259800	.59939200
3	.59631100	.59334700	.59049000	.58773400	.58507400	.58250100	.58001200	.57760200	.57526500	.57299800
4	.57079700	.56865900	.56658000	.56455700	.56258800	.56066900	.55879900	.55697500	.55519600	.55345800

91% 81A

	0	1	2	3	4	5	6	7	8	9
		1.00000000	.91000000	.86115700	.82810000	.80333600	.78365300	.76738700	.75357100	.74159100
1	.73103500	.72161700	.71312400	.70539900	.69832300	.69179800	.68575000	.68011600	.67484800	.66990100
2	.66524200	.66084100	.65667100	.65271100	.64894300	.64534800	.64191400	.63862600	.63547300	.63244700
3	.62953600	.62673400	.62403200	.62142500	.61890600	.61647000	.61411100	.61182600	.60961000	.60745900
4	.60537000	.60334000	.60136500	.59944300	.59757100	.59574600	.59396700	.59223200	.59053800	.58888300

92% 83A

	0	1	2	3	4	5	6	7	8	9
		1.00000000	.92000000	.87620400	.84640000	.82398200	.80610700	.79129700	.77868800	.76773300
1	.75806400	.74942200	.74161900	.73451200	.72799300	.72197600	.71639300	.71118700	.70631400	.70173500
2	.69741900	.69333700	.68946800	.68579100	.68228900	.67894700	.67575100	.67269000	.66975400	.66693300
3	.66421800	.66160300	.65906200	.65664600	.65424200	.65201500	.64980900	.64767100	.64559600	.64358200
4	.64162500	.63972200	.63797000	.63606700	.63431100	.63259800	.63092800	.62929800	.62770600	.62615100

93% 85A

	0	1	2	3	4	5	6	7	8	9
		1.00000000	.93000000	.89134700	.86490000	.84492800	.82895200	.81568100	.80435700	.79449900
1	.78578300	.77798100	.77092600	.76449200	.75858400	.75312400	.74805200	.74331900	.73888400	.73471300
2	.73077800	.72705500	.72352200	.72016300	.71696100	.71390300	.71097800	.70817400	.70548300	.70289600
3	.70040500	.69800500	.69568800	.69345100	.69128700	.68919200	.68716200	.68519400	.68328300	.68142800
4	.67962400	.67786900	.67616100	.67449700	.67287600	.67129400	.66975100	.66824500	.66677400	.66533600

Table 44

PROGRESS CURVE VALUES

(For slopes of .94 to .99 for 1 thru 49 units)

94% 87A

	0	1	2	3	4	5	6	7	8	9	
		1.00000000	.94000000	.90658500	.88360000	.86617300	.85219000	.84054400	.83058400	.82189700	
1	.81420300	.80730500	.80105900	.79535500	.79011100	.78526000	.78074900	.77653500	.77258300	.76886300	1
2	.76535100	.76202500	.75886700	.75586100	.75299500	.75025600	.74763400	.74512000	.74270400	.74038200	2
3	.73814400	.73598700	.73390400	.73189100	.72994300	.72805700	.72622800	.72445400	.72273100	.72105700	3
4	.71943000	.71784600	.71630300	.71480000	.71333500	.71190500	.71051000	.70914700	.70781600	.70651400	4

95% 89A

	0	1	2	3	4	5	6	7	8	9	
		1.00000000	.95000000	.92191900	.90250000	.88772000	.87582300	.86588900	.85737500	.84993500	
1	.84333400	.83740700	.83203200	.82711800	.82259500	.81840600	.81450600	.81086000	.80743800	.80421400	1
2	.80116700	.79828000	.79553600	.79292400	.79043000	.78804600	.78576200	.78357100	.78146500	.77943800	2
3	.77748500	.77560100	.77378100	.77202100	.77031700	.76866700	.76706600	.76551200	.76400300	.76253600	3
4	.76110900	.75971900	.75836600	.75704600	.75575900	.75450400	.75327700	.75208000	.75090900	.74976400	4

96% 91A

	0	1	2	3	4	5	6	7	8	9	
		1.00000000	.96000000	.93734700	.92160000	.90956800	.89985300	.89172100	.88473600	.87862300	
1	.87318500	.86829700	.86385900	.85979700	.85605200	.85258100	.84934700	.84631900	.84347500	.84079400	1
2	.83825800	.83585200	.83356600	.83138600	.82930500	.82731400	.82540500	.82357200	.82181000	.82011400	2
3	.81847800	.81689900	.81537300	.81389600	.81246700	.81108100	.80973600	.80843100	.80716200	.80592600	3
4	.80472700	.80355800	.80241800	.80130700	.80022300	.79916500	.79813100	.79712100	.79613300	.79516700	4

97% 93A

	0	1	2	3	4	5	6	7	8	9	
		1.00000000	.97000000	.95287000	.94090000	.93171900	.92428400	.91804400	.91267300	.90796100	
1	.90376700	.89999000	.89655500	.89340800	.89050300	.88780700	.88529300	.88293700	.88072300	.87863300	1
2	.87665400	.87477700	.87299000	.87128700	.86965900	.86810000	.86660500	.86516900	.86378800	.86245700	2
3	.86117300	.85993300	.85873400	.85757400	.85644900	.85535900	.85430100	.85327300	.85227400	.85130100	3
4	.85035500	.84943200	.84853300	.84765700	.84680100	.84596500	.84514800	.84435000	.84356900	.84280500	4

98% 95A

	0	1	2	3	4	5	6	7	8	9	
		1.00000000	.98000000	.96848700	.96040000	.95417400	.94911700	.94486200	.94119200	.93796600	
1	.93509100	.93249600	.93013500	.92796700	.92596500	.92410500	.92236800	.92074000	.91920700	.91776000	1
2	.91638900	.91508600	.91384700	.91266300	.91153200	.91044800	.90940800	.90840800	.90744600	.90651800	2
3	.90562300	.90475800	.90392100	.90311000	.90232500	.90156300	.90082300	.90010400	.89940500	.89872400	3
4	.89806100	.89741500	.89678500	.89617000	.89557000	.89498300	.89441000	.89385000	.89330100	.89276500	4

99% 97A

	0	1	2	3	4	5	6	7	8	9	
		1.00000000	.99000000	.98419700	.98010000	.97693400	.97435500	.97217900	.97029900	.96864300	
1	.96716500	.96582900	.96461100	.96349200	.96245800	.96149500	.96059600	.95975200	.95895700	.95820500	1
2	.95749300	.95681600	.95617100	.95555500	.95496500	.95440000	.95385700	.95333600	.95283300	.95234800	2
3	.95188000	.95142800	.95099000	.95056600	.95015400	.94975500	.94936700	.94899000	.94862300	.94826600	3
4	.94791800	.94757900	.94724800	.94692500	.94660900	.94630100	.94599900	.94570400	.94541500	.94513300	4

The use of slope factors, while convenient, can be mesmerizing. For example, a construction program for 49 ships under conventional shipbuilding techniques would require construction in several shipyards. Thus the average unit cost for 49 ships would not be the cumulative average for 49 units taken directly from the tables. The MarAd empirical data (cumulative average) approximates a log linear plot with a slope of .929. A comparison of the empirical multiple ship reduction factors and the theoretical factors using a (.929) slope is shown in Table 45.

Table 45

MarAd Total Cost Multiple Ship Reduction Factors

Each of -	Empirical	Theoretical	Each of -	Empirical	Theoretical
(1)	1.000	1.000	(6)	.827	.827
(2)	.921	.929	(7)	.814	.813
(3)	.880	.891	(8)	.802	.802
(4)	.859	.863	(9)	.791	.792
(5)	.842	.843	(10)	.780	.783

A comparison with other sources equating the slope for the total price of ships are shown in Table 46.

Table 46

Total Cost Slope Factors

MarAd Empirical Data..................................(.929)
Benford (4)...(.933)
Couch (5)...(.935)
Average Navy LST Bids 17 Ships........................(.941)
Average Navy DE Bids 20 Ships.........................(.954)

Note, however, that a shipyard's estimate of cost for multiple ships seldom relies entirely on these specific relationships. Further, the relationships will:

- Vary with each shipyard and for each bid
- Vary for material, labor and overhead
- Vary for new designs and repeat designs

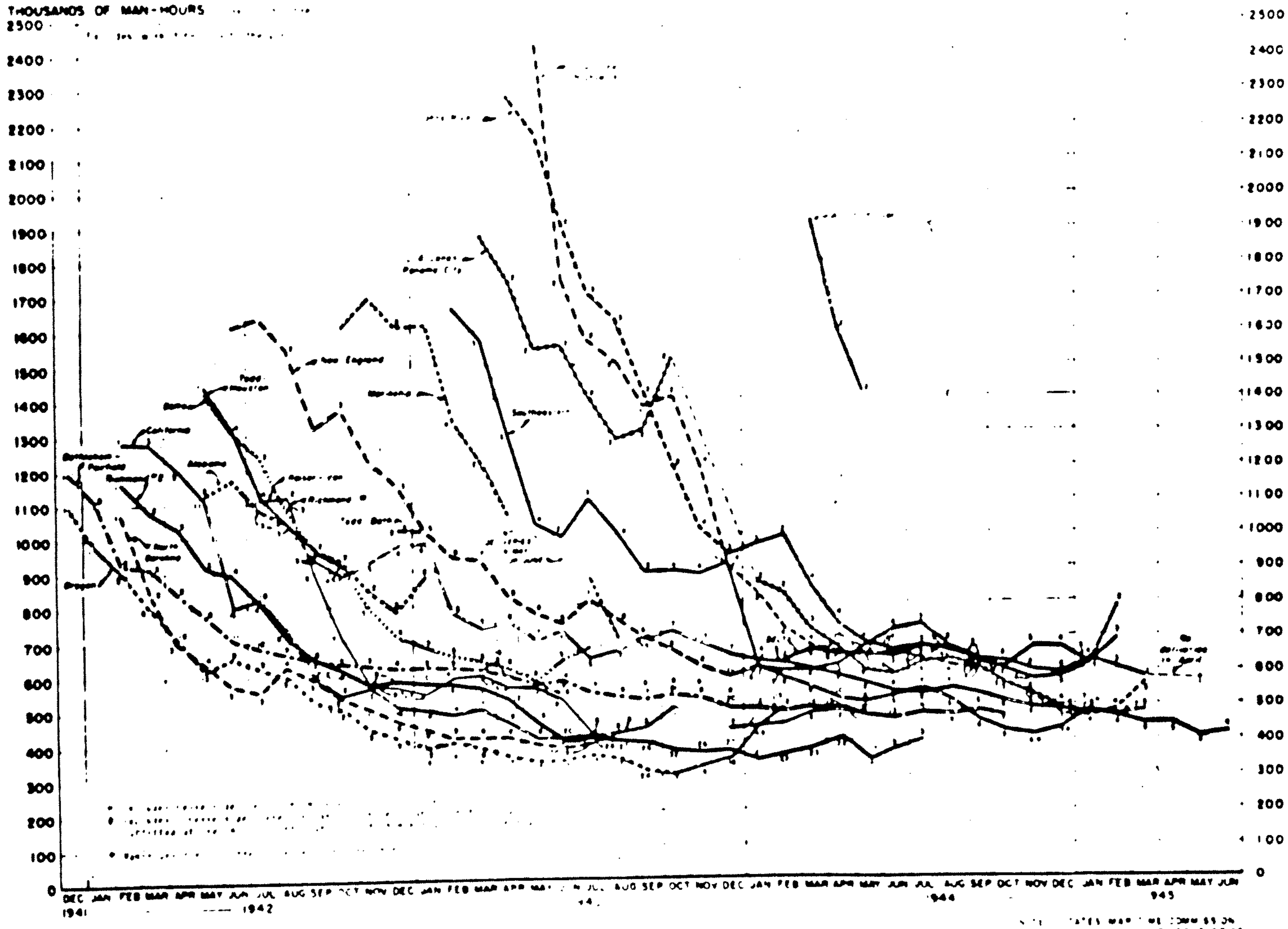
Figure 34

LIBERTY SHIPS

NUMBER OF VESSELS DELIVERED AND AVERAGE NUMBER OF MAN-HOURS USED IN THEIR CONSTRUCTION BY YARDS AND BY MONTHS

December 1941 through June 1945

Figures shown on curves indicate the number of vessels delivered by each yard during the month



SOURCE Data from Production Division and Finance Division

To determine following ship costs, it is the general practice of the shipyard to estimate the labor savings, material purchase savings, and prorate the initial non-recurring cost (i.e. ship engineering) over the remaining ships in a contract. The overhead and profit, expressed as a percentage, may or may not change. Prorating the engineering is one of the most significant causes of the initially steep drop in cost. Repeat designs for example, do not exhibit the same cost-quantity relationships as do initial designs. The cause of the drop in following ship prices can be expressed in another manner, that is, by equating recurring (material and labor) costs to non-recurring costs.

The reduction expressed as a slope factor is different for material and labor. Based on MarAd's empirical studies the average slope factors for cumulative average costs are:

Material = (.97) slope
Labor = (.88) slope

Another factor to remember is that, with expanded production line techniques, the values flatten more quickly. For example, cargo containers are susceptible to advanced production line techniques and after the price has been reduced for a quantity purchase, the remaining units show no significant cost change.

While the cost advantage of large quantity production for ships is not questioned, expected savings can be easily overestimated by the quick use of an arbitrary slope. Data concerning the results of large quantity construction during World War II can likewise be misleading. Figure 34 shows the actual manhours for the construction of liberty ships during the early period of World War II. The average slope for all the yards and in particular, the yards at the top would be relatively steep (i.e. a significant reduction). It must be realized, however, that most of the yards showing really significant decreases were either new or otherwise essentially inexperienced in building ships. In fact, there had to be a significant drop since there was true learning. The important point is that if yards are presently operating at a level employing far more advanced techniques than those used before World War II, a similar slope for an expanded program would require a greater advance in technology.

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THE COST SAVINGS OF MULTIPLE SHIP PRODUCTION

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THE DEPARTMENT OF NAVAL ARCHITECTURE AND MARINE ENGINEERING

THE UNIVERSITY OF MICHIGAN
COLLEGE OF ENGINEERING

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THE COST SAVINGS OF MULTIPLE SHIP PRODUCTION

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The Cost Savings of Multiple Ship Production

John C. Couch, University of Michigan

Introduction

We are all aware that increased production tends to lower costs, especially in mass production industries. To a lesser degree, this is also true in shipbuilding (See Fig. 1). However, few of the publications on manufacturing cost-quantity relationships, which mathematically express this downward trend, acknowledge their application to the shipbuilding industry. This lack of available information, plus the author's participation in a recent student project related to the problem, provided the impetus for further research which is reported here. Then, the object of this paper is to discuss the relationship between units built and unit costs and to present a theory which, it is found, can be used to estimate the cost savings of multiple ship production. Before discussing cost-quantity relationships applied to shipbuilding, it will be necessary to review briefly the development of these theories in other industries.

General Principle and Current Theories

In a repetitive manufacturing process many units can usually be produced for less apiece than can a few. The principal reasons for this cost reduction are:

1. The existence of non-recurring, preparatory, or tooling charges that are not repeated once production begins.
2. The savings resulting from buying materials in large quantities, and in more efficient sizes and shapes.
3. Increased labor efficiency with succeeding units.

This principle has been recognized for some time, and the first attempts,[1] to the author's knowledge, to express the mathematical relationship between product cost and quantity appeared in 1928. However, the early papers generally oversimplified the problem by ignoring some of the factors that contribute to the resulting cost reductions. The most sophisticated analyses are found in aircraft industry publications and apparently this industry pioneered work in the field. In fact, the first published formulation of the cost-quantity relationship that the author believes applicable to shipbuilding, appeared in the *Journal of Aeronautical Sciences* in 1936.[2] This is the progress of learning curve theory.

The learning curve theory is a cost-quantity formulation that was developed and used prior to World War II by airframe manufacturers and the U.S. Air Force for estimating the cost of producing airframes.[3] The theory, as it is most popularly known, states that as the number of units produced doubles the "cost per unit" decreases by some constant percentage. Two different forms of the theory have developed: the first treats the "cost per unit" as the cumulative average cost of X units; the second treats it as the added cost of producing the Xth unit. In either form, the relationship expressed by the theory is a hyperbolic function that plots as a straight line on logarithmic grid paper (i.e., it is a log-linear relationship). Figures 2 and 3 are the graphical representations of these two forms. Their traditional mathematical formulations are easily understood and the popularity of this theory may be attributed to the simplicity of these formulations and to the ease with which they may be plotted.

(Continued on next page)

Mathematics of Learning Curve Theory

The first form of this theory, cumulative average cost log-linearity, was originally expounded by T. P. Wright in Ref. 3. He proposed cumulative average log-linearity for both direct labor and material costs, but excluded non-recurring costs. This form of the learning curve theory is formulated as

$$\bar{Y} = aX^{b} \qquad (1)$$

where

$\bar{Y}$ = the cumulative average cost per unit
X = the number of units
a = the cost of the first unit
b = a parameter related to the Slope of the learning curve (it is literally the geometric slope of the line on logarithmic grid paper).

In learning curve terminology, Slope is normally defined as the ratio of the cost per unit for 2X units to the cost per unit for X units. That is,

$$\text{Slope} = S = \frac{a(2X)^{b}}{aX^{b}} = 2^{b} \qquad (2)$$

when we speak of an 80 per cent learning curve (S = 0.800, b = —0.322), we mean that the cost per unit decreases 20 per cent every time the number of units is doubled.

Now if Equation 1 holds true for cumulative average cost, the cumulative total for X units (Y) would be

$$Y = \bar{Y}X = aX^{1+b} \qquad (2)$$

and the added cost of the Xth unit (y_i) would be

$$y_i = a(X_i^{1+b} - X_{i-1}^{1+b}) \qquad (3)$$

The various relationships expressed by this form of the theory are plotted in Fig. 2.

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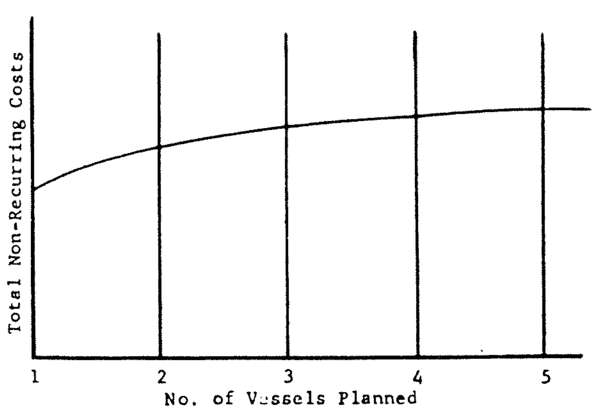


Fig. 4

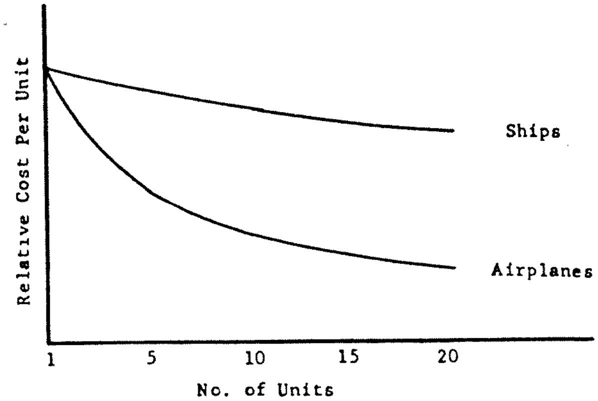


Fig. 1

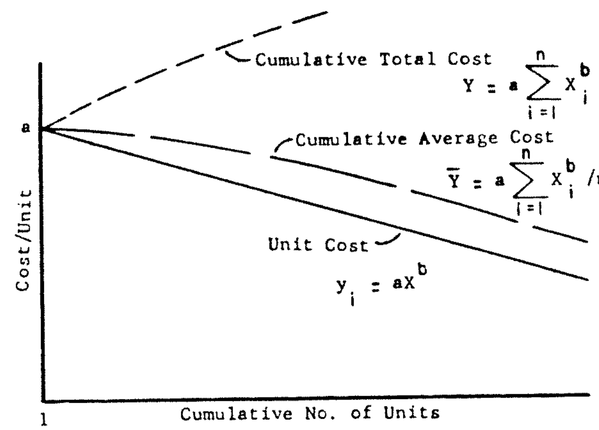


Fig. 2 Cumulative Average Cost Log.-Linearity (Logarithmic grid)

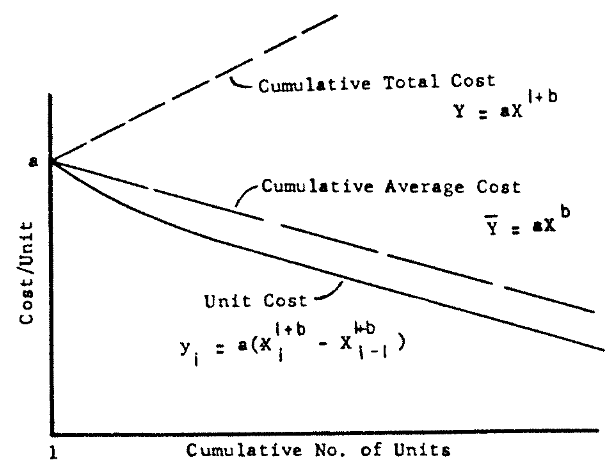


Fig. 3 Unit Cost Log.-Linearity (Logarithmic grid)

(Continued from page 51)

The second form of the learning curve theory was probably originally presented in Ref. 4. This form assumes unit cost rathes than cumulative average cost, log-linearity. Again, in Ref. 4, the theory was applied to direct labor costs, exclusive of non-recurring costs. The log-linear unit cost curve is formulated as

$$y_i = aX^b \qquad (4)$$

where the symbols have the previously stated meanings. If the Equation 4 holds true for unit costs, then cumulative total and cumulative average costs would be expressed by Equations 5 and 6 respectively:

$$Y = a \sum_{i=1}^{n} X_i^b \qquad (5)$$

$$\bar{Y} = a \sum_{i=1}^{n} X_i^b \quad /n \qquad (6)$$

The relationships expressed by Equations 4, 5 and 6 are plotted in Fig. 3.

In studying the relationships proposed by these two forms of the theory and represented in Figs. 2 and 3, several observations can and should be made. First, if the cost-quantity relationship for a particular product is found to be log-linear it can be either unit cost log-linear, or cumulative average log-linear, but it cannot be both. Second, since no matter how many units are produced, the costs can never reach zero, there must be a limit to the proposed long-linear relationships. Some attempts have been made[3] to determine where this deviation would begin and have indicated that a leveling off of the curve will take place only after a very large number of units have been produced (i.e., 100 to 1000 or more, depending on the complexity of the product and the experience of the plant). Since comparatively few vessels are involved in peacetime multiple shipbuilding contracts we need not be concerned with this aspect of the problem. The third observation that can be made is that in order to assume a log-linear relationship between costs per unit and cumulative output, we assume that plant facilities and product design remain more or less constant. That is, no significant changes are made in the plant's production facilities and no major product design changes occur.

Obviously, to be able to estimate costs of succeeding units by means of the learning curve technique, once the cost of the first unit is estimated, we must know what Slope is applicable to the particular product and plant concerned. This can only be determined from evaluation of the past cost records of that plant—the accuracy of the chosen Slope depending on the extent and accuracy of the company's records of costs of similar products. Because of the many studies done and the wealth of empirical data available to airframe manufacturers, they have made considerable progress in predicting reliable Slopes for different types of aircraft.

The Slope of a given learning curve will depend on several factors, the most important of which are the particular plant's experience and the product's complexity. The more experienced plants and/or the less complex products will dictate rather flat learning curves (greater per cent Slopes) since their increase in overall production efficiency stands to improve less with succeeding units than if the plant were inexperienced and/or the product relatively complex. Another factor that will influence the Slope is the extent of initial planning and tooling. The more extensive the preparation, the flatter the learning curve because more effort would have been made to optimize production before it actually began.

Cost-Quantity Relationships Applied to Shipbuilding

The author found that there is little published material on shipbuilding costs and cost estimating and that what *has* been written generally gives no more than token acknowledgement to the principle discussed here. What is more surprising is the absence of any published attempt (to the author's knowledge) to determine the relation between ship costs and the quantity built, prior to December, 1945.[5] In July of that same year, in fact, H. M. Neuhaus,[6] in discussing the effect on cost of a multiple ship contract and the information available on the subject, stated that, "Unfortunately no statistics or data were available, no reports, correspondence or literature having been published anywhere either in domestic or foreign papers."

Whether this absence of published material on the subject was due to a lack of knowledge of an applicable cost-quantity relationship or due to the industry's reluctance to release its cost data is difficult to determine. There is evidence to support either possibility. Since the early papers on shipbuilding costs attributed these costs savings sing-

(Continued on next page)

ularly to the resulting greater distribution of overhead[7] or just to the non-recurring costs,[8] there apparently was some lack of understanding of the problem and it is significant that the first application of a particular cost-quantity relationship to shipbuilding[5] appeared in a government publication, *Monthly Labor Review.*

In this particular publication, A. D. Searle applied the learning curve concept to man-hour cost information obtained from several shipbuilders (where man-hour cost is that of direct labor plus overhead in proportion to direct labor and exclusive of non-recurring costs). Searle shows that for each yard's wartime Liberty, Victory, and tanker shipbuilding programs, the unit man-hour costs (man-hour cost for each additional, similar vessel) are log-linear. Specifically he shows that the Slope of these unit cost curves for each type of vessel built in the various yards is close to 80 per cent.

Three years after Searle's work appeared, W. B. Ferguson and B. V. Tornborgh[9] presented another cost-quantity relationship for shipbuilding man-hours. This was

$$Z = C\sqrt{X - 1} \tag{7}$$

where

Z = Per cent savings of recurring direct labor costs
X = Number of units produced
C = A constant for any given yard, varying from 8 for an old and experienced yard to 20 for a "green" yard.

Although Ferguson and Tornborgh give an excellent comprehensive discussion of the whole problem, they present a mathematical formulation, Equation 7, only for direct labor costs, exclusive of non-recurring costs.

(Continued on page 55)

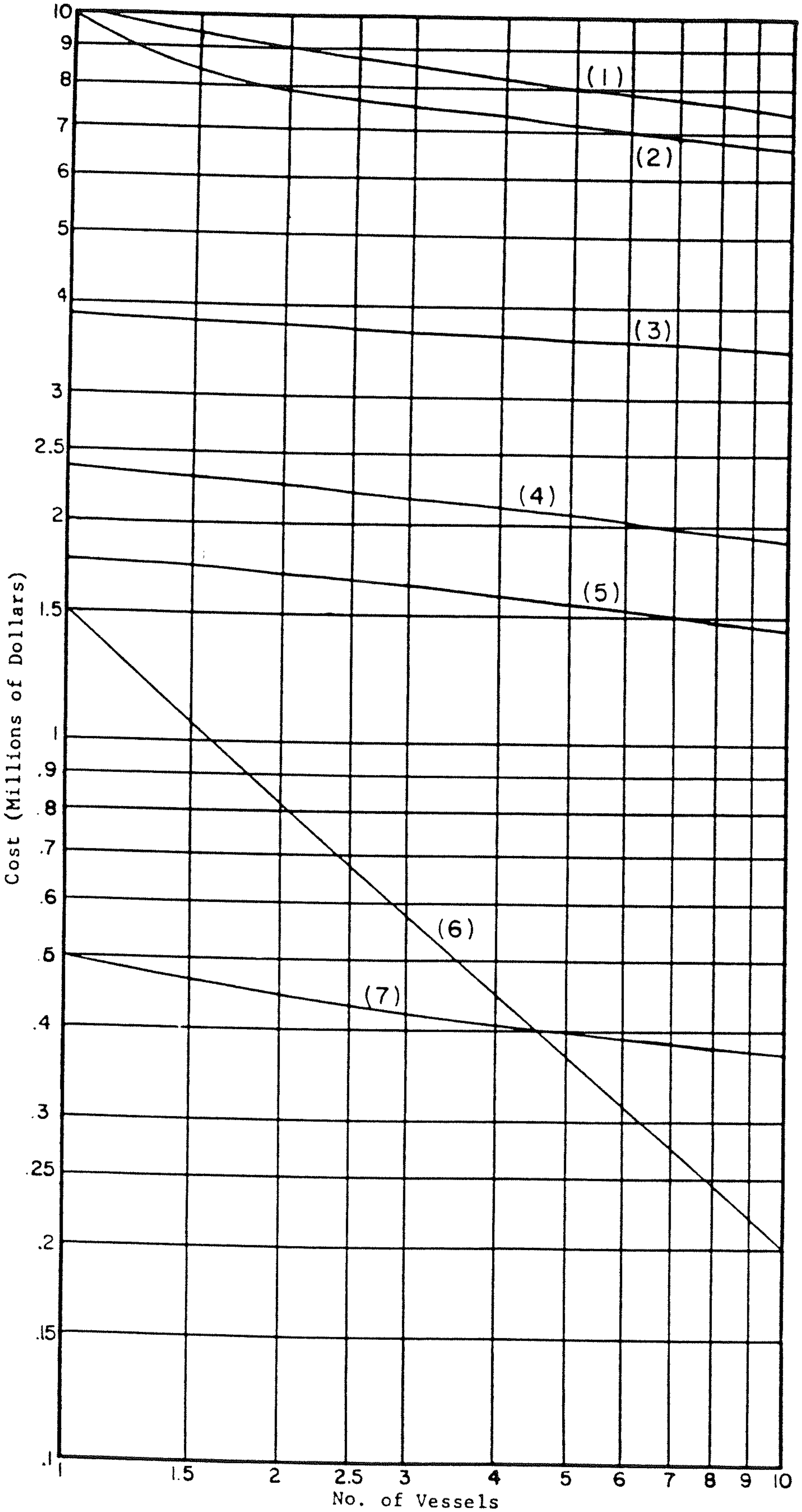
Table I

Summary of y_i Versus $\overline{Y}$ Analysis

Number of Ships	Number of Bidders	Type of Ship	y_i Slope	y_i Accur.*	$\overline{Y}$ Slope	$\overline{Y}$ Accur.*	Choice
3	11	T-AKA	0.825	E	0.91	A	$\overline{Y}$
5	1	Gen'l Cargo	0.890	C	0.945	A	"
10	1	Container		E	0.956	C	"
5	1	(Marad Data)		E	0.940	B	"
5	1	C-1		E	0.920	B	"
6	1	Farrel		E	0.910	A	"
10	Aver.	Cargo		E	0.930	A	"
6	1	Cargo		E	0.920	B	"
6	4	Cargo		E	0.937	B	"
3		Ferry	08.40	E	0.940	E	
3	2	Ferry	0.887	A	0.940	A	TIE
8	1	Roll-On	0.950	B	0.965	A	$\overline{Y}$
10	1	Roll-On		C	0.970	A	"
5	Many		0.940	C	0.960	B	"
3	5	Cargo	0.930	A	0.960	A	TIE
3	5	Ferry	0.880	E	0.930	B	$\overline{Y}$
	1	Cargo	0.877	E	0.917	C	"
	1		0.930	E	0.970	B	"
3	1	Ferry	0.840	C	0.910	A	"
6	5	Cargo	0.92	C	0.950	A	"
7	Many	Cargo	0.83	E	0.940	C	"
			0.96	A	0.980	A	
3	2	Container	0.93	B	0.960	A	"
3	7	Tanker	0.81	E	0.91	C	"
3	7	Bulk		E	0.982	B	"

*Bids rated A, B, C, D, or E, depending on how accurately they conformed to each type of Learning Curve.

Fig. 5
Component Cost Synthesis



Curve	Title
(1)	Cumulative Average (Total Cost)
(2)	Unit (Total) Cost
(3)	Cumulative Average Material Cost
(4)	Cumulative Average Labor Cost
(5)	Cumulative Average Overhead Cost
(6)	Cumulative Average Non-Recurring Cost
(7)	Cumulative Average Profit

(Continued from page 53)

Apparently no further information on shipbuilding cost-quantity relationships appeared until July, 1962, when Professor Harry Benford[10] proposed a cumulative average log-linear relationship for total shipbuilding costs, with an average Slope of 93.3 per cent for general cargo ships. This proposal was based on the evaluation of limited data and was put forth without knowledge of work done in other industries.

In view of this dearth of conclusive information pertinent to shipbuilding cost-quantity relationships and with the knowledge that other industries have found strong evidence of log-linear cost quantity relationships, a group of students* at the University of Michigan undertook the following analysis to determine if these relationships would, in fact, hold true for total shipbuilding costs.

Total Shipbuilding Cost Analysis

The analysis consisted of the evaluation of recent bids, from many yards, for 23 different designs. In each case the bids applied to alternative numbers of ships. It was assumed that the estimators, in preparing the bids, were unfamiliar with the cumulative average and unit cost log-linear concepts, or at least they ignored them, and therefore their bids were influenced by neither school of thought. The various bids were converted, where necessary, to both cumulative average (total) costs and unit (total) cost and then both were plotted (versus the number of ships to be built) on logarithmic grid paper. The overwhelming conclusion of the analysis, which is summarized in Table I, is that cumulative average ship costs approach log-linearity; unit costs do not. It was found that cumulative average cost of recent general cargo ships, in particular, could be closely represented by a 93.5 per cent learning curve.

Table 2 shows the close agreement between the prices, determined by the apparent low bidder, for C4-S-65a vessels,[12] and those predicted by a 93.5 per cent learning curve, where $\overline{Y} = \$15,090,000\ X^{-0.097}$. Note that the 93.5 per cent Slope is an average for all the yards bidding on the eleven general cargo vessels included in the study. Since the individual Slopes ranged from 91 to 96 per cent this average must be used with caution. Also, individual circumstances may cause alternating fluctuations above and below the theoretical line. Table 3 gives ratios of average cost per ship to the cost of the first ship for multiple general cargo vessels where cumulative average costs are log-linear with a 93.5 per cent Slope.

Because some of the bid data used for this analysis were the same as those used by Benford, the close agreement of the two separate conclusions does not mean one definitely confirms the other; however, the class study does strengthen Benford's original conclusion. This conclusion can be rationally substantiated only by evaluating separately each of the factors that contribute to the downward trend of cost with succeeding vessels. In fact, the reliability of estimating techniques, based on the cumulative average learning curve theory, will depend, to a large extent, on the individual yard's ability to evaluate the effect of the various component costs on the total. Because an analysis of the component shipbuilding costs would provide a better understanding of their inter-relationships and could serve as a check on the conclusion reached by Benford and the class study, the author prepared the following synthesis.

Component Cost Synthesis

Imaginary contracts of from one to ten vessels were assumed, with the cost of the first vessel set at $10,000,000. The total ship cost was divided, to the best of the author's ability, into five broad components, the effect of multiple production on each was estimated, and they were then synthesized to provide total costs. Total costs were then plotted versus the number of ships, on logarithmic grid paper.

The five cost components used in the study were the recurring direct and miscellaneous production costs for *labor* and *materials*, the *non-recurring costs*, *overhead* and *profit*. The following assumptions were made in regard to the distribution of these component costs for the first vessel (See Table 4).

Miscellaneous Assumptions:

1. Labor and material costs were $2,370,000 and $3,860,000 respectively (i.e., they were assumed to be 38 and 62 per cent of a $6,230,000 direct building cost).
2. Overhead charges (75 per cent of labor) were $1,770,000.

(Continued on next page)

*Naval Architecture and Marine Engineering students in Professor Benford's Fall, 1962, Shipbuilding Contracts and Cost Estimating class.

(Continued from page 55)

3. Labor, materials, and overhead amounted to 80 per cent of the ship's total cost to the customer.
4. Non-recurring costs amounted to 15 per cent of the total.
5. Profit was 5 per cent of the total.

The following reasoning determined how each component of this synthesis would be affected by multiple production.

Labor: Of the recurring costs in many industries, that of labor decreases most with succeeding units. Extensive analysis of labor learning in aircraft manufacturing[3], as well as Searle's analysis of shipbuilding labor efficiency during World War II, indicated that labor learning curves are unit cost log-linear with approximately 80 per cent Slopes. In view of this evidence and with the additional consideration that peacetime shipyard labor forces are experienced and would show less labor learning than the wartime industry as a whole, a 90 per cent unit cost, log-linear, labor curve was chosen.

Material: The cost savings resulting from buying materials in larger quantities and in more efficient shapes and sizes, together with the savings from reduced scrappage are usually relatively small. This is especially true in well established industries like shipbuilding and in industries that buy from manufacturers who have already produced their product in larger numbers. In 1936, Wright[2] proposed cumulative average, log-linear material cost curves with Slopes ranging from 90 to 95 per cent. He showed that the Slope depended on the amount of labor involved in processing the material before it was purchased from the vendor, the more complex, hardware items, having steeper Slopes than raw materials. Because large quantities of "raw" materials are used in shipbuilding and because of the many standard

(Continued on next page)

Table 2

Cumulative Average Costs ($1,000)
For C4-S-65a Vessels

Cumulative Average Cost for Each of	1	2	3	4	5	6
Low Bidder	$15,090	$14,094	$13,595	$13,150	$12,650	$12,600
93.5% Learning Curve	15,090	14,109	13,566	13,189	12,905	12,679
Per cent Difference	——	0.1%	—0.2%	.03%	2.0%	0.6%

Table 3

Multiple Ship Cost Reduction Factors
For 93.5 Per Cent Cumulative Average

Number of Ships In Contract	Ratio of Average Cost per Ship to Cost of Single Ship	Ratio of Cost of Each Additional Ship to Cost of Single Ship
1	1.000	1.000
2	0.935	0.870
3	0.897	0.830
4	0.874	0.796
5	0.856	0.784
6	0.840	0.760
7	0.828	0.750
8	0.816	0.745
9	0.808	0.735
10	0.800	0.730

sizes and types of these materials that are purchased in quantity by today's yards, the author felt that a curve for shipbuilding material costs would have a somewhat flatter Slope than those predicted by Wright. Therefore a 97 per cent cumulative average, log-linear curve was chosen for material costs.

Overhead: Overhead charges were assumed to to be a constant percentage (in this case 75 per cent) of direct labor costs, primarily because those factors causing a decrease in direct labor costs would also be at work in overhead costs.

Non-Recurring Costs: In shipbuilding the costs that, for the most part, are not repeated once production begins include:

1. Engineering and Drafting
2. Production Planning
3. Purchasing
4. Mold Loft Work
5. Jigs and Forms

The increase in these costs with increasing planned output is a recognized phenomenon in other industries[3] and some mention of it in regard to shipbuilding is contained in Ref. 9. The lack of empirical data, however, precludes its accurate formulation. A study of the above components suggests that the increase would be slight and that it would be less as the planned number of vessels increases. A similar conclusion is reached in Ref. 11 with regard to total engineering manhours in aircraft production. This assumed relationship is shown in Fig. 4. If plotted on a logarithmic grid the curve would be linear. For this synthesis, therefore, total non-recurring costs versus the number of planned vessels were assumed log-linear, increasing from 15 per cent of the total for a single-vessel contract, to 20 per cent of the first vessel's cost for a ten-vessel contract.

(Continued on next page)

Table 4

1. Determination of Costs for First Ship

Recurring Material Cost	$ 3,860,000
Recurring Labor Cost	2,370,000
Recurring Overhead Cost	1,770,000
Recurring Direct Building Cost	$ 8,000,000
Non-Recurring Cost	1,500,000
Profit	500,000
Total Cost to Customer	$10,000,000

2. Component, Cost-Quantity Relationships

Recurring Material—Cumulative Average Cost Log-Linear (97% Slope)

Recurring Labor—Unit Cost Log-Linear (90% Slope)

Recurring Overhead—75% of Labor

Total Non-Recurring Costs—Log-Linear

Profit—5% of Total

3. Calculation of Unit Costs (Millions of Dollars)

No. Planned	1	2	3	4	5	6	7	8	9	10
Labor	2.37	2.13	2.01	1.92	1.86	1.81	1.76	1.73	1.70	1.67
Materials	3.86	3.63	3.54	3.49	3.46	3.43	3.40	3.36	3.34	3.32
O.H.	1.77	1.60	1.51	1.44	1.40	1.36	1.32	1.30	1.28	1.25
Non-Recur.	1.50	0.07	0.03	0.02	0.01	0.04	......	......	......	......
Profit	0.50	0.39	0.37	0.36	0.35	0.35	0.34	0.34	0.33	0.33
Total	10.00	7.82	7.46	7.23	7.08	6.96	6.82	6.73	6.65	6.57

4. Calculation of Cumuative Average Costs (Millions of Dollars)

No. Planned	1	2	3	4	5	6	7	8	9	10
Labor	2.37	2.25	2.17	2.11	2.06	2.02	1.98	1.95	1.92	1.90
Materials	3.86	3.74	3.68	3.63	3.59	3.56	3.54	3.52	3.51	3.49
O.H.	1.77	1.69	1.63	1.58	1.55	1.52	1.49	1.46	1.44	1.43
Non-Recur.	1.50	0.82	0.57	0.45	0.37	0.31	0.27	0.24	0.22	0.20
Profit	0.50	0.45	0.42	0.41	0.39	0.39	0.38	0.37	0.37	0.37
Total	10.00	8.95	8.47	8.18	7.96	7.80	7.66	7.54	7.46	7.39

(Continued from page 57)

Profit: Profit was always assumed to be 5 per cent of the total cost to the customer.

The synthesis of the above cumulative average component costs yielded a cumulative average (total) cost curve, Fig. 5, which was very nearly log-linear and again the unit (total) cost curve was not. Since the cumulative curve has a mean Slope of 90.5 per cent, the cumulative average costs of multiples of the hypothetical ship could be expressed by the formula $\overline{Y} = \$10{,}000{,}000\ X^{-0.144}$.

Because the final result of this synthesis is realistic, the author believes that the method is sound and that it suggests how careful evaluation of component cost-quantity relationships could predict reliable estimates for multiple contract ship costs. Cost estimators should have better inputs than used here, of course, and to use this technique, their accounting procedures should be modified to separate out the non-recurring costs and, where necessary, to group costs in similar categories so the data could be readily evaluated and synthesized.

Conclusion

The foregoing investigations indicate that reliable predictions of the cost savings of multiple ship production can be made by using the learning curve technique to estimate cumulative average ship costs for any number of vessels. Furthermore, individual yards, through careful analysis of cost records and the incorporation of accounting procedures that adequately evaluate component cost behavior, could determine accurate curves for different types of vessels and, in so doing, provide a valuable tool for easing the task of analyzing multiple cost savings.

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[3] H. Asher, "Cost-Quantity Relationships in the Airframe Industry," *RAND Corporation Report*, R-291 (July 1, 1956).

[4] J. R. Crawford, "Learning Curve, Ship Curve, Ratios, Related Data," Lockheed Aircraft Corporation, Burbank, California (no date).

[5] A. D. Searle, "Productivity Changes in Selected Wartime Ship Building Programs," *Monthly Labor Review*, Vol. 61, No. 6 (December, 1945).

[6] H. M. Neuhaus, "Ship Cost and Labor Estimating," *Marine Engineering and Shipping Rev.*, Vol. 50, Nos. 7 and 8 (August, 1945).

[7] J. A. Pennypacker, "Cost of New Vessel Construction," *Marine Engineering and Shipping Age*, Vol. 35, No. 11 (November, 1930).

[8] M. Francis Carr, "Estimating the Cost of Ships," Theo. Gaus' Sons, Inc., publishers (1929).

[9] F. G. Fassett, Jr. (Editor), "The Shipbuilding Business in The USA," SNAME (1948).

[10] Harry Benford, "General Cargo Ship Economics and Design," University of Michigan, Office of Research Administration Report (July, 1962).

[11] AFT 70-1-3, "Air Force Guide to Pricing," Department of the Air Force, September 18, 1962. U. S. Government P.O.: 1962-651319.

[12] *Maritime Reporter/Engineering News* (April 15, 1963).

Accession No._______

"The Cost Savings of Multiple Ship Production," Couch, J. C., *AACE Bulletin*, Vol. 6, No. 2, p. 50 (June, 1964).

AACE BULLETIN KEYWORD CONCEPTS

— Link A —

Active (8)	**Passive (9)**	**Means or Methods (10)**
Estimating Calculating	Multiple Ship Costs Component Costs Non-Recurring Costs Unit Costs	Cost-Quantity Relationships Learning Curve Techniques Accounting Procedures Log-Linearity
Used In (4)	**Dependent Variables (7)**	**Independent Variables (6)**
Shipbuilding	Unit Cost	Number of Ships

Abstract:
This paper discusses the application of cost-quantity relationships used in other industries to shipbuilding. Specifically, the author shows how reliable estimates of the cost savings of multiple ship production can be made by careful accounting procedures which separate the component shipbuilding costs and by the application of learning curve techniques. The mathematical formulation of applicable cost-quantity relationships is included, as well as ship cost data. The author believes that these techniques provide a valuable tool for easing the task of cost estimating for multiple ship contracts.

5.1 EFFICIENCY CRITERIA RELATED TO VOLUME AND RATE OF PRODUCTION

5.1.1 Progress Curves and Scale Efficiencies

Volume-related efficiencies have only been addressed by economists in the last ten years, but of late much has been said and written about the "progress" curve or "learning" curve phenomenon illustrated in Figure 10. Some confusion has arisen mainly because economists tend to assume away the notion of internal inefficiency when discussing a firm's production function. Actually, it appears the learning effect is a result of the trial and error process that firms typically undergo in trying to reach minimum cost levels, and this learning effect is primarily a function of the number of units produced. However, Alchian has argued that costs are also a function of total planned output as well as the rate of output.[1] The previous lack of consideration of the effects of volume is understandable since economic theory usually assumes that production of a product will continue indefinitely into the future, and for many goods this is a reasonable assumption. However, in numerous other markets, especially in military procurement, the size of production runs is finite and of short enough duration that their size will definitely influence costs.

For example, a firm might receive an order to produce a large number of destroyer escorts at a specified rate of production. Even if the firm knew how to allocate its resources optimally at each rate of production, for a given rate and without resources that were specific to the industry, the average cost per ship when plotted against the number of units would be a downward sloping curve, simply because of certain start-up charges that inevitably must be spread over time. Actually, it would be a rare firm indeed that would be able to optimize its resource inputs at the first ship. What is more likely to happen is that more efficient ways of producing the ship will be discovered each time a ship is produced, and the actual costs will approach the least-cost curve asymptotically.[2] If curves of this nature appear

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1. A. Alchian, Costs and Outputs, The RAND Corporation, P-1449 (Santa Monica, California, 3 September 1958).

2. Ibid., p. 19.

WILLAMS ET AL. 1966

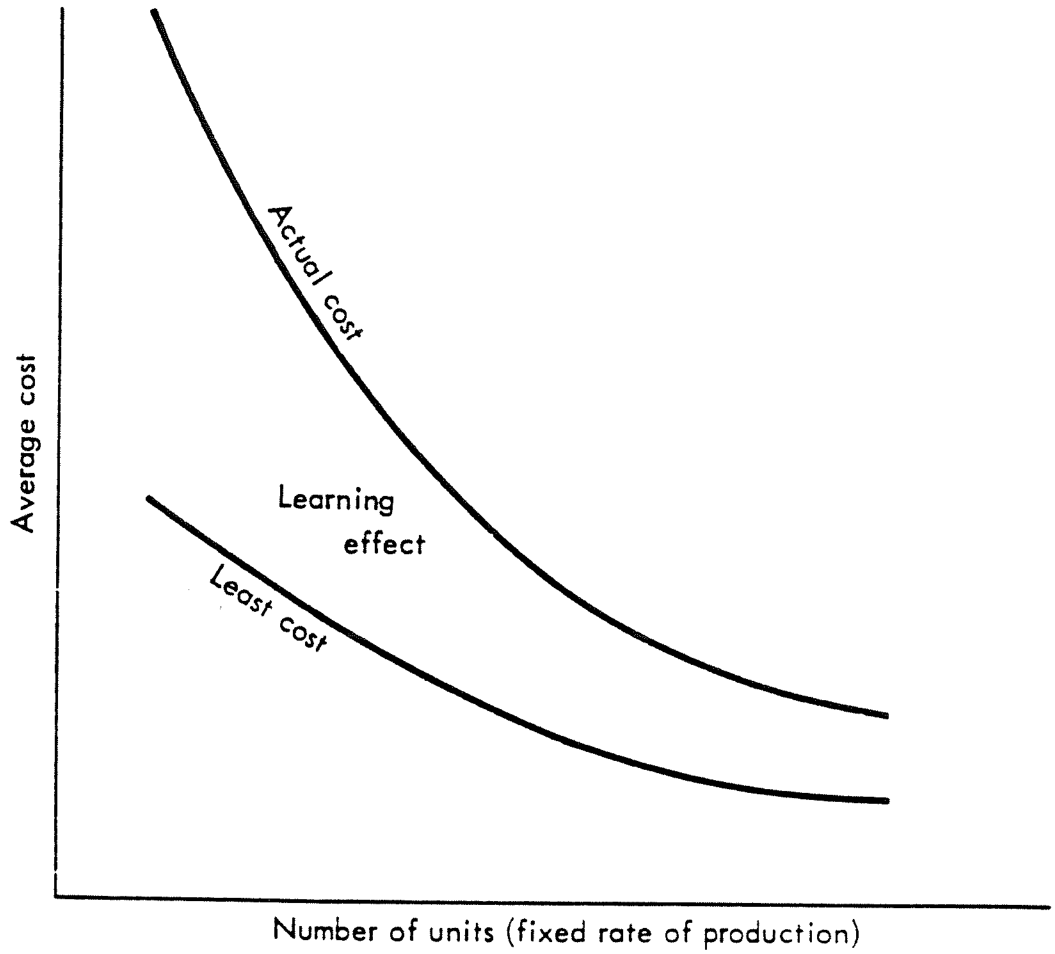

FIGURE 10 Learning Effect as a Function of Number of Units

for each rate of production, then the effect of volume and rate of production on costs might result in three-dimensional models on the order of those represented in Figure 11.

Curves of this nature may also be said to exist for each planned volume. Another way of interpreting the "height" of the learning effect in Figure 10 and the difference in Figure 11 is by making no distinction between "short" and "long" run but rather assuming that the differences in the figures simply represent various different sizes in planned production volume.[3] In this case, costs decline

3. A. Alchian, op. cit., pp. 16-21.

with respect to cumulated volume and because of scheduled volume as well.[4] The buyer can be indifferent to whether the shipbuilder is considering volume effects at a given rate or is considering all the variations in rate possible.

The size of the buyer's scheduled volume will largely determine the extent to which the supplier will explore alternative rates. Constrained only by his ability to foresee his total demand for ships of a given type, the buyer should *ex ante* maximize his scheduled volume offered so that suppliers can explore the whole spectrum of rate which runs from the left side of Figure 11 through to the right side. Then, if the planned volume is realized, economies of learning will be realized and the possibilities for economies due to rate which will have been addressed *ex ante* will, if present, be realized.

The model in Figure 11 illustrates several points. First, at very low rates of production, relatively little improvement can be expected from the learning phenomenon regardless of the number of units produced. An example of this extreme case would exist where a shipbuilding firm is given an order to produce a particular type of ship at the rate of, say, one every three years. Even if they were identical ships, such a long time between successive ships would virtually preclude labor learning and probably much of management learning. This problem would be exacerbated during periods of high turnover in management and labor.

Second, the figure illustrates that, regardless of the rate of production, if the volume of ships is small and the contract is finite and discontinuous without past or future orders for the same ship, cost reduction from learning is minimized. An example of this could occur if a firm were ordered to produce, say, two DE's on a crash program. Under these conditions, the firm would probably consider each DE as a separate problem and assign a separate work force to each ship.

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4. For a discussion of this point, see: Jack Hirshleifer "The Firm's Cost Function: A Successful Reconstruction?" in *The Journal of Business*, Vol. XXXV (July, 1962), pp. 233-55.

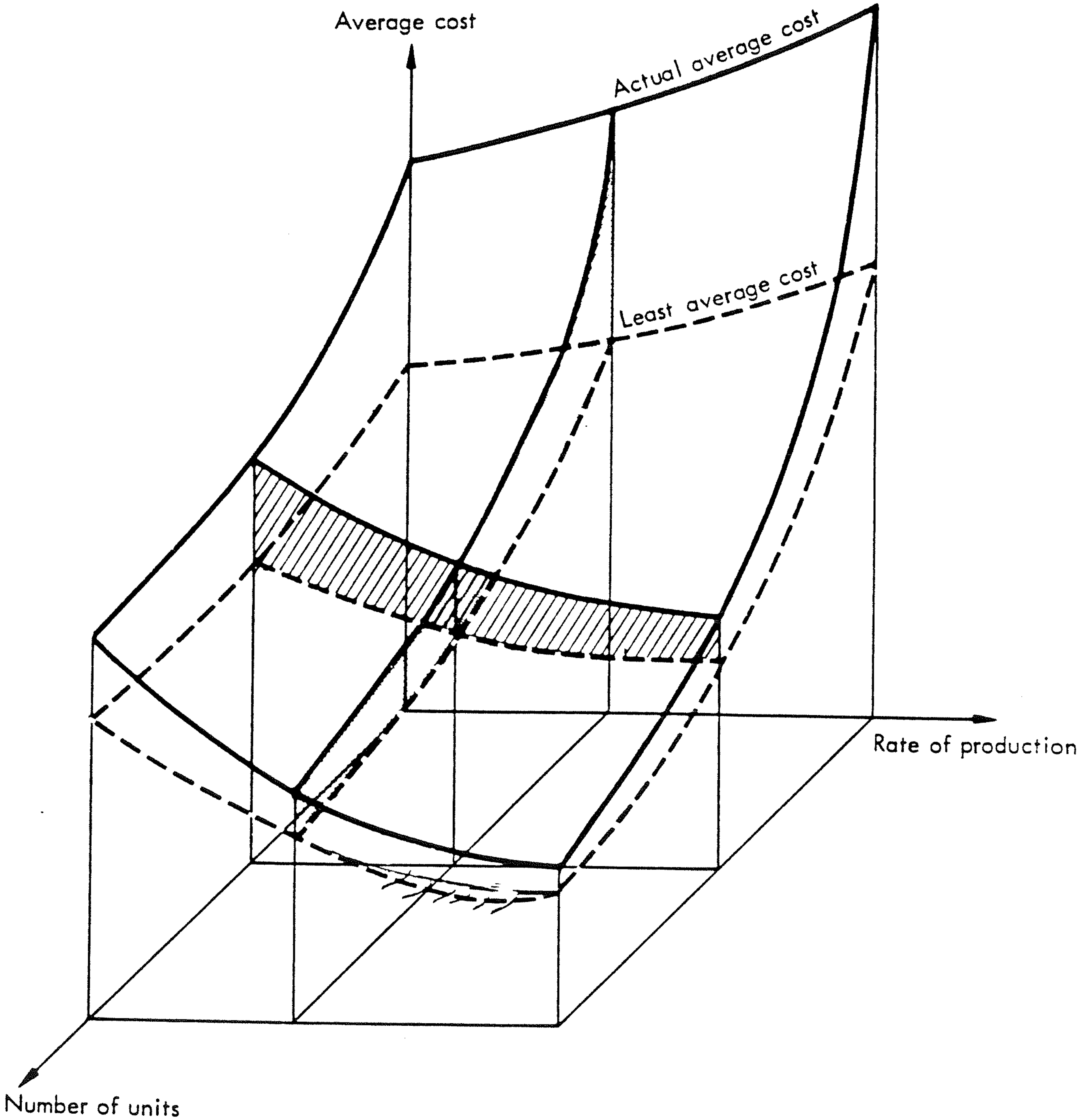

FIGURE 11 Volume, Rate of Production and the Learning Effect

The third point the diagram illustrates is that up to some point maximum cost reductions may only be realized as both the volume and the rate of production are increased.[5] Furthermore, the curve is also drawn to illustrate the possibility that from the standpoint of actual cost the optimum rate of production could be higher than the design optimum rate, although this is not probable. In the case of shipbuilding, however, the "design rate" is likely to be a rather broad band of output rates rather than a unique output.

Now consider the possibility that a firm may reduce costs by increasing its scale of production, i.e., changing the technology used.

Figure 11 may be further interpreted to account for possible economies of scale. The figure shows that:

(1) For small buys of ships, there is likely to be little, if any, benefit from economies of scale. In fact, costs may increase as scale increases.

(2) Regardless of scale, there is little benefit from the learning phenomenon if the ship buy is small.

(3) It is inefficient to operate a plant at a low unit volume where increased scale means a higher degree of mechanization. Cost reductions from learning are relatively small after a mechanized plant has had its initial shakedown.[6]

Thus, it is not difficult to show that, theoretically, production costs could be higher than they would otherwise be simply because volume and rates of production are inadequate. "The significant implication of this...is that in addition to rate of output, an important variable in determining total costs is the total planned

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5. The rate effect in Figure 11 is generated by varying techniques of production as well as changes in technology. A monopsonist, if he maximizes his planned volume, can induce suppliers to examine a broad range of production techniques as well as changes in technology.

6. It is, of course, possible for two or more plants to operate at the same scale but with different degrees of mechanization. The actual cost curve of a more labor-intensive facility will tend to approach the least-cost curve more slowly than that of a highly mechanized plant. This has been illustrated by the experience of Gotaverken's Arendal plant in contrast to the old Gotaverken facility in Goteborg.

output...Thus the average cost per unit of output will be lower, the greater is the planned, and ultimately experienced, output."[7]

There is no difficulty in measuring and testing the validity of the learning phenomenon for the finite batch-order types of production delineated above. There is still some difficulty in disaggregating the combined effects of learning and rate of production. It does appear from the evidence which follows that shipbuilding is susceptible to cost reductions arising from learning realized on volume orders. It is important to keep in mind, as do Alchian and Hirshleifer, that it is a simple matter for the buyer to also cause his suppliers to explore rate effects by offering them the largest possible planned volumes to bid on.

5.1.2 Progress Curves in Shipbuilding

The question that now arises is whether there is empirical evidence that shipbuilding costs tend to decline as unit volume increases.[8] The experience in the United States is presented by an examination of data for World War II, MARAD programs since World War II, and for the recent (summer 1966) LST and DE procurement.

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7. Alchian, *op. cit.*, p. 21.

8. Mainly as a result of empirical studies of the airframe industry by Harold Asher and others, two types of progress curve functions have become popular in cost analysis. (See particularly: Harold Asher, *Cost-Quantity Relationships in the Airframe Industry*, The RAND Corporation, R-291 (Santa Monica, California: July 1956); and J. W. Noah and R. W. Smith, *Cost-Quantity Calculator*, The RAND Corporation, RM-2786-PR, (Santa Monica, California: January 1962).) One function is applied to the average cost of a given number of units and is known as the log-linear cumulative average curve. The characteristic of this function is that as the number of units doubles the average cost per unit declines by a fixed percentage; e.g., a 90 percent slope means that as the number of units doubles the average cost per unit declines by 10 percent. The other function is known as the log-linear individual unit curve. This function has the characteristic that as the number of units doubles the unit cost declines by a fixed percentage.

Both of these functions will be used in the discussion to follow. For the sake of brevity, the former function will be called the average curve and the latter function will be called the unit curve.

5.1.2.1 US World War II Experience. Since the large declines in man-hours required to produce both cargo ships and warships during World War II are well known, there is no need to discuss these matters in great detail.[9] The purpose in presenting the figures below is to establish the approximate progress curves attained for both kinds of ships.

Tables 19 and 20 indicate the number of man-hours needed to produce successive Liberty Ships. The first table shows for all shipyards the average man-hours by round of way, i.e., the man-hours for the first ship produced on each way, the second ship on each way, and so on. These man-hours are then expressed as a percent of the first-ship man-hours and plotted in part A of Figure 12. The second table shows the average man-hours according to the total number of successive ships. No allowance is made for the shipways on which the ships were produced. These figures are plotted in part B of Figure 12.

The figure shows that in terms of rounds of ways--which is perhaps the best way of measuring performance--Liberty Ship man-hours appeared to follow about a 77 percent unit curve up to the fourth round. Then, after an adjustment, the curve follows an 80 percent slope. In terms of number of successive ships, the curve followed an 80 percent slope up to 35 ships and about an 85 percent slope thereafter.[10]

Table 21 presents similar data for Destroyer Escorts. The percentage figures are plotted in Figure 13. Up to about 14 ships the curve follows about an 88 percent slope. After 14 ships the curve is irregular but appears to follow a trend between 80 and 85 percent.

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9. See Frederic C. Lane, Ships for Victory (Baltimore: Johns Hopkins Press, 1951) for an excellent history of shipbuilding during World War II. The basic analysis of labor productivity in shipyards in World War II is Gerald J. Fischer's "Labor Productivity in Shipbuilding under the U.S. Maritime Commission during World War II," a typescript in Historian's Collection, Research Archives File 210.11. A more recent analysis can be found in Leonard Rapping's "Learning and World War II Production Function," The Review of Economics and Statistics, Vol. XLVII (February 1965) pp. 81-86.

10. Many more ships were produced. We have truncated at 100 ships to stay within likely peacetime limits.

Table 19

AVERAGE MAN-HOURS FOR CONSTRUCTION OF LIBERTY SHIPS BY ROUNDS OF WAYS[a]

Round of Way	Average Man-Hours (1000)	Percent of First Round
1	1257	100
2	982	78
3	853	68
4	740	59
5	727	58
6	661	53
7	606	48
8	583	46
9	571	45
10	558	44
11	530	42
12	516	41
13	509	40
14	500	40
15	485	39
16	466	37
17	458	36
18	449	36
19	445	35
20	449	36
21	442	35
22	440	35
23	428	34
24	426	34
25	410	33
26	416	33
27	416	33
28	401	32
29	350	28
30	390	31
31[b]	460	37

a. Data derived from Gerald J. Fischer, A Statistical Summary of Shipbuilding, (Washington, D. C.: U.S. Maritime Commission, 1949). Another basic source for World War II data is: Allan D. Searle, "Productivity Changes in Selected Wartime Shipbuilding Programs," Monthly Labor Review, Vol. 61, No. 6 (December 1945), pp. 1132-1146.

b. Small number of ways in operation.

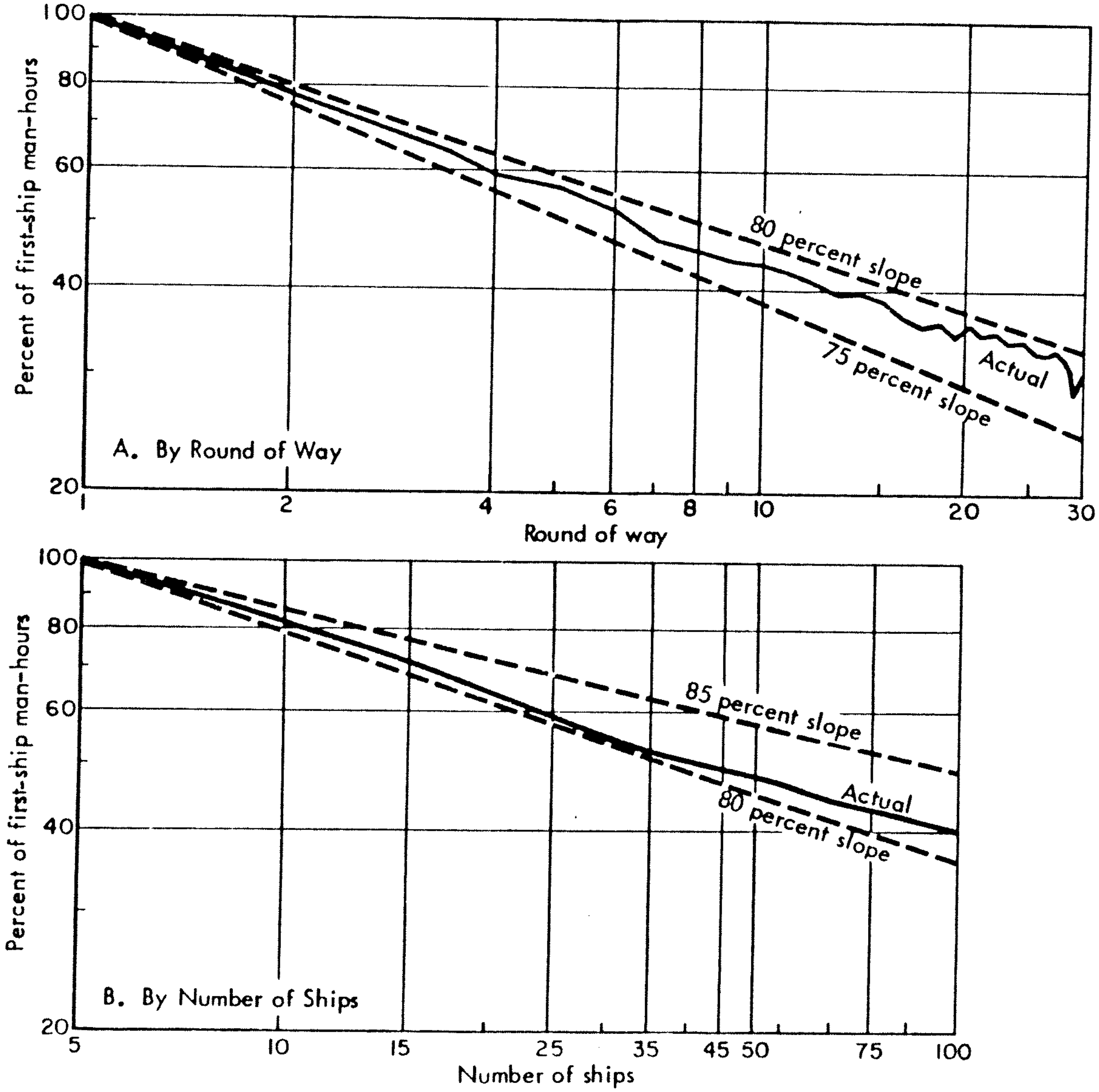


FIGURE 12 Progress Curves for Liberty Ships During World War II

Table 20

AVERAGE MAN-HOURS FOR CONSTRUCTION OF LIBERTY SHIPS[a]

Number of Ships	Class Midpoint	Average Man-Hours (1000)	Percent of Fifth Ship Average
1-10	5	1310	100
11-20	15	931	71
21-30	25	776	59
31-40	35	692	53
41-50	45	661	50
51-60	55	627	48
61-70	65	593	45
71-80	75	571	44
81-90	85	574	44
91-100	95	532	41

a. Data derived from F. G. Fasset, Jr., ed., The Shipbuilding Business in the United States of America, Society of Naval Architects and Marine Engineers (New York, 1948), p. 101.

5.1.2.2 Post-World War II MARAD Data. To protect proprietary interests of individual firms, actual man-hour estimates for representative ship designs have been converted to percent of first-ship man-hours (see Table 22). Six shipyards are represented by the sample. The largest order for a single design since 1958 has been for six ships.

Figure 14 and the lower half of Table 22 show that the range of slopes of the unit curves varies from 75 percent to 95 percent. It should be noted that the original figures indicate that some yards tend to have low first-ship man-hours and relatively flat progress curves. Others have high first-ship man-hours and more steeply sloped curves. Much depends, of course, upon previous experience with a similar design and the degree of participation in initial design and engineering activities. However, it is interesting that in virtually every case there is a strong downward movement in man-hours per ship associated with the number of ships and that the slope coefficients are roughly similar to those experienced with Liberty Ships during World War II.

D-11

Table 21

AVERAGE MAN-HOURS FOR CONSTRUCTION OF DESTROYER ESCORTS[a]

Number of Ships	Class Midpoint	Average Man-Hours (1000)	Percent of Second Ship
1-3	2	1265	100
4-6	5	1062	84
7-9	8	954	75
10-12	11	912	72
13-15	14	878	69
16-18	17	882	70
19-21	20	908	72
22-24	23	876	69
25-27	26	824	65
28-30	29	818	65
31-33	32	777	61
34-36	35	828	65
37-39	38	937	74
40-42	41	916	72
43-45	44	822	65
46-48	47	673	53
49-51	50	689	54
52-54	53	668	53
55-57	56	677	54
58-60	59	668	53
61-63	62	629	50
64-66	65	600	47
67-69	68	589	47
70-72	71	584	46
73-75	74	618	49

a. Data derived from Table 19.

5.1.2.3 Recent Naval Ship Procurement. Up to this point unit progress curves have been applied only to man-hour figures rather than to dollar cost. The summer 1966 procurement of 17 LST's and 20 DE's on a multiyear basis presents the opportunity to examine what shipbuilders believe to be the relationship of volume of buy to average cost.[11]

11. Average cost to the Government, average revenue to the shipbuilder. We shall continue to use the term "cost" rather than "revenue."

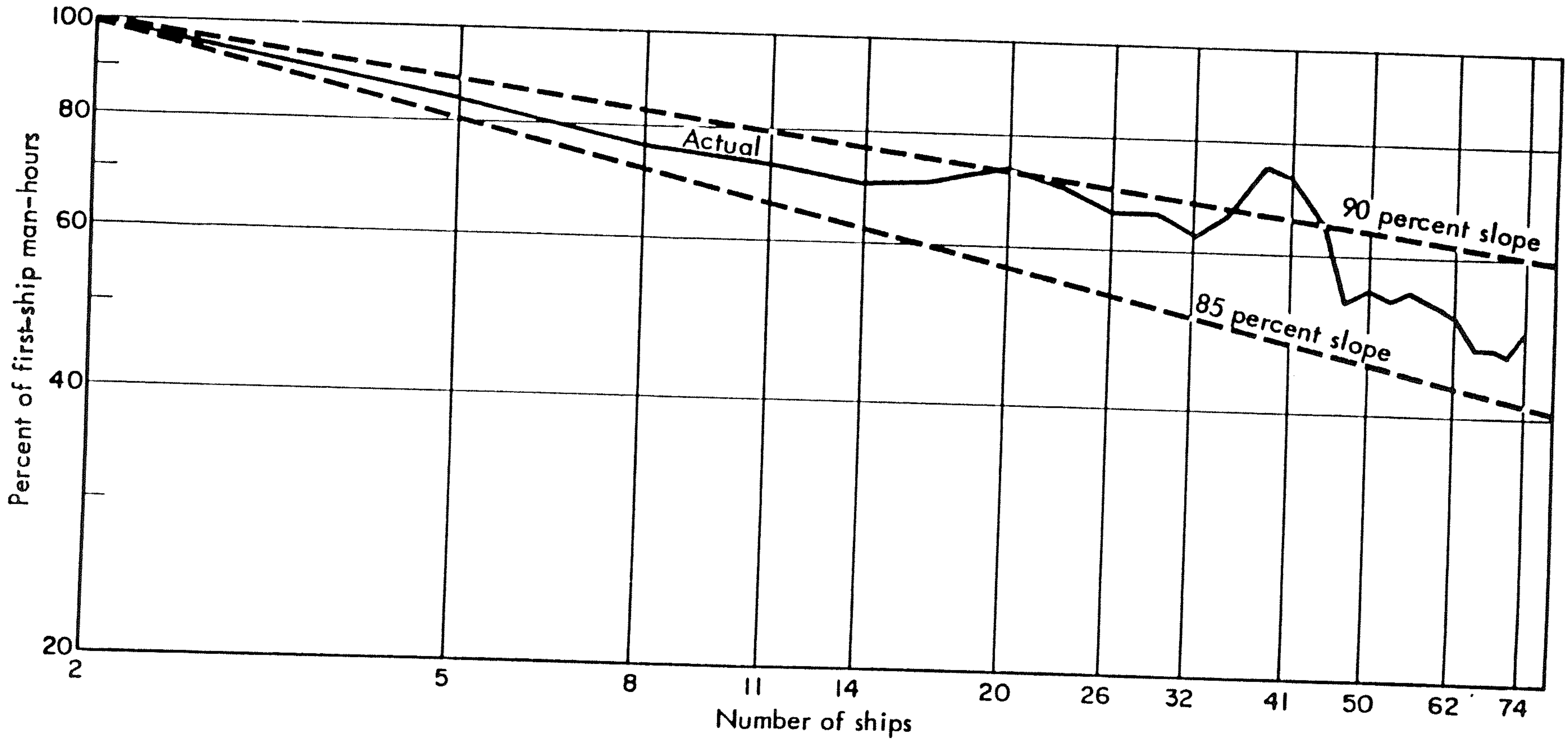


FIGURE 13 Progress Curve for Destroyer Escorts During World War II

Table 22

MAN-HOURS PER SHIP AS A PERCENT OF FIRST-SHIP MAN-HOURS IN MARAD SHIP CONSTRUCTION SINCE 1958[a]

MARAD Ship Construction	Ship Number					
	1	2	3	4	5	6
Ship Design:						
C3-S-37a	100	90	85	85	85	
C3-S-37c	100	89	83	79		
C4-S-57a:						
Yard A	100	87	78	71	66	
Yard B	100	69	65	60	56	50
C4-S-58a	100	95	91	90	89	87
C4-S-60a	100	93	87	85	85	80
C4-S-64a	100	113	98	95	92	
(C4-S-64a)[b]	100	~~86~~ 87	84	81		
Unit Progress Curve, %:						
95	100	97	96	94	93	92
90	100	90	85	81	78	76
85	100	85	77	72	69	66
80	100	80	70	64	60	56
75	100	75	63	56	51	48

a. Computed from Maritime Administration estimates.
b. Same group of ships as above, but second ship used as base.

In Tables 23 and 24 the bid cumulative average costs of LST's and DE's are expressed as a percent of the first ship. In the two requests for bids the Government asked the suppliers to bid on various combinations of orders during a two-year period. For example, the possible combinations of five ships to be purchased in two years are five ships the first year, none the next; four the first year, one the next, etc. As a result, the shipbuilders prices for each size of order were obtained. Several of the suppliers, especially in the case of the DE's, bid a single price for each sized buy regardless of the combination; e.g., the same price would be given for a one-five combination for six ships as for a three-three combination. In any case, variations to the combinations were small, and for this analysis the least-cost combination was always chosen.

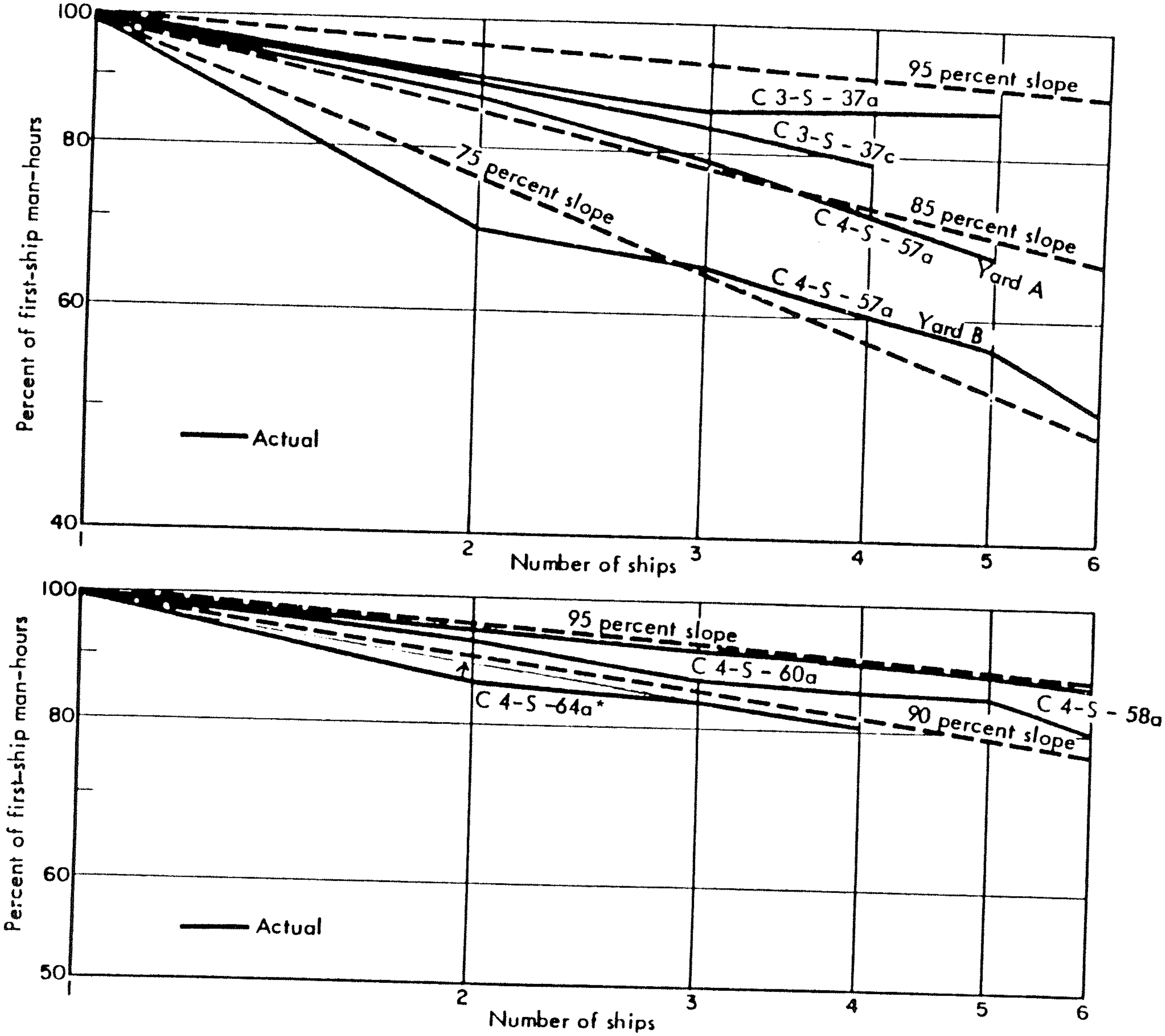


FIGURE 14 Progress Curves in MARAD Construction Post-World War II

Table 23

BID CUMULATIVE AVERAGE COST OF LST'S (Summer 1966 Procurement)

Ship	Yard 1		Yard 2		Yard 3		Yard 4		Yard 5	
	Amount ($1000)	Percent of First Ship	Amount ($1000)	Percent of First Ship	Amount ($1000)	Percent of First Ship	Amount ($1000)	Percent of First Ship	Amount ($1000)	Percent of First Ship
1	19,133	100.0	22,289	100.0	20,398	100.0	20,942	100.0	20.271	100.0
2	17,462	91.3	19,737	88.6	18,656	91.4	19,322	92.3	19,338	95.4
3	16,884	88.2	18,470	82.9	17,924	87.8	18,578	88.7	18,734	92.4
4	16,475	86.1	17,600	79.0	17,417	85.4	18,229	87.0	18,360	90.6
5	16,207	84.7	16,900	75.8	17,123	83.9	17,985	85.9	18,174	89.7
6	15,967	83.5	16,389	73.5	16,880	82.8	17,434	82.2	17,749	87.6
7	15,818	82.7	16,210	72.7	16,651	81.6	17,291	82.6	17,651	87.1
8	15,667	81.9	16,080	72.1	16,515	81.0	17,182	82.0	17,585	86.7
9	15,544	81.2	15,963	71.6	16,385	80.3	17,084	81.6	17,502	86.3
10	15,400	80.5	15,886	71.3	16,263	79.7	16,997	81.2	17,459	86.1
11	15,304	80.0	15,759	70.7	16,092	78.9	16,597	79.3	17,380	85.7
12	15,195	79.4	15,643	70.2	16,036	78.6	16,513	78.9	17,324	85.5
13	15,109	79.0	15,556	69.8	15,942	78.2	16,446	78.5	17,279	85.2
14	15,037	78.6	15,479	69.4	15,891	77.9	16,386	78.2	17,245	85.1
15	14,971	78.2	15,414	69.2	15,822	77.6	16,331	78.0	17,221	85.0
16[a]										
17	14,653	76.6	15,154	67.9	15,680	76.8	16,243	77.6	16,994	83.8

a. No bids were asked for or received for 16-ship combinations.

Table 24

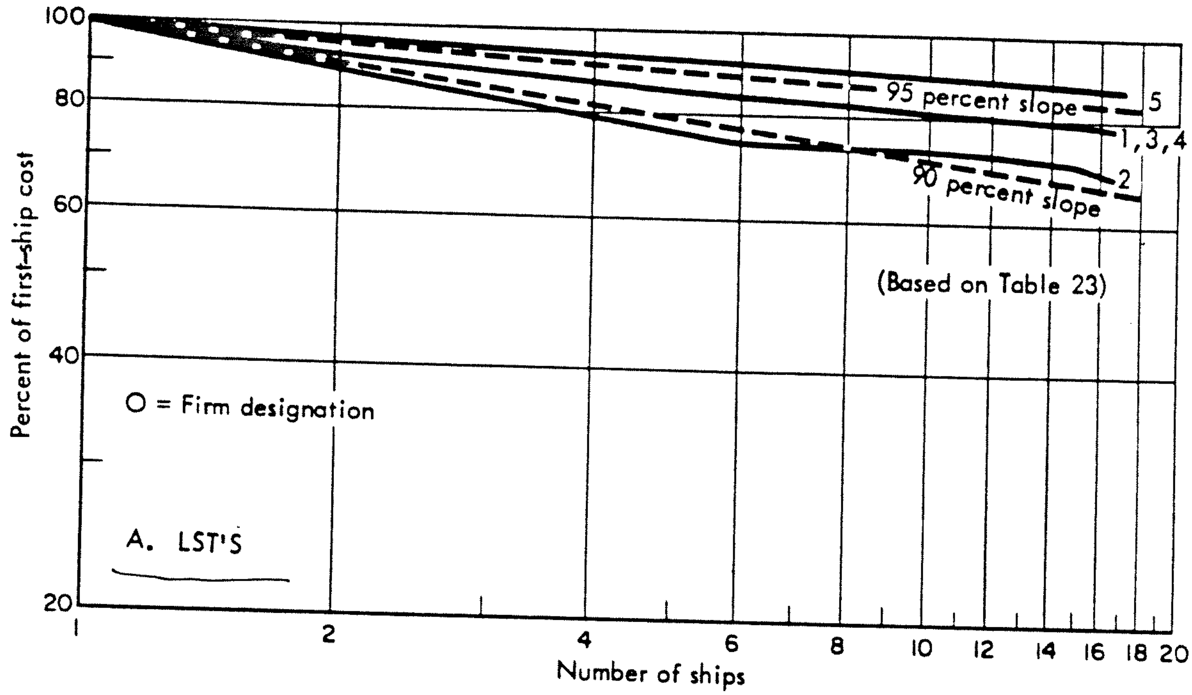
AVERAGE COST PER UNIT AS A PERCENT OF FIRST-SHIP COST-- RECENT DE PROCUREMENT

Number of Ships	Yard 1		Yard 2		Yard 3	
	($000)	Percent of 1st Ship Cost	($000)	Percent of 1st Ship Cost	($000)	Percent of 1st Ship Cost
1	12,649	100.0	14,396	100.0	16,169	100.0
2	12,220	96.6	13,569	94.2	15,107	93.4
3	11,900	94.1	13,261	92.1	14,684	90.8
4	11,660	92.2	13,088	90.9	14,410	89.1
5	11,485	90.8	12,969	90.1	14,202	87.8
6	11,345	98.7	12,880	89.5	13,970	86.4
7	11,230	88.8	12,807	89.0	13,832	85.5
8	11,160	88.2	12,746	88.5	13,734	84.9
9	11,110	87.8	12,693	88.2	13,634	84.3
10	11,066	87.5	12,495	86.8	13,170	81.4
11	11,044	87.3	12,561	87.2	13,044	80.7
12	11,022	87.1	12,523	87.0	12,960	80.2
13	11,002	87.0	12,489	86.8	12,881	79.7
14	10,985	86.8	12,456	86.5	12,819	79.3
15	10,970	86.7	12,337	85.7	12,756	78.9
16	10,955	86.6	12,309	85.5	12,672	78.4
17	10,940	86.5	12,282	85.3	12,612	78.0
18	10,925	86.4	12,258	85.1	12,558	77.7
19	10,910	86.2	12,234	85.0	12,505	77.3
20	10,887	86.1	11,990	83.3	12,445	77.0

Part A of Figure 15 shows that the bids of four of the five firms that bid on all 17 LST's followed about a 95 percent cumulative average cost curve. One of the firm's bids closely followed a 90 percent slope. In this case the first-ship cost was higher than the other four. Part B of Figure 15 indicates that a 94 to 95 percent slope adequately describes the curves of all three suppliers who bid on all combinations of 20 DE's.

An interesting discontinuity occurs in the all-17-LST and all-20-DE bids of some of the firms. On a "winner-take-all" basis, the average cost per ship declined sharply--more than would be expected if the firms were bidding on a marginal-cost or progress-curve basis. There could be several explanations of this phenomenon. The firms could have sensed that the Government planned to buy from a single supplier and only bid carefully on the "winner-take-all" basis. They may have forecast economies of scale. The intelligence from other companies may have dictated certain pricing policies. Many other reasons can be given, but one point is quite clear: The shipbuilders themselves believe that there are economies from volume production and a 90 to 95 percent cumulative average progress curve applied to the entire cost of the first ship adequately describes the <u>pricing</u> policies of the firms. What is difficult to sort out is the extent to which the producer in this case consciously explored rate as well as volume effects. This is of no great interest to the buyer at this point, however.

5.1.2.4 <u>Experience of Foreign Firms</u>. Virtually all foreign shipbuilders interviewed by the study team indicated that labor man-hours per ship decline significantly as the number of ships of the same design are produced. The typical response of managers of conventional European shipyards was that the man-hours began to flatten at about the fifth ship, and that the fifth-ship man-hours were about 60 to 65 percent of the first ship. This places the learning curve in the neighborhood of an 80 to 85 percent slope. Some managers of conventional Japanese yards indicated that their progress curves were relatively flat and attributed the flatness to (1) the standardization of



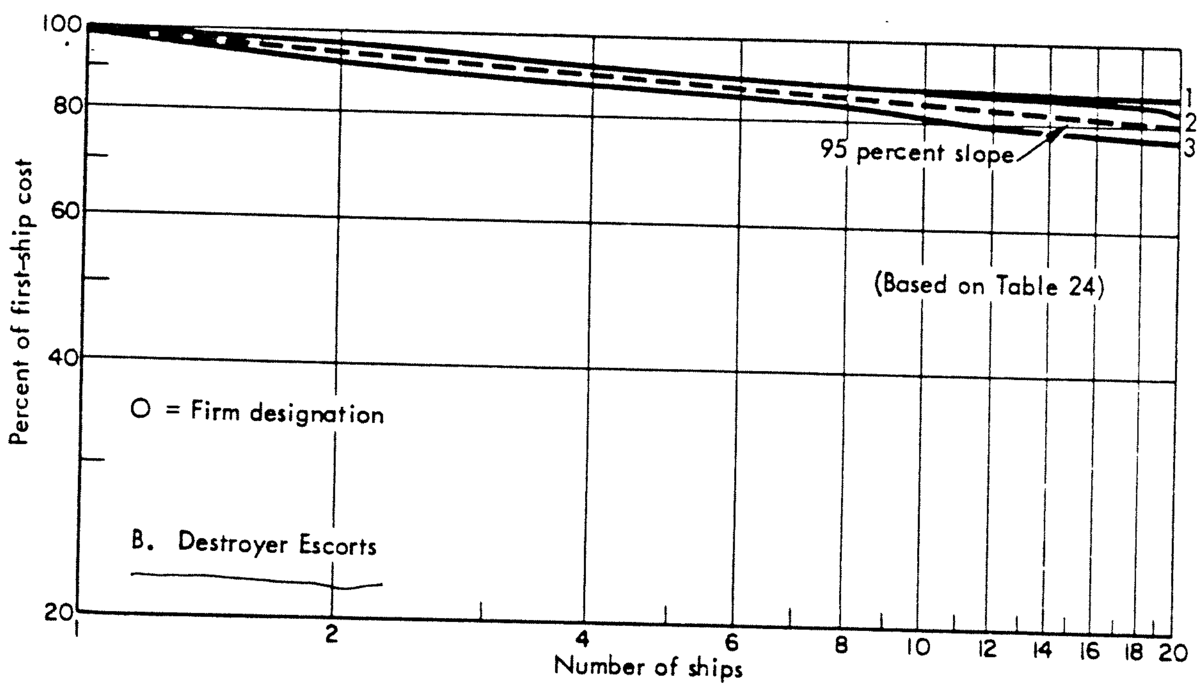


FIGURE 15 Cumulative Average Cost of LST's and Destroyer Escorts for Several Firms (Summer, 1966 Procurement)

their shipbuilding technique regardless of the type of ship and (2) the longevity and skill of the production workers. It should be recognized, however, that few foreign yards have had the experience of long production runs of the same design of ship that US shipbuilders had during World War II.

With respect to new mechanized yards such as Arendal, it is clear that two kinds of learning or progress should be considered. First, there is the man-hour reduction attributable to learning how to use the new facility itself, i.e., the yard "shakedown" period. Second there is the learning associated with the production of the ship. Arendal experienced some difficulty in reaching expected man-hour levels with the first run of ships. However, by the time that the production run of thirteen 70,800-DWT tankers began, most of the difficulties had been ironed out. As a result, the first ship of the new run was produced at a substantially lower number of man-hours than would normally be expected by a conventional yard. Unfortunately, the owners of the tankers added extras to subsequent tankers in the run so that Arendal's actual progress curve does not represent that of a completely standardized tanker. However, Curve C in Figure 16 represents an estimate of the shape based on information provided to the study team. The curve follows about a 90 percent slope after the second ship. D-10

Curve A represents an approximate progress curve for a good conventional yard producing 70,800-DWT tankers. It is assumed that the first ship would require 800,000 man-hours and the yard has an 85 percent progress curve. Curve B indicates an estimate of what the nature of the curve would have been if Arendal's shakedown period were included in the production run. The first two or three ships probably would have taken more man-hours than a conventional yard. However, we would expect that by the fifth ship, the curve would have reached the same position as Curve C, for by this time each of the two building docks would have processed two ships. The following table shows that under these circumstances the cumulative average man-hours per ship (and, therefore, cumulative total labor cost) would be higher than

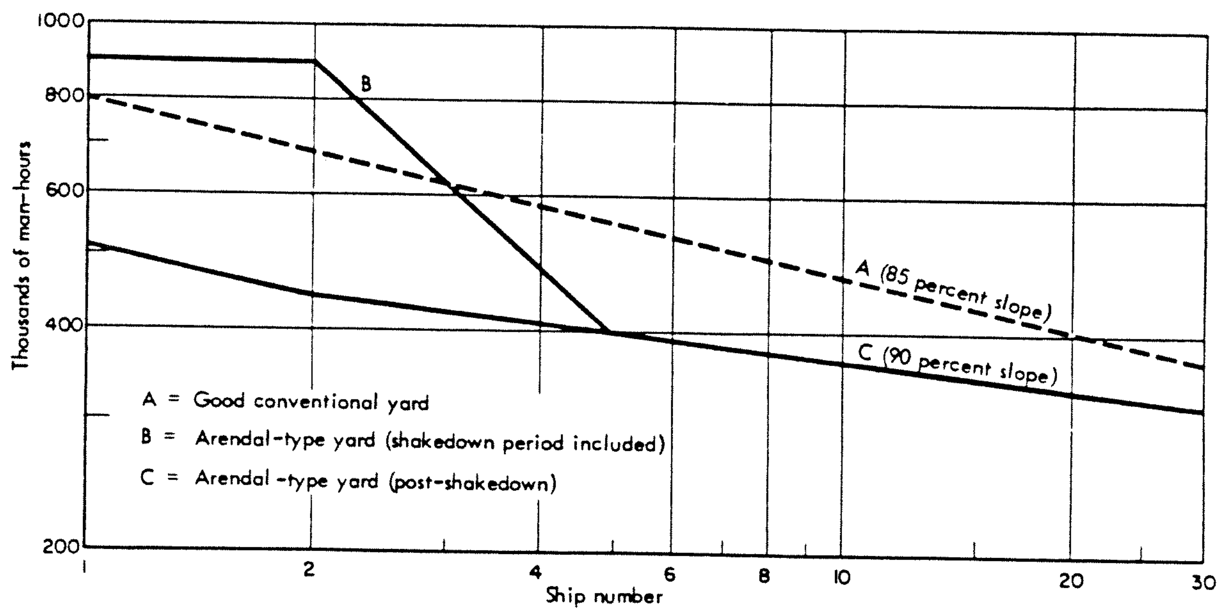


FIGURE 16 Man-hours to Produce a 70,800 DWT Tanker

for a conventional yard up until the fifth ship. From then on the average labor cost would be lower.[12]

	Cumulative Average Man-Hours	
Ship	Conventional Yard	Arendal-Type Yard
1	800	900
2	740	900
3	700	807
4	668	725
5	654	658
6	623	602

12. The actual shape of Curve B is, of course, a matter of conjecture. The important point is that a distinction should be made between whether the production run is the first run of the new yard or a subsequent run. Clearly, if both Curve A and Curve C are for post-shakedown production runs, Curve C will always yield a lower labor cost (assuming equal wage rates). This, of course, is the advantage that the Arendal plant offers and the advantage that a new US yard would have over a conventional US yard provided capital costs are not prohibitive.

Productivity of Labor and Industry

Productivity Changes in Selected Wartime Shipbuilding Programs[1]

Summary

PROGRESSIVE reductions in unit labor requirements and in the time required for delivery at virtually all shipyards were important factors in meeting the enormous wartime demand for ships of all types. The most substantial reductions in labor requirements were recorded in yards building large numbers of ships of uniform design. Liberty ships delivered in December 1944 required, on the average, only 45 percent of the number of man-hours and little more than 20 percent of the time from keel laying to delivery needed for the first vessels, delivered in December 1941. Similarly, labor requirements for Victory ships were reduced by 50 percent and time requirements by 18 percent between February 1944, the month of the first deliveries, and December 1944. Labor requirements for destroyer-escort vessels built for the Navy dropped 45 percent from April 1943 to January 1944 and rose somewhat thereafter as the program became less urgent. Man-hour requirements for two types of tankers and for cargo vessels of seven types showed less-pronounced declines.

Analysis of unit labor requirements for individual yards revealed that, in all yards for which data were obtainable, a given percentage increase in output tended to result in a constant percentage decrease in labor requirements. Average declines of 16 to 22 percent in the number of man-hours required per ship accompanied each doubling of output in representative yards building Liberty ships, Victory ships, tankers, and standard cargo vessels. Within each program there was considerably more variation in the rate of decline than between programs, but in all cases the percentage reduction was significant, ranging from 10 to 26 percent for individual yards each time production doubled.

Apparently, differences in the types of vessel are not nearly so important in determining the extent of reduction in man-hour requirements as differences between individual yards. Furthermore, substantial percentage reductions were made by all yards constructing large numbers of vessels of standardized design by means of mass-production techniques.

[1] Prepared in the Bureau's Productivity and Technological Development Division by Allan D. [illegible] under the supervision of Celia Star Gody. For detailed information concerning the shipbuilding pro[illegible] as a whole (employment, production, labor turnover, absenteeism, wages, etc.) see Bureau's Bulletin [illegible] Wartime Employment, Production, and Conditions of Work in Shipyards.

Wartime Growth of Shipbuilding

One of the outstanding war-production achievements was the performance of the shipyards. At the outset of the war, the shipbuilding industry was poorly prepared to undertake the tremendous volume of ship construction which would be required. In 1936 the shipbuilding industry of the United States produced only 9 merchant ships, totaling about 108,000 dead-weight tons. With the passage of the Merchant Marine Act of 1936 and the formation of the United States Maritime Commission in 1937, a stimulus was given to shipbuilding in the form of direct operating and construction subsidies. The volume of shipbuilding rose gradually until in 1939 it reached the modest total of 28 vessels of 340,000 dead-weight tons. During the war, however, the volume of shipbuilding assumed enormous proportions. The naval programs greatly expanded, and the dead-weight tonnage of merchant ships constructed increased to a peak (1943) of almost 1,900 ships totaling 19 million tons—more than 50 times the 1939 tonnage.

The shortage of shipping capacity was critical during the early period of the war, and it was imperative that a larger number of vessels be built speedily. The required volume obviously could not be obtained without a radical departure from conventional methods of ship construction. Accordingly, a few standardized types were selected to make up the bulk of the shipbuilding program. Concentration on these vessels made it possible to apply mass-production methods to ship construction. Components were prefabricated in fairly large quantities back of the ways, frequently on subcontract, and put together into large subassemblies, which were then incorporated into the vessel. Since work could thus be done simultaneously on different parts of the ship, the time needed between keel laying and completion was sharply reduced. Moreover, the amount of labor required per vessel was also cut substantially, and this factor became of increased importance as labor supplies grew stringent. The Liberty ship is, of course, the outstanding example of mass-production shipbuilding, but similar techniques were used for other programs—Victory ships, tankers, and even destroyer-escort vessels.

Scope of Study, and Nature of Basic Data

Average labor requirements and average time requirements (keel laying to delivery) are presented here for selected types of vessels included in the shipbuilding programs of the U. S. Maritime Commission and of the Navy Department. The programs represented constitute the major part of the Maritime Commission programs—Liberty ships, Victory ships, selected C1, C2, and C3 cargo vessels, and selected types of tankers. Liberty ships comprised the greater part of the Maritime Commission war program to December 1944—approximately 57 percent of all ships delivered. At the end of the period covered by the indexes, however, the Liberty-ship program was nearing completion, and Victory ships were assuming greater importance.

The indexes and averages here given do not include all vessels delivered, but coverage is generally high for the periods represented. Data on man-hours are not available for all types of vessels; the cargo vessels and tankers are represented by selected types for which sufficient data could be obtained. The index for Liberty ships includes the one principal type (which constitutes over 97 percent of total deliverexcludes only those converted to military use. The index for Victory ships represents the three types delivered through December 1944.

The indexes and averages of labor requirements per ship are based on data furnished by the U. S. Maritime Commission and the Navy Department and on reports of shipyards to the Bureau of Labor Statistics. Data for time requirements from keel laying to delivery are based on reports of the Maritime Commission and of the Navy Department.

The indexes or averages of labor requirements for any month refer to those vessels delivered during the month, and not to the work done in that month. All ships completed and all man-hours worked are allocated to the months in which the vessels were delivered. Since most vessels require more than 1 month to complete, a change in yard efficiency may not be reflected in the average or index until some months later, when delivery is made. The importance of this lag is negligible for those types requiring only a month or two to build—Victory and Liberty ships—but is significant for types with long building periods, such as destroyer-escort vessels. The lag is of less importance, generally, for ships built after a program is well under way than for ships built at the beginning of a program, because of the usual progressive reduction in average building time.

The labor data used in constructing the labor-requirements indexes and averages are total man-hours—direct man-hours plus the hours worked by "other employees." [2] Data concerning the number of man-hours worked outside the yards on subcontracts are not generally available, and hence such man-hours are not included.

Changes in the proportion of work subcontracted may have some effect on the indexes. Since man-hour data of subcontractors are not reported, labor requirements are underestimated for yards sending work outside. Furthermore, the proportion of subcontracting done by any one yard may vary from time to time, depending on the availability of facilities and manpower within the yard to perform the required work. Subcontracting tends to increase when yards fall behind schedule and to decrease when schedules are being met. The resultant reduction or expansion in man-hours per ship is, of course, quite unrelated to real changes in yard efficiency. The yards of the West Coast are more likely to subcontract work than the older East Coast yards. Part of the index decrease, therefore, may be due to slight increases in subcontracting as new yards begin construction.

It is not likely, however, that subcontracting influences the trend significantly in any program. In one program—Victory ships—the proportion of subcontracting is constant and need not be considered.

Labor and Time Requirements for Individual Programs

LIBERTY SHIPS

The Liberty-ship program was begun in 1941 under the jurisdiction of the U. S. Maritime Commission. The Liberty vessels were designed to meet an emergency demand for cargo-carrying capacity for the United States and its allies. In order that large-scale production could commence without delay, relatively simple plans were adopted—those of a type of vessel previously constructed for British account. The Liberty vessels are of 10,800 dead-weight tons, are propelled by triple-expansion reciprocating steam engines, and have a speed of 11 knots. Welding replaced riveting as means of hull construction. The standardization of design made possible not only mass production but prefabrication of parts and considerable subcontracting.

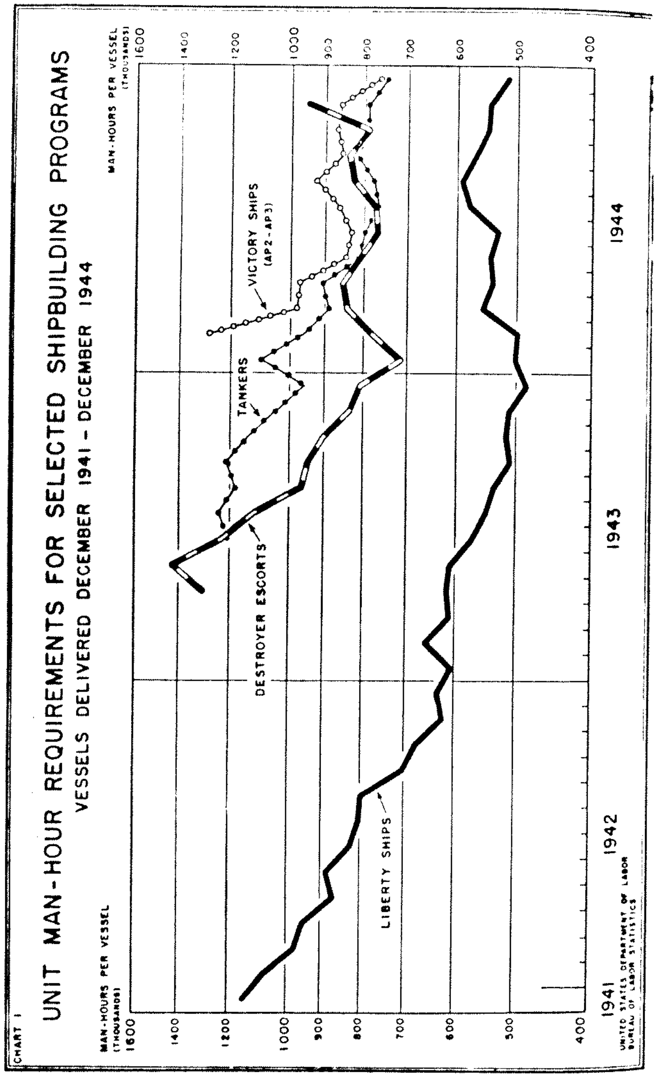
The first Liberty vessels, delivered in December 1941, required an average of 1,150,000 man-hours to build, and 236 days elapsed between keel laying and delivery (table 1). As experience was gained, however, outstanding progress was made in reducing both man-hour and time requirements. By December 1944, man-hour requirements had been reduced to 515,000, a decline of 55 percent. The decrease in average building time was even more marked. In December 1944, average building time was less than 50 days—approximately a fifth of the building time of the vessels delivered in December 1941. Of course, there was some variation among yards. For vessels delivered in December 1944, man-hour requirements ranged from 411,000 to 683,000 and construction time from 35 to 64 days.

TABLE 1.—*Man-Hour and Time Requirements for Liberty Vessels Delivered from December 1941 to December 1944* [1]

Month	Number of yards included	Number of vessels included	Man-hours per vessel (in thousands)	Days per vessel—keel laying to delivery	Indexes (December 1941=100)	
					Man-hours per vessel	Days per vessel—keel laying to delivery
1941: December	2	2	1,146.6	236	100.0	100.0
1942: January	2	3	1,073.6	242	93.6	102.5
February	5	12	978.8	229	85.4	97.0
March	5	16	953.0	219	83.1	92.8
April	5	26	868.9	180	75.8	76.3
May	8	43	886.1	156	77.3	66.1
June	9	51	826.7	124	72.1	52.5
July	9	51	804.2	110	70.1	46.6
August	10	56	798.9	84	69.7	35.6
September	10	67	703.1	71	61.3	30.1
October	11	65	676.2	67	59.0	28.4
November	11	68	622.5	57	54.3	24.2
December	11	82	632.7	56	55.2	23.7
1943: January	11	76	607.4	53	53.0	22.5
February	12	77	657.4	62	57.3	26.4
March	12	102	611.0	59	53.3	25.1
April	14	110	618.0	58	53.9	24.7
May	14	120	609.5	58	53.2	24.4
June	14	115	570.9	56	49.8	23.8
July	14	109	548.2	54	47.8	22.8
August	13	110	533.6	47	46.5	19.9
September	11	104	510.2	42	44.5	18.0
October	11	97	516.1	43	45.0	18.1
November	9	85	511.2	42	44.6	17.6
December	10	113	486.1	40	42.4	17.1
1944: January	11	71	502.3	43	43.8	18.4
February	12	77	499.3	50	43.5	21.2
March	12	83	555.3	55	48.4	23.4
April	12	75	538.0	54	46.9	22.8
May	11	64	541.7	55	47.2	23.2
June	9	54	530.0	52	46.2	21.9
July	9	50	579.3	61	50.5	25.7
August	8	47	592.3	66	51.7	27.8
September	8	42	567.7	58	49.5	24.7
October	8	50	546.7	57	47.7	24.2
November	7	45	542.8	53	47.3	22.4
December	7	40	515.4	49	45.0	20.6

[1] EC2-S-C1 only; modified Liberty ships excluded.

[2] The time worked by "other employees" includes that of supervisory, technical, clerical, office, maintenance, power-plant employees, etc. The time worked by these employees is allocated to the individual hulls in proportion to the number of direct man-hours worked on these hulls.



The most substantial decline in both labor and time requirements occurred during the early phases of the program as yards took advantage of standardized design, improved assembly techniques, and mass-production methods to reduce labor requirements and expedite deliveries. Between December 1941 and December 1942, man-hours per vessel decreased 45 percent, and days per vessel 76 percent. Thereafter, unit labor and time requirements continued to decline until December 1943, the record month, but the declines were small in comparison with those of the preceding year—23 percent for man-hour requirements and 28 percent for time requirements. The increases after December 1943 may be attributed to the tapering off of construction as contracts were terminated and some of the yards converted to Victory-ship production. Chart 1 shows the average man-hour requirements for the Liberty-ship program as well as for tankers, Victory ships, and destroyer-escort vessels.

VICTORY SHIPS

Although Liberty ships provided a large amount of cargo capacity to meet emergency needs, they had certain disadvantages. Speeds were low—11 knots—and the vessels were less durable than other types. It was recognized that, for both reasons, Liberty ships would have little postwar value. During 1943, therefore, the Maritime Commission replaced part of the Liberty-ship program with a program for the Victory ship—a faster type and equal to the Liberty vessel in dead-weight capacity. The Victory ships were designed to provide approximately 10,800 dead-weight tons and travel at a rate of 15 knots upward. These vessels are expected to be a major factor in the post-war merchant fleet of the United States.

Victory ships are of three principal types: VC2–S–AP2, VC2–S–AP3, and VC2–S–AP5. The VC2–S–AP2 and AP3 types are primarily bulk-cargo vessels. The former type is somewhat the slower of the two, with a rate of 15½ knots compared with 17 knots for the AP3. The third type, VC2–S–AP5, represents conversions to military use as combat transports, but it is possible that some of these vessels may be converted to postwar use as merchant ships.[3]

The plans to substitute Victory for Liberty ships initially entailed the expenditure of additional labor per vessel. In February 1944, when the first Victory ship was delivered, Liberty ships required an average of approximately 500,000 man-hours. The first Victory ship, of the AP3 type, consumed more than 2½ times that amount—1,285,000 man-hours (table 2). However, this total was only 12 percent above the average for the initial Liberty ships, and it was reduced sharply in successive months. The AP3 vessels delivered in March 1944 required only 982,000 man-hours, or 24 percent less than the first vessel; by September 1944, labor requirements had been reduced to 844,000 man-hours per vessel. Unit man-hour requirements for the AP2 vessels were roughly similar to those for the AP3, declining from 927,000 in September 1944 to 765,000 in December 1944. The labor requirements for the AP5 type were considerably higher than for the other two types—1,813,000 in August 1944 and 1,104,000 in December 1944.

[3] The Adaptability for Postwar Service of U. S. Maritime Commission "C"-Type and Victory-Type Ships, a paper presented April 27, 1945, by Vice Admiral Howard L. Vickery before the New York Metropolitan Section, Society of Naval Architects and Marine Engineers.

TABLE 2.—*Man-Hour and Time Requirements for Victory Ships Delivered from February 1944 to December 1944*

Month	Man-hours per vessel (in thousands)			Number of yards included	Number of vessels included	Indexes (February 1944 = 100)	
	VC2-S-AP2	VC2-S-AP3	VC2-S-AP5			Man-hours per vessel	Time [illegible]
February		1,285.0		1	1	100.0	[illegible]
[illegible]		981.5		1	4	76.4	[illegible]
[illegible]		976.0		2	10	76.0	[illegible]
[illegible]ay		845.7		2	16	65.8	[illegible]
June		835.2		3	15	65.0	[illegible]
July		864.5		3	13	67.3	[illegible]
August		927.3	1,812.9	4	13	72.2	[illegible]
September	927.4	843.7	1,637.5	5	22	65.7	[illegible]
October	869.5		1,310.6	6	32	57.7	[illegible]
November	860.1		1,055.9	6	39	51.0	[illegible]
December	765.0		1,104.3	6	34	49.6	[illegible]

The rate of decline in average labor requirements was even more pronounced for Victory ships than for Liberty ships. A labor-requirement index covering all three types of vessels declined 50 percent from February 1944 to December 1944. During the comparable stage of the Liberty-ship program, December 1941 to October 1942, the labor-requirements index dropped 41 percent. Almost all the yards selected for building the Victory ships had gained experience constructing Liberty vessels and had made good records.

Time requirements for Victory ships were initially less than half as great as for the first Liberty vessels—approximately 100 days. The index of time requirements declined only 18 percent during the first 11 months of the construction program. At the end of that period, time requirements remained substantially higher than for Liberty vessels, varying from 80 to 90 days for different types.

The increases in the indexes in August 1944 are due to the withdrawal of a yard with relatively low labor and time requirements. The downward trend was resumed in September, but the index of time requirements remained relatively high through October. In several yards which made initial deliveries of the military type in August, time requirements increased slightly after the first vessels were completed, even though labor requirements declined.

The ships included in the indexes represent 95 percent of all Victory ships delivered through December 1944. Each index includes two segments linked in August 1944 to provide a continuous series.[4]

CARGO VESSELS OF SELECTED TYPES

The C2-type vessels represent, in general, the long-range cargo-vessel program of the U. S. Maritime Commission. Some of the types were built before the war for commercial uses and others were developed during the war. In addition to designing vessels for peacetime uses, the Maritime Commission is charged, under the terms of the legislation creating it, with the responsibility of designing the

[4] The first segment, for February to August 1944, consists of simple relatives of average time or labor requirements for the one type produced; the second segment, for August 1944-December 1944, was constructed as a weighted average of labor or time requirements for two classes of vessels (VC2-S-AP2 and AP3 [illegible]

vessels so that they may serve as auxiliaries in time of war. Thus, many wartime conversions have been made. For example, C3 types have become aircraft carriers, destroyer tenders, seaplane tenders, passenger and cargo vessels, attack transports for the Navy, and troop transports for the Army. Many minor modifications have been made from time to time to meet the needs of the operators.

The C2 types are generally considered as potential postwar competitors of the Victory ships. They have speeds approximating that of the AP2-type Victory ship but have somewhat greater bale capacity. According to Vice Admiral Howard L. Vickery, "the C2 is adaptable to general cargo trades, particularly package freight, whereas the Victory ship could be considered better suited to routes where dead-weight or bulk cargoes are to be found."[5] The C1B type and the earlier C1A have undergone fewer wartime conversions owing to their smaller size, lack of flexibility of operation, and slower speeds in comparison with other types. They will, of course, be available for postwar use.

No summary measure of labor requirements per ship can be prepared for these cargo vessels because of the multiplicity of types, intermittent deliveries and unavailability of man-hour statistics for a number of the vessels.

TABLE 3.—*Index of Man-Hours Per Ton for Cargo Vessels of Selected Types[1] Delivered from April 1943 to December 1944*

Month	Number of yards included	Number of vessels included	Index (April 1944 = 100) of man-hours per ton (light displacement)	Month	Number of yards included	Number of vessels included	Index (April 1944 = 100) of man-hours per ton (light displacement)
1943: April	2	3	129.0	1944: March	5	16	101.7
May	2	4	121.6	April	7	16	100.0
June	3	4	119.0	May	6	13	100.1
July	4	5	122.5	June	4	9	101.9
August	4	6	113.1	July	5	9	89.1
September	3	4	113.4	August	2	3	92.9
October	3	3	101.6	September	3	5	89.2
November	4	11	126.4	October	2	3	105.1
December	4	13	126.3	November	4	6	95.8
1944: January	5	14	93.6	December	2	3	93.4
February	5	10	106.4				

[1] C1B, C1-S-AY1, C1-S-D1, C2-S-AJ1, C2-S-B1, C2-S-E1, C3-S-A2.

A rough measure of labor requirements—an unweighted index of man-hours per ton (light displacement)[6]—is presented in table 3 for 7 types of "other cargo" vessels, and average labor requirements for 4 of the 7 types are shown in table 4. Labor requirements for the 7

[5] See footnote 3.

[6] Light displacement is a measure of the weight of the vessel itself, i. e., the displacement of the vessel complete with all items of outfit, equipment, and machinery on board but excluding all cargo, fuel, water, stores, passengers, dunnage, and the crew and their effects. Dead-weight tonnage, which is used more frequently to represent shipbuilding output, is a measure of carrying capacity. It is the difference between the light displacement and the full-load displacement of a vessel. It represents the total weight of cargo, fuel, water, stores, passengers, and crew and their effects that a ship can carry when at her maximum allowable draft. The indications are that labor requirements are more directly associated with light displacement than with dead-weight tonnage.

selected types declined more gradually than for Liberty and Victory ships. The ships are not standardized to the same degree, and only relatively small numbers of each type have been delivered. Furthermore, the index does not cover the entire construction period, 25 percent of all ships of the selected types delivered through December 1944 having been completed before April 1943, the first month shown in the index. It is Possible that the greatest declines in unit labor requirements and building time occurred during the early stages.

Nevertheless, even during the period of the index (April 1943-December 1944), the unit labor requirements for each of the seven selected types of vessels decreased significantly. The index of labor requirements per ton declined 28 percent from April 1943 to December 1944. The rise from October to November 1943 is due to the entrance into the index of a type with higher labor requirements per ton.

TABLE 4.—*Man-Hour Requirements for Four Ty[illegible] of Cargo Vessels Delivered from April 1943 to Decem[illegible]*

Month	Man-hours per vessel (in thousands)			
	Type A	Type B	Type C	Type D
1943: April	1,290.3	....	1,112.3	
May	1,236.3	....	1,184.4	....
June	1,113.5	1,416.1	....	976.6
July	1,061.8	1,455.5	996.0	976.6
August	1,128.1	1,445.3		804.6
September	1,022.1	....	1,052.6	826.6
October	1,007.5	1,401.3	....	
November	....	1,630.9	1,114.8	....
December	....	1,523.9	....	....
1944: January	1,024.5	1,439.4	1,113.4	....
February	1,026.1	1,308.2	....	747.4
March	....	1,328.6	....	709.4
April	991.2	1,285.2	1,025.6	705.8
May	....	1,194.8	960.6	753.4
June	1,128.2	1,171.0	....	....
July	1,081.5	1,139.8	957.8	....
August	....	....	....	729.5
September	....	....	972.9	710.5
October	....	1,091.4	....	
November	....	1,081.1	961.0	726.4
December	....	1,071.3	....	....

The data on which the averages and index are based include 63 percent of the vessels of the 7 selected types and 32 percent of all types of "other cargoes" delivered during the period covered.

COMPARISON OF CARGO VESSELS UNDER THREE PROGRAMS

Table 5 shows the average number of man-hours required per ton (light displacement) for each of the three cargo programs—Liberty ships, Victory ships, and other cargo vessels. Tonnage provides only a rough basis for comparison, as the different vessels vary in design. Labor requirements per ton might also be expected to vary. Nevertheless, the figures indicate that the greatest economies have been achieved in the case of the mass-production programs—Liberty ships and Victory ships. The average labor requirements per ton are lower for Liberty ships than for "other cargoes" in every month shown. The labor requirements per ton for Victory ships exceed the labor requirements per ton for "other cargoes" for the initial months of the

Victory-ship program. Cargo ships delivered in February 1944 required 215 man-hours per ton, whereas Victory ships required 297. By December 1944, however, labor requirements for Victory ships were 165 man-hours per ton, and for "other cargoes," 189 man-hours.

TABLE 5.—*Man-Hours Per Ton for Cargo Vessels of Selected Types, Liberty Ships, and Victory Ships Delivered from April 1943 to December 1944*

Month	Man-hours per ton (light displacement)			Month	Man-hours per ton (light displacement)		
	Cargo vessels, selected types [1]	Liberty ships	Victory ships		Cargo vessels, selected types [1]	Liberty ships	Victory ships
1943: April	260.5	182.8	....	1944: March	205.4	164.3	227.2
May	245.6	180.3	....	April	202.0	159.2	225.9
June	240.3	168.9	....	May	202.2	160.3	195.8
				June	205.8	156.8	193.3
July	247.4	162.2	....				
August	228.4	157.9	....	July	179.9	171.4	200.1
September	229.0	150.9	....	August	187.7	175.3	234.6
October	205.3	152.7	....	September	180.1	168.0	228.5
November	255.3	151.2	....	October	212.4	161.7	191.8
December	255.1	143.8	....	November	193.6	160.6	180.4
				December	188.7	152.5	165.0
1944: January	189.1	148.6	....				
February	215.0	147.7	297.4				

[1] C1B, C1-S-AY1, C1-S-D1, C2-S-AJ1, C2-S-B1, C2-S-E1, C3-S-A2.

TANKERS OF SELECTED TYPES

The tanker program was one of the U. S. Maritime Commission's most vital programs. When the European war began, the United States had 430 oil tankers. By June 1, 1945, many had been lost in action, but U. S. shipyards had made up the losses and the tanker fleet (including Army and Navy) contained 1031 tankers—648 had been built under Maritime Commission contract. Now that the war is over, many tankers will be available for our postwar merchant fleet.

Table 6 shows man-hour and time requirements for two types of tankers, which together represent 81 percent of all tankers delivered from June 1943 to December 1944. The two types have the same general hull characteristics and approximate equality in dead-weight tonnage (16,600 and 16,800 dead-weight tons). Each is powered by single-screw steam-turbine electric engines. One type is of all-welded construction. The other utilizes riveting in the seams of side-shell plating and upper-deck plating.[7]

The index of labor requirements for the two types of tankers shows a decrease of 38 percent between June 1943 and December 1944. Fluctuations in the time-requirements index are greater than those in the labor-requirements index, but the two indexes generally move in the same direction.[8]

[7] New Developments in Tanker Design, by E. L. Stewart, in Marine Engineering and Shipping Review, December 1944 (p. 186).

[8] The indexes and averages were obtained by weighting average labor or time requirements for each type by the total number of vessels of that type delivered or scheduled for delivery through December 1944. The index period covers the early stages of the construction program, and only 15 percent of the vessels completed to December 1944 were delivered prior to the first month shown. Coverage is high—97 percent of the vessels of the selected types and 78 percent of all types delivered June 1943–December 1944.

TABLE 6.—*Man-Hour and Time Requirements for Tankers of Selected Types [1] Delivered from June 1943 to December 1944*

Month	Number of yards included	Number of ships included	Man-hours per vessel (in thousands)	Days per vessel, keel laying to delivery	Indexes (June 1943 = 100): Man-hours per vessel	Indexes (June 1943 = 100): Days per vessel, keel laying to delivery
1943: June	3	7	1,210.1	165	100.0	100.0
July	4	13	1,247.3	168	103.1	102.0
August	4	12	1,182.8	141	97.7	85.9
September	3	11	1,214.0	136	100.3	82.9
October	3	15	1,138.1	134	94.3	81.5
November	4	15	1,048.9	116	86.7	70.3
December	4	20	960.6	113	79.4	68.4
1944: January	4	10	1,093.8	140	90.4	84.9
February	4	15	981.7	133	81.1	81.1
March	4	18	891.1	115	73.6	69.9
April	4	15	904.2	134	74.7	81.1
May	4	21	816.3	120	67.5	72.6
June	4	19	798.1	102	65.9	61.8
July	4	19	767.0	96	63.4	58.4
August	3	16	778.7	101	64.3	61.4
September	4	18	819.8	102	67.7	61.7
October	4	18	790.4	100	65.3	60.9
November	4	23	791.3	99	65.4	60.3
December	4	23	746.7	95	61.7	57.9

[1] T2-SE-A1, T2-SE-A2.

DESTROYER-ESCORT VESSELS

The destroyer-escort program was developed to meet the need for a naval vessel which would combine maneuverability with the speed necessary to protect convoys. The vessels carry torpedo tubes, depth charges, and heavy-caliber machine guns. They are of three types—1,150, 1,275, and 1,400 tons light displacement. The plans are uniform, although modifications have been made from time to time. Yards participating in the destroyer-escort program have been able to take advantage of mass-production methods to reduce cost, time, and labor requirements. Considerable prefabrication of hull sections has been practiced.

The indexes for destroyer-escort vessels (table 7) include only vessels built in private shipyards. All vessels of 1,150 tons (light displacement) are omitted, as they were built in Navy yards. The indexes represent vessels of 1,275 and 1,400 tons and include 98 percent of all vessels of these types built in private yards during the period from April 1943 to December 1944, inclusive.[9] Vessels built at the beginning of the program are included, and consequently the full reduction in time and labor requirements is evident.

The 45-percent reduction in average labor requirements for destroyer escorts delivered during the initial stages of the program (April 1943 to January 1944) was slightly larger than the decline for Liberty ships during the first 10 months of that program. It will be noted that average labor requirements for destroyer escorts rose from January to April 1944 and then resumed a downward trend. The rise was due to a change in design involving a different method of

[9] The indexes are based on unweighted averages of labor and time requirements. Inasmuch as the unit

propulsion. As experience was gained in building the new design, unit labor requirements declined again. The increase in the number of days necessary to complete vessels delivered after January 1944 is attributable to the fact that destroyer escorts no longer retained a high priority. Thus there was a tendency for yards to schedule work on more urgent programs and to complete destroyer escorts during periods of diminished activity.

TABLE 7.—*Man-Hour and Time Requirements for Destroyer-Escort Vessels Delivered from April 1943 to December 1944* [1]

Month	Number of yards included	Number of vessels included	Man-hours per vessel (in thousands)	Days per vessel, keel laying to delivery	Indexes (May 1943=100): Man-hours per vessel	Indexes (May 1943=100): Days per vessel, keel laying to delivery
1943: April	2	3	1,311.1	292	92.0	102.5
May	4	7	1,425.6	285	100.0	100.0
June	6	12	1,226.0	257	86.0	90.2
July	6	15	1,112.9	231	78.1	81.1
August	6	24	965.9	207	67.8	72.6
September	7	25	944.6	198	66.3	69.5
October	9	33	902.4	177	63.3	62.1
November	9	36	835.2	163	58.6	57.2
December	9	34	807.6	166	56.7	58.2
1944: January	8	23	717.2	146	50.3	51.2
February	8	24	780.0	170	54.7	59.6
March	8	15	841.9	188	59.1	66.0
April	9	20	852.7	192	59.8	67.4
May	9	22	806.8	208	56.6	73.0
June	9	16	768.9	213	53.9	74.7
July	6	14	773.7	241	54.3	84.6
August	5	9	828.6	243	58.1	85.3
September	4	9	838.6	237	58.8	83.2
October	2	6	790.4	185	55.4	64.9
November	2	4	950.5	233	66.7	81.8
December	...	...	...	...	...	...

[1] Includes vessels built in private shipyards only.

Reduction of Labor Requirements in Individual Yards [10]

The averages and indexes of labor requirements per vessel are influenced by many different factors, and the reduction of labor requirements does not always appear as a steady, uniform process. Substantial changes in the indexes of labor requirements may occur from month to month because of the entry or withdrawal of yards having comparatively high or low unit labor requirements, since relatively few yards build any one type of vessel. As man-hour requirements tend to be higher in yards entering into production of a specific type of vessel than in those which have built a considerable number, declines in labor requirements for any program are retarded during months when many new yards make initial deliveries. As a result, the indexes may be subject to apparently erratic fluctuations, particularly for those types of vessels built by only a few yards.

The declines in labor requirements within individual yards with continued construction of standardized vessels have been remarkably steady, however. The general downward trend of average man-hour

[10] The number of man-hours required for groups of vessels delivered by individual yards producing Liberty ships, Victory ships, and destroyer-escort vessels are shown in Bureau of Labor Statistics Bulletin

requirements for the various programs is due primarily to improvements in yard efficiency achieved as management and labor gained experience in constructing successive vessels of standardized types. Examination of the data for individual shipyards showed that each time a yard doubled its output, man-hour requirements per vessel tended to decline by a constant percentage. The percentage decrease varied from yard to yard, but the average declines were almost identical for the different types of vessels considered.

Adequate statistics were available for 10 yards which built Liberty ships, 4 which constructed Victory ships, 2 which built "other cargoes," and 4 which turned out tankers.[11] The experience gained by any shipyard, and hence the reduction in labor requirements, depends primarily on the number of vessels constructed, and not on the number of months the yard has been engaged in construction. Averages of labor requirements were prepared for successive groups of five vessels, and an analysis was made of the trend of man-hours per vessel as successive groups were completed.

It was found that, in each yard, the percentage decline in man-hours per vessel tended to be constant for a specified percentage change in output; for example, with each doubling of output, labor requirements would decline by the same percentage. If 1,000,000 man-hours were assumed to be required per vessel for the first group of five ships delivered, the number might be reduced by 20 percent to an average of 800,000 for the second group and by an additional 20 percent to 640,000 for the fourth group. When the data are shown on ratio scales, as in charts 2 and 3, a constant percentage decline in man-hours per vessel appears as a straight line.[12]

In the 10 yards which built Liberty vessels, the reductions in man-hours per ship with each doubling of cumulative output ranged from 12 to 24 percent. Chart 2 shows changes in man-hours per vessel for two typical yards. An average line, representing the composite experience of the 10 yards, is shown in chart 3. It shows a 19-percent decline in man-hours per vessel with each doubling of output.

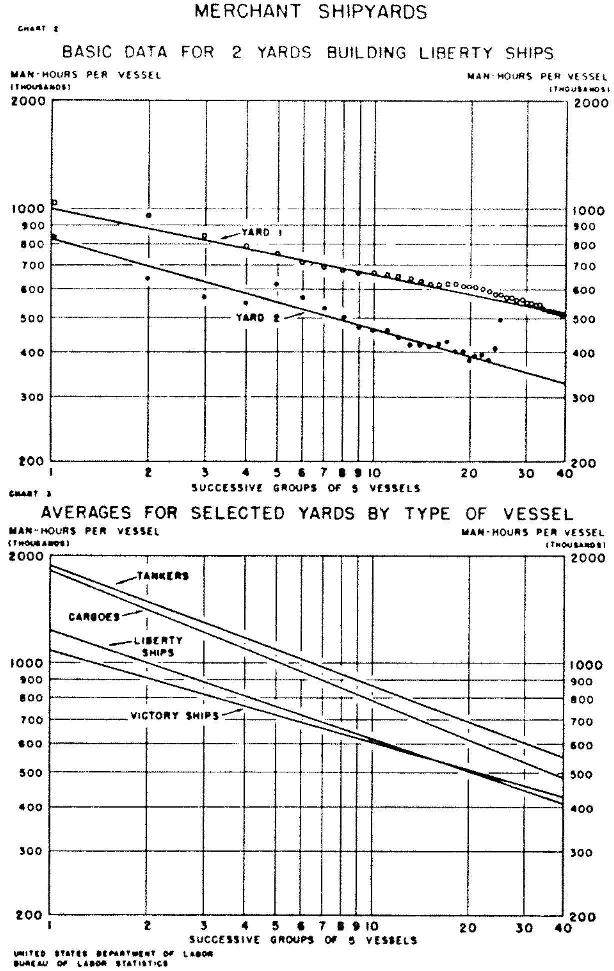
Yards with high labor requirements for the initial vessels tended to decrease labor requirements more rapidly than yards with low labor requirements for the first group. The divergence among the trends for the different yards thus becomes smaller after the initial group has been completed. For the first group of ships, the highest trend value of labor requirements was 2.0 times as great as the lowest; by the tenth group (vessels 46–50), however, the relative difference had been narrowed to 1.7. The divergence again increases at high levels of production experience. The rates of decline and the levels of labor requirements did not appear to be related to the size of the yard nor to the date construction began.

[11] Six yards which built fewer than 80 Liberty vessels through December were omitted. Three of these yards experienced percentage rates of decrease in unit labor requirements greatly outside the range for the 10 yards included.

[12] An alternative approach was attempted, in which each group of vessels included, not five ships, but a number equal to the number of ways in the yard. The assumption implicit in this analysis is that experience gained in the course of construction of any vessel could not generally be applied to the next vessel scheduled for delivery, since this vessel might already be nearing completion. This experience could, however, be applied to the next round of vessels on the ways. If this assumption is correct, the divergence among the trend lines for the separate yards would be smaller when "way turn-over" was used as a measure of production experience than when number of vessels was used. There was no substantial difference between the results obtained by the two methods and the "way turn-over" analysis was therefore abandoned. In any yard, the percentage decline in labor requirements is the same for a doubling of output as for a doubling of "rounds," since each "round" includes an identical number of vessels. The relative levels for different yards are affected, however, by the use of "way turn-over" or "rounds" completed, rather than by number of vessels as a measure of production experience.

REDUCTIONS IN MAN-HOURS PER VESSEL WITH INCREASING PRODUCTION

MERCHANT SHIPYARDS



Similar data were compiled for four yards producing AP2 and AP3 Victory ships. All these yards had had experience in the construction of Liberty ships. Chart 3 shows their composite experience with Victory ships. It will be noted that the labor requirements were below the average for the 10 Liberty-ship yards. The four yards considered, however, had better-than-average records in Liberty-ship construction, and the average line for the Victory ships almost coincides with that for Liberty ships built in the same yards. The experience gained in Liberty-ship construction doubtless was of great benefit in the Victory program, and the relative levels of labor requirements for Victory and Liberty vessels do not necessarily reflect the relative complexity of the two types of ships. The rate of decrease with each doubling of output was almost the same in the case of Victory ships and Liberty ships built in the same four yards—16 percent for Victory ships and 18 percent for Liberty ships.

Estimates of changes in labor requirements within yards building "other cargo" types could be made for only two yards. The multiplicity of types, the small numbers of some types constructed by any one yard, and the lack of complete data preclude any comprehensive analysis for the "other cargo" types. The average decrease in labor requirements for the two yards for which data are available, however, compares favorably with the reductions for Liberty and Victory ships—22 percent with each doubling of output.[13]

As in the case of cargo vessels, the yards building tankers experienced a constant rate of improvement with each doubling of output. The average decline in man-hours per vessel accompanying a doubling of deliveries was 21 percent for the four yards for which sufficient data are available.

The rate of decline in labor requirements as production doubled was rather uniform from one program to another—19 percent for Liberty ships, 16 percent for Victory ships, 21 percent for tankers, and 22 percent for "other cargoes." The range within two programs was wide, however—12 to 24 percent for Liberty ships and 10 to 26 percent for Victory ships (AP2 and AP3). The range within the tanker program was narrower, 19 to 22 percent. In all yards for which data are available, the rate of improvement was significant and steady. Apparently, similar substantial improvements might be expected in any yard building large numbers of vessels of standardized design.[14]

The uniformity of the percentage reductions in labor requirements among yards engaged in different programs is particularly striking in view of the considerable differences in the extent of reduction of average labor requirements when each program is considered in successive months. As was indicated above, larger month-to-month declines in labor requirements occurred for the Liberty and Victory programs than for the "other cargo" vessels. Nevertheless, two yards which produced substantial numbers of identical types of cargo vessels achieved reductions in labor requirements comparable to those of yards constructing Liberty and Victory vessels. The decline in Labor requirements for the "other cargo" program as a whole was smaller than those for Liberty and Victory ships because few yards produced substantial numbers of identical "other cargo" vessels.

[13] The two yards produced different types of cargo vessels. The rates of decline in man-hours per vessel were 18 and 26 percent.

[14] A similar analysis for various types of aircraft was shown in Wartime Productivity Changes in the Air-

Similarly, the decline in man-hours per vessel for the tanker program as a whole was smaller than for Liberty and Victory vessels, despite the fact that equivalent improvements were achieved by yards with comparable production experience. This difference appears to arise from the fact that the average number of days required from keel laying to delivery has been greater for tankers than for Liberty or Victory ships. In a 1-year period, a yard constructing Liberty vessels can complete many more vessels than a yard building tankers and hence achieve a larger reduction in labor requirements. Thus, any techniques which make possible reductions in time between keel laying and delivery in themselves afford opportunity for more rapid reductions in labor requirements from month to month.

Postwar Shipbuilding

The close of the war brought immediate, sharp cut-backs in the shipbuilding programs of both the Navy and the Maritime Commission. Production may be resumed on some naval craft that were under construction at the time of the cut-back, and reductions in the war program of the Maritime Commission may be partially offset by construction of cargo and tanker vessels for peacetime use, particularly during the period while many of the merchant ships are serving their purpose as troop transports. The Liberty-ship program had, of course, been completed by the time of the Japanese surrender.

The prospects of postwar shipbuilding are indefinite. It is certain only that the wartime volume of shipbuilding will be drastically reduced. Even if plans to scrap or to hold the Liberty ships in stand-by status are carried out, there will remain a large volume of merchant tonnage available, much of which can be converted to peacetime use.

It will not be possible to use uniform plans or mass-production methods in the future to the extent practiced by yards which built the Liberty ships. The degree to which mass-production methods can be applied will depend not only on the number of ships of a fixed type built but also on whether a few large yards or a greater number of smaller yards are to have responsibility for meeting the postwar demand for ships.

Some production methods and practices developed during the war will undoubtedly have postwar utility. Many yards have greater crane capacity than they had before the war. These yards will be able to perform many welding jobs off the ways, later hoisting the welded part onto the hull. The wider use of welding in place of riveting may be expected. The lightweight metals, such as aluminum, have recently been used for boats, pilot houses, davits, and outer casings for smokestacks, etc. The use of these metals tends to reduce the ratio of superstructure weight to total weight and to increase the ratio of cargo weight to the total; greater stability and economy result. The continued use of light metals will presumably depend on relative prices.

Because of the experience gained during the war period, labor and time requirements in the future will doubtless be less than before the war for comparable types of vessels, but they are not likely to approach the wartime record. The great improvements in man-hour and time requirements that have occurred should be viewed primarily as contributions to the successful development and completion of

APPENDIX D

CG47 CLASS RETURN COST DATA

CRUISER HISTORIAL DATA

SWBS	DESCRIPTION	SHIP - CG 47 (FY78$) LABOR KHRS	SHIP - CG 47 (FY78$) MATL $M	FY80 SHIP - CG 48 LABOR KHRS	FY80 SHIP - CG 48 MATL $M	FY81 CG 49/50/52/53 (COMBINED SHIPS) LABOR KHRS	FY81 CG 49/50/52/53 (COMBINED SHIPS) MATL $M	CG 49/50/52/53 (UNIT AVG) LABOR KHRS	CG 49/50/52/53 (UNIT AVG) MATL $M	FY83 CG 54/55/56 (SHIPS COMBINED) LABOR KHRS	FY83 CG 54/55/56 (SHIPS COMBINED) MATL $M
	TOTAL SHIP	9,926.3	157.7	6,281.1	121.0	22,635.9	576.0	5,658.9	144.0	12,747.2	415.9
1	HULL	808.9	14.43	735.0	18.30	2,870.0	0.00	717.5	0.00	1,987.7	0.00
11	Hull Structure	514.0	6.30	471.0	11.70	1,828.8	0.00	457.2	0.00	1,268.9	0.00
12	Superstructure	129.0	3.81	117.3	2.70	455.1	0.00	113.8	0.00	269.1	0.00
13	Sonar Dome	26.5	2.36	14.2	2.00	51.1	0.00	12.8	0.00	31.4	0.00
14	Hull Detail	139.4	1.97	132.6	1.90	535.2	0.00	133.8	0.00	418.3	0.00
2	PROPULSION	186.1	27.08	149.1	29.30	511.1	0.37	127.8	0.09	344.3	0.00
21	Power Trans Sys	62.2	22.88	51.7	25.20	178.8	0.00	44.7	0.00	125.3	0.00
22	Prop Fluid Sys	118.9	4.00	94.1	4.10	320.6	0.37	80.2	0.09	213.8	0.00
23	Controls	5.1	0.21	3.3	0.08	11.6	0.00	2.9	0.00	5.2	0.00
3	ELECTRICAL	760.4	28.26	589.2	15.00	2,163.8	0.00	541.0	0.00	1,382.9	0.00
31	Power Gen	34.0	7.41	25.1	6.50	344.9	0.00	86.2	0.00	218.7	0.00
32	Equip install	509.9	18.64	393.5	5.10	1,494.9	0.00	373.7	0.00	919.8	0.00
33	Power Light Hookup	216.5	0.86	170.6	1.20	323.9	0.00	81.0	0.00	244.4	0.00
34	Cable Commodity	0.0	1.35	0.0	2.10	0.0	0.00	0.0	0.00		
4	COMMAND & CONTROL	205.0	11.34	142.4	11.80	575.5	0.00	143.9	0.00	387.4	0.00
41	Ship Control Sys	6.9	0.16	4.5	0.11	21.4	0.00	5.4	0.00	16.6	0.00
42	Interior Commo	49.7	1.03	38.2	0.49	144.1	0.00	36.0	0.00	103.7	0.00
43	Exterior Commo	26.7	0.03	23.7	0.00	87.3	0.00	21.8	0.00	54.0	0.00
44	Countermeasures	38.5	0.00	30.6	0.00	98.3	0.00	24.6	0.00	69.0	0.00
45	Tact Data Sys	12.9	0.00	7.3	0.00	40.2	0.00	10.1	0.00	25.8	0.00
46	Radar	20.4	0.00	11.7	0.00	57.4	0.00	14.4	0.00	33.0	0.00
47	Fire Control	36.8	0.00	15.6	0.00	75.7	0.00	18.9	0.00	46.8	0.00
48	Sonar	13.1	10.13	11.2	11.20	51.1	0.00	12.8	0.00	38.4	0.00
5	AUXILIARY SYSTEMS	868.2	20.81	765.6	20.90	2,875.8	0.08	719.0	0.02	1,967.9	0.00
51	Environmental Cont	318.8	6.07	259.2	5.79	989.4	0.01	247.4	0.00	603.9	0.00
52	Fluid Sys	516.8	10.94	477.7	9.71	1,833.6	0.07	458.4	0.02	1,264.4	0.00
53	Hull Aux Mach	32.5	2.61	28.6	3.10	144.7	0.00	36.2	0.00	99.5	0.00
54	Mach Piping Instl	0.0	1.20	0.0	2.40	0.0	0.00	0.0	0.00	0.0	0.00

6	OUTFIT & FURNISH	749.3	5.11	646.2	6.57	2,433.4	0.01	608.4	0.00	1,590.1	0.00
61	Hull Outfitting	503.6	2.50	442.4	3.70	1,584.7	0.01	396.2	0.00	1,067.6	0.00
62	Store Rooms-Storage	27.6	0.00	24.5	0.00	107.9	0.00	27.0	0.00	70.9	0.00
63	Equip & Furnishing	25.1	0.40	26.8	0.58	99.7	0.00	24.9	0.00	68.8	0.00
64	Insulation & Protection	193.0	2.20	152.4	2.32	641.1	0.00	160.3	0.00	382.8	0.00
7	ARMAMENT	71.8	3.78	68.6	2.71	252.1	0.00	63.0	0.00	137.5	0.00
71	Guns & Mounts	8.7	0.00	10.8	0.00	38.1	0.00	9.5	0.00	20.2	0.00
72	Ammo Hand & Stow	31.2	2.54	30.1	2.08	112.0	0.00	28.0	0.00	55.8	0.00
73	Missile/Rocket Hand	26.7	0.00	20.1	0.00	75.8	0.00	19.0	0.00	46.6	0.00
74	Torpedo Hand & Stow	6.2	1.20	7.5	0.64	26.3	0.00	6.6	0.00	14.9	0.00
75	Misc Ord Matl	0.0	0.04	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
8	INTEGRATION ENGINEERING	2,537.9	16.29	925.6	2.15	4,117.5	0.00	1,029.4	0.00	1,298.8	0.00
81	Engineer Design	1,429.2	8.05	340.0	1.60	1,923.9	0.00	481.0	0.00	227.9	0.00
82	Project Eng	529.7	8.24	158.2	0.55	605.3	0.00	151.3	0.00	145.7	0.00
83	Prod Plan & Cont	579.0	0.00	427.4	0.00	1,588.3	0.00	397.1	0.00	925.2	0.00
9	CONSTRUCTION SERVICE	1,480.7	8.18	1,053.5	6.09	3,881.0	0.23	970.3	0.06	2,594.8	0.00
91	Ship Service	540.8	0.05	371.2	0.11	1,335.2	0.01	333.8	0.00	953.4	0.00
92	Launching/Drydocking	23.5	0.26	11.0	0.14	31.2	0.00	7.8	0.00	18.9	0.00
93	Molds,Templates,Jigs	94.8	0.15	47.9	0.18	129.4	0.00	32.4	0.00	48.3	0.00
94	Inspection	236.6	0.16	165.3	(4.08)	637.5	0.00	159.4	0.00	372.0	0.00
95	Manufacting Spt	577.5	1.53	454.1	3.46	1,747.6	0.22	436.9	0.06	1,202.2	0.00
96	Vendor Serv	7.5	1.77	4.1	0.82	0.0	0.00	0.0	0.00	0.0	0.00
97	Inventory Stores	0.0	4.27	0.0	5.46	0.0	0.00	0.0	0.00	0.0	0.00

OTHER SUPPORT

SYSTEM TEST & EVAL	145.1	0.83	121.9	1.73	428.1	0.00	107.0	0.00	304.8	0.00
Tech Eval Equip Fac	0.0	0.69	0.0	1.57	0.1	0.00	0.0	0.00	0.0	0.00
Contractor Tests	132.4	0.12	116.2	0.14	400.6	0.00	100.2	0.00	278.8	0.00
Accep Test/Final Test	12.7	0.02	5.7	0.03	27.4	0.00	6.9	0.00	26.0	0.00
PROJECT MANAGEMENT	1,268.3	3.58	673.5	2.00	1,303.3	0.66	325.8	0.17	430.5	0.09
Project Mgt	142.3	1.90	133.7	0.82	294.7	0.66	73.7	0.17	117.7	0.09
Prog Plan & Control	1,126.0	1.67	539.8	1.19	1,008.6	0.00	252.2	0.00	312.7	0.00
SYSTEM ENGINEERING	409.7	0.18	178.2	0.33	574.0	0.06	143.5	0.02	178.6	0.00
Test Eng	108.7	0.08	44.3	0.23	177.9	0.06	44.5	0.02	93.2	0.00
System Eng	208.4	0.13	95.3	0.05	271.3	0.00	67.8	0.00	11.3	0.00
QA Eng	43.1	0.07	38.6	0.04	109.9	0.00	27.5	0.00	74.0	0.00
Models & Mockups	49.6	0.05	0.0	0.01	14.9	0.00	3.7	0.00	0.0	0.00

TRAINING SERVICES	29.1	0.02	11.4	0.05	18.7	0.00	4.7	0.00	2.0	0.00
DATA, TECH & MANUAL	259.7	1.93	103.3	2.10	370.6	0.00	92.7	0.00	18.4	0.00
FITTING OUT FOR DELIV	52.9	15.87	38.2	1.46	145.3	0.00	36.3	0.00	105.4	0.00
CONTRACTOR SUPPORT	93.2	0.03	79.4	0.54	115.5	0.01	28.9	0.00	16.1	0.04
Planning Yard Svc	1.1	0.01	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
Post Del Supt	84.1	0.00	62.5	0.12	87.9	0.01	22.0	0.00	5.6	0.04
Misc	8.1	0.03	16.9	0.42	27.6	0.00	6.9	0.00	10.5	0.00
SHIP MATERIAL					0.2	574.57	0.1	143.64	2.0	415.80

BATH SHIPS	FY82 CG 51		FY84 CG 58		FY85 CG 60		FY85 CG 61		FY85 CG 63	
	LABOR KHRS	MATL $M	LABOR KHRS	MATL $M	LABOR KHRS	MATL $M	LABOR KHRS	MATL $M	LABOR KHRS	MATL $M
TOTALS	9,581.2	60.3	7,430.0	46.7	4,112.5	73.8	4,343.7	72.3	4,450.0	77.0
SHIP CONTRUCTION	5,516.0	44.70	4,892.3	40.10	3,027.3	71.70	3,899.4	71.40	3,688.7	75.20
SYSTEM TEST/EVAL	198.8	0.12	155.3	0.04	128.9	0.06	92.4	0.03	121.4	0.04
SYS ENG/PROJ MGT	3,828.1	14.00	2,371.9	6.59	948.5	2.04	350.4	0.85	632.5	1.74
DATA MGT	38.3	0.00	10.5	0.00	7.8	0.00	1.5	0.00	7.4	0.00
SPARES/REPAIR PARTS	0.0	1.50	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00

CRUISER H

		CG 54/55/56 (UNIT AVG)		FY84 CG 57/59 (SHIPS COMBINED)		CG 57/59 (UNIT AVG)	FY85 CG 62	
SWBS	DESCRIPTION	LABOR KHRS	MATL $M	LABOR KHRS	MATL $M	LABOR KHRS	LABOR KHRS	MATL $M
	TOTAL SHIP	4,249.1	138.6	7,832.1	122.2	3,916.2	2,357.3	91.10
1	HULL	662.6	0.00	1,098.3	0.00	549.2	249.4	0.00
11	Hull Structure	423.0	0.00	739.8	0.00	369.9	173.7	0.00
12	Superstructure	89.7	0.00	165.3	0.00	82.7	26.7	0.00
13	Sonar Dome	10.5	0.00	15.5	0.00	7.8	1.4	0.00
14	Hull Detail	139.4	0.00	177.8	0.00	88.9	47.6	0.00
2	PROPULSION	114.8	0.00	178.0	0.00	89.0	27.8	0.00
21	Power Trans Sys	41.8	0.00	66.8	0.00	33.4	14.3	0.00
22	Prop Fluid Sys	71.3	0.00	109.6	0.00	54.8	13.0	0.00
23	Controls	1.7	0.00	1.5	0.00	0.8	0.4	0.00
3	ELECTRICAL	461.0	0.00	721.9	0.00	361.0	37.3	0.00
31	Power Gen	72.9	0.00	167.4	0.00	83.7	4.2	0.00
32	Equip install	306.6	0.00	417.4	0.00	208.7	17.7	0.00
33	Power Light Hookup	81.5	0.00	137.3	0.00	68.7	15.4	0.00
34	Cable Commodity							
4	COMMAND & CONTROL	129.1	0.00	247.8	0.00	123.9	9.1	0.00
41	Ship Control Sys	5.5	0.00	10.9	0.00	5.5	0.4	0.00
42	Interior Commo	34.6	0.00	67.0	0.00	33.5	0.9	0.00
43	Exterior Commo	18.0	0.00	38.7	0.00	19.4	0.1	0.00
44	Countermeasures	23.0	0.00	45.2	0.00	22.6	6.3	0.00
45	Tact Data Sys	8.6	0.00	16.2	0.00	8.1	0.0	0.00
46	Radar	11.0	0.00	22.5	0.00	11.3	0.3	0.00
47	Fire Control	15.6	0.00	27.0	0.00	13.5	1.0	0.00
48	Sonar	12.8	0.00	20.2	0.00	10.1	0.1	0.00
5	AUXILIARY SYSTEMS	656.0	0.00	840.3	0.00	420.2	150.5	0.00
51	Environmental Cont	201.3	0.00	267.3	0.00	133.7	36.0	0.00
52	Fluid Sys	421.5	0.00	518.5	0.00	259.3	105.0	0.00
53	Hull Aux Mach	33.2	0.00	54.5	0.00	27.3	9.5	0.00

54	Mach Piping Instl	0.0	0.00	0.0	0.00	0.0	0.0	0.00
6	OUTFIT & FURNISH	530.0	0.00	1,039.6	0.00	519.8	322.2	0.00
61	Hull Outfitting	355.9	0.00	803.1	0.00	401.6	260.3	0.00
62	Store Rooms-Storage	23.6	0.00	31.2	0.00	15.6	1.0	0.00
63	Equip & Furnishing	22.9	0.00	22.2	0.00	11.1	1.0	0.00
64	Insulation & Protection	127.6	0.00	183.1	0.00	91.6	59.8	0.00
7	ARMAMENT	45.8	0.00	91.1	0.00	45.7	10.1	0.00
71	Guns & Mounts	6.7	0.00	12.8	0.00	6.4	2.6	0.00
72	Ammo Hand & Stow	18.6	0.00	30.9	0.00	15.5	2.8	0.00
73	Missile/Rocket Hand	15.5	0.00	39.1	0.00	19.6	3.8	0.00
74	Torpedo Hand & Stow	5.0	0.00	8.3	0.00	4.2	0.9	0.00
75	Misc Ord Matl	0.0	0.00	0.0	0.00	0.0	0.0	0.00
8	INTEGRATION ENGINEERING	432.9	0.00	856.3	0.00	428.2	505.3	0.00
81	Engineer Design	76.0	0.00	111.2	0.00	55.6	90.0	0.00
82	Project Eng	48.6	0.00	101.7	0.00	50.9	74.1	0.00
83	Prod Plan & Cont	308.4	0.00	643.5	0.00	321.8	341.2	0.00
9	CONSTRUCTION SERVICE	864.9	0.00	2,040.5	0.00	1,020.3	701.0	0.00
91	Ship Service	317.8	0.00	666.4	0.00	333.2	268.5	0.00
92	Launching/Drydocking	6.3	0.00	9.2	0.00	4.6	4.0	0.00
93	Molds,Templates,Jigs	16.1	0.00	42.6	0.00	21.3	7.2	0.00
94	Inspection	124.0	0.00	228.0	0.00	114.0	108.2	0.00
95	Manufacting Spt	400.7	0.00	842.1	0.00	421.1	304.3	0.00
96	Vendor Serv	0.0	0.00	252.3	0.00	126.2	8.7	0.00
97	Inventory Stores	0.0	0.00	0.0	0.00	0.0	0.0	0.00
	OTHER SUP							
	SYSTEM TEST & EVAL	101.6	0.00	169.4	0.00	84.7	90.5	0.00
	Tech Eval Equip Fac	0.0	0.00	0.0	0.00	0.0	0.0	0.00
	Contractor Tests	92.9	0.00	157.2	0.00	78.6	84.0	0.00
	Accep Test/Final Test	8.7	0.00	12.2	0.00	6.1	6.5	0.00
	PROJECT MANAGEMENT	143.5	0.00	298.6	0.00	149.3	152.9	0.00
	Project Mgt	39.2	0.03	74.0	0.00	37.0	43.3	0.00
	Prog Plan & Control	104.2	0.00	224.6	0.00	112.3	109.6	0.00
	SYSTEM ENGINEERING	59.5	0.00	108.6	0.00	54.3	60.8	0.00
	Test Eng	31.1	0.00	61.5	0.00	30.8	35.7	0.00
	System Eng	3.8	0.00	3.3	0.00	1.7	2.0	0.00

QA Eng	24.7	0.00	43.8	0.00	21.9	23.1	0.00
Models & Mockups	0.0	0.00	0.0	0.00	0.0	0.0	0.00
TRAINING SERVICES	0.7	0.00	1.3	0.00	0.7	0.0	0.00
DATA, TECH & MANUAL	6.1	0.00	3.8	0.00	1.9	1.5	0.00
FITTING OUT FOR DELIV	35.1	0.00	74.0	0.00	37.0	34.6	0.00
CONTRACTOR SUPPORT	5.4	0.01	62.6	0.00	31.3	4.3	0.00
Planning Yard Svc	0.0	0.00	0.0	0.00	0.0	0.0	0.00
Post Del Supt	1.9	0.01	54.8	0.00	27.4	0.0	0.00
Misc	3.5	0.00	7.9	0.00	4.0	4.3	0.00
SHIP MATERIAL	0.7	138.60	0.0	122.22	0.0	0.0	91.10

FY85

BATH SHIPS CG 64

	LABOR KHRS	MATL $M
TOTALS	4,071.8	76.2
SHIP CONTRUCTION	3,525.7	75.28
SYSTEM TEST/EVAL	121.2	0.03
SYS ENG/PROJ MGT	422.9	0.88
DATA MGT	2.0	0.00
SPARES/REPAIR PARTS	0.0	0.00