DEVELOPMENT OF PRODUCIBILITY EVALUATION CRITERIA

Prepared by

WILKINS ENTERPRISE INC.

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The content of this report was developed by a project team led by Dr. Wilkins. The other team members were Mr. Gilbert L. Kraine of Enterprise Assistance Inc. (EAI), Mr.Daniel H. Thompson of Coastal Group Technology, Mr. Kenneth H. Borchers and Mrs. Marilyn M. Borchers of Borchers & Associates. The final content is the sole responsibility of the team leader.

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TABLE OF CONTENTS

TABLE OF CONTENTS - Continued

1.0 INTRODUCTION

1.1 DEFINITIONS

1.1.1 Producibility

It is generally understood that by improving the producibility of a product, the cost of that product will be decreased. Unfortunately, many so-called producibility studies have been conducted on the invalid conclusion that the reverse is also true, i.e., that anything that decreases the (acquisition) cost of the ship is a producibility improvement. To accept this definition is to equate producibility with productivity, and normally leads to consideration of many more elements than should be taken into account for evaluating producibility.

Establishment of a relatively narrow definition is essential for correctly understanding what elements of a ship design affect the design's producibility. For the purposes of this project, producibility has been understood as the recurring cost of construction of a product. Analysis of this "definhion" reveals that it is not a definition of producibility per se, but a description of how producibility is to be measured.

Consequently, in order to focus the efforts of the study team the following statement was developed and used as a "definition" of producibility

> **Producibility relates to the recurring expenditure of resources for constructing a product. Recurring cost is the measure of producibility. There is an inverse relationship between recurring cost and producibility.**

One of the major features of this definition is that it differentiates producibility cost from nonrecurring cost. This is necessary because nonrecurring cost maybe prorated over several units when determining total cost, and therefore is a variable, while the recurring cost is essentially non-variant (ignoring learning curve effects).

1.1.2 cost

It is essential to the understanding of this project to recognize that "cost", when related to producibility, relates only to the shipbuilder's required expenditure of construction manpower or other production resources to produce the ship. In most cases, the measure of cost will be manhours, which are directly translatable into dollars. The expenditure of other resources, such as consumable materials, will normally be defined in dollars.

Producibility cost should include labor cost material cost and the cost of operating the facilities used directly in the production of an item. However, the facility operational costs have not been taken into account in the techniques presented herein.

1.1.3 Producibility Change

A producibility change is one that is made primarily for the purpose of reducing the amount of production resources used to build the ship. A "pure" producibility change is one that will not cause any change to the basic functions of the affected systems. In most cases, there probably will be some impact on the overall ship, such as an increase or decrease in weight. Although the effect of these impacts will have to be evaluated, those evaluations will be separate from the evaluation of the producibility aspects of the change.

The significance of this definition is that it separates producibility changes from design changes that are really efforts to reduce acquisition cost by making changes in the ship or system's functional requirements These latter types of change may reduce acquisition cost, but the resultant product serves a different function. Since producibility is in essence a relative measure, it can only be applied validly to products which are to perform the same function. It also excludes changes which are primarily weight related, since there is no direct correlation between weight and producibility.

1.2 BACKGROUND

The cost of construction is a major portion of the cost of any ship acquisition program. Of that cost, about half represents labor costs (manhours). The primary objective of introducing "producibility" into a ship design is to reduce the construction manhours which must be expended to build the ship. This is accomplished by making the ship easier to build in its details or in its entirety.

Construction manhours not only represent a significant part of the total ship cost, but also are a significant driver of the indirect costs of ship construction. A reduction in construction manhours normally will be accompanied by a reduction in the time required to construct the ship. This, in turn, reduces those indirect costs of construction which are associated with time in the yard.

In the past, many of the changes that have been proposed to Navy ship designs as "producibility" improvements have mainly addressed ways to reduce the weight of the ship. This is not surprising, since the Navy's cost estimating model is primarily weight based. Therefore, to the NAVSEA cost estimators, and thus effectively to the ship designers, a reduction in weight is counted as a reduction in cost. As a result, attempts to control the cost of a new ship construction program have usually become exercises in controlling or reducing the weight or displacement of the design. This, in turn, has resulted in anomalies in which more costly construction details have been used because they reduce weight. Numerous examples can be cited to demonstrate that cost estimating by weight alone can be counterproductive to the cost of constructing the ship.

Efforts to evaluate the cost savings based upon parameters other than weight have been hampered by the lack of an established and accepted approach for doing so. Although many attempts have been made for estimating the costs of proposed changes, primarily for evaluations made during the detail design stage, there has not been agreement on what criteria should be considered or on what weight should be given to each criterion considered, compared to the others. The lack of a standardized list of criteria and criteria weights has so complicated and delayed the review and approval process for producibility design changes that many good ideas have had to be rejected because they could not be accomplished without schedule delay.

For maximum effectiveness, producibility should be considered throughout all stages of the design cycles. At each stage in the design cycle, decisions are made which may foreclose the introduction of producibility improvements at a later stage in the cycle. Failure to consider producibility early in the design may result in specifying a design which is more difficult to construct than is necessary. Only in recent years has the Navy given serious consideration to producibility during the early phases of the design process (before the shipbuilder's Detail Design). This has limited the shipbuilder's ability to improve producibility during the detail design.

1.3 OBJECTIVE

The objective of this Project has been to provide a mutually acceptable technique for use by Navy and industry in evaluating the construction cost of competing ship designs and design features, based on the work content of the design rather than on the weight of the design. The technique is intended for application in any stage of design so that early stage designers can assess the producibility of design features that they are considering as effectively as detail design stage designers are able to do. The methods are intended for use by both sides of the negotiating process, so that evaluations of the cost of a design change may be standardized and agreements more quickly obtained. Finally, with such techniques available, the efforts of ship designers to include true producibility improvements in their designs will be encouraged, rather than discouraged, by the cost estimating methodology.

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2.0 APPROACH

2.1 GENERAL

The overall approach to this project was to obtain as much information as possible about the methods that are in use in the shipbuilding industry for making producibility related design decisions, evaluate this information to identify the criteria that were used in actual decision making, identfy the most useful of these criteria and develop others as considered appropriate, test them on producibility related items that were actually considered during current shipbuilding projects, and conduct a workshop to develop an industry-wide consensus of the type of criteria that would be meaningful to both ship owners (government) and shipyards. These criteria would then be provided in Manual form for use during the design phases.

2.2 TASK BREAKDOWN

To carry out the project described above, the work was planned by tasks as described below.

Task One - Analyze Evaluation Methods

Obtain and analyze the techniques *that have* been used to evaluate "producibility" changes during recent NavSea design projects. These projects include the DDG-51, SWATH T-AGOS and the SSN-21, among others. Identify other proven methods and/or analytic models which have potential for being used in shipbuilding projects, by contacting government and industry personnel who have been involved with comparable projects. Develop a list of significant attributes for further evaluation.

Task Two - Analyze Early Stage Design Results

Identify and analyze the content and effectiveness of the design changes that have been considered as producibility changes in recent ship design projects. Identify what attributes of the evaluation process were involved in the decision to accept or reject the proposed changes. Determine what modifications were required in the ship's mission characteristics, if any, taking maintenance and other operating factors into consideration. Identfy the most cost effective design stage for accomplishing such design changes or for making the decision which would have permitted the change to be accepted.

Task Three - Analyze Detailed Design Results

Contact USN offices and representative private shipyards to identify producibility changes that have been proposed and considered during the detailed design process of recent shipbuilding projects. Classify these into changes that were proposed primarily to reduce the number of man-hours needed to construct the ship, without intending to modfy the specification requirements, and those whose primary emphasis was a reduction in some design requirement.

Identify the technical content of the changes, the expected life cycle impact, the reasons for the anticipated improvements in producibility and the basis for rejection of those which were not implemented. Determine whether any of these types of changes could have been made in earlier design stages, and if so, what needs to be done to ensure that this is accomplished in future design efforts. Identfi any cases in which producibility may have been traded off for performance.

Task Four - Develop Assessment Methods

Based on the data obtained from the previously described tasks and from the past experience of the team members assembled to accomplish this project, evaluate the effectiveness and efficiency of each producibility assessment evaluation techniques identified. Identify and compare other available analytic models, computer programs, forms and other tools for recording producibility ideas and conducting trade-off studies. Develop quantitative parameters for relating construction man-hours with variations in major design features. Develop preliminary producibility assessment criteria and methods based on the attributes and parameters which have been identified.

Task Five - Test Parameters

Demonstrate the validity of the criteria and assessment methods developed in the preceding task by application to the more significant changes that have been made in existing shipbuilding programs, as determined in Tasks 2 and 3.

Task Six - Conduct Workshop

After having presented the initial results of this study to SP-4, schedule a government and industry workshop, for the purpose of explaining how the proposed criteria and assessment techniques were developed and with the objective of either obtaining an industry consensus or identifying areas for additional work to be done. Include participation by others involved in similar or related studies, as appropriate.

Task Seven - Prepare Producibility Evaluation Manual

Taking the results of the workshop into account develop recommendations for methods and criteria to be used in assessing the producibility of competing design features of USN ship programs. Prepare a manual which will provide the results of these initial studies in a format which will be useful as a general standard for application to ship Acquisition project managers and Ship Design Managers to particular projects and shipyards.

Task Eight - Prepare Final Report

The first two tasks involved identification and analysis of criteria used during NAVSEA Producibility studies that had been made during preliminary or contract design efforts of recent past ship design projects. The third task involved identification and analysis of criteria that had been used by shipbuilders and Supervisors of Shipbuilding during the detailed design and construction phases of current programs. Task 4 was to develop recommended criteria and assessment methods. These were to be tested on some significant changes that had been considered during existing shipbuilding programs, for validation during Task 5. The presentation of these results and input from experienced industry personnel during a Workhop comprised Task 6. Task 7 involved the production of a manual describing the producibility Evaluation Criteria developed as *a* result of this study and providing guidance in the application of those criteria. Task 8 covered the production of monthly status reports and the preparation and publishing of this final report.

2.3 TASK PERFORMANCE

2.3.1 Members of the team met with NAVSEA personnel who had participated in or were currently participating in the following ship design projects DDG-51, SSN-21, T-AGS-45, SWATH T-AGOS, T-AGOS-19, FFG-7. Design studies of interest were obtained from these personnel.

2.3.2 The following shipyards were visited. Team members met with various personnel to discuss the producibility evaluation criteria currently in use.

National Steel and Shipbuilding Company (NASSCO)
Bath Iron Works (NW)
Newport News Shipbuilding and Drydock Company (NN)
McDermott Inc. (McD)
Ingalls Shipbuilding Company (ISD)

2.3.3 Members of the team visited the following Navy Supervisor of Shipbuilding Offices and met with various personnel to discuss the producibility evaluation criteria currently in use.

SOS Bath
SOS Newport News
SOS New Orleans (Amelia)

2.3.4 The team conducted a workshop on August 21, 1990 in Milwaukee, Wisconsin in conjunction with the NSRP 1990 Ship Production Symposium.

2.3.5 Based on the activities above, team members identified two different techniques for evaluating producibility of ship designs. One method considers each of the work elements involved in the construction of a design and develops a cost estimate for building each competing design. The design that costs the least is the most producible alternative. The other method considers various criteria that affect the producibility of a design, identifies the weighing factor to be applied to each criterion and then uses these to compare two or more design alternatives. The alternative that gets the highest score will be the most producible, but the scores do not relate directly to cost. Although this latter approach does not provide direct cost data, and therefore is not truly a cost estimating technique, it was developed in detail because it requires somewhat less information about specific production practices, and therefore can be utilized in cases where inadequate information exists to use the first technique. An additional reason for having developed the second method is that it is suitable for evaluating all of the other decision elements that must be considered before a decision to approve a producibility change will be made. The elements of the total decision making process were developed as additional programs.

2.3.6 The techniques described above were tested by application to several producibility changes that had been considered on currently ongoing shipbuilding programs, thanks to the input from the shipyards which supported this effort. The tests and their results are provided in following chapters.

2.3.7 The results of the above efforts have been developed as computer programs. A description of how to use these programs, and a copy of a floppy disk that contains the programs have bene provided in the *Producibility Evaluation Criteria, Cost Estimating Computer Programs - Manual (NSRP 0398),* Reference (l), which is an additional product of this project.

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3.0 FINDINGS AND ANALYSIS

3.1 EARLY DESIGN PHASE PRODUCIBILITY STUDIES

3.1.1 Designs Considered

Several different ships of varying types have had “producibility” studies performned during their preliminary or contract design stages within NavSea. Each of these has utilized personnel from shipyards and design agents in varying numbers. Most were funded efforts, conducted at least partly within NavSea. With only one exception NavSea personnel made all of the results of these studies available to team members. The ships whose producibility studies were reviewed were DDG-51, T-AO-1 87, AOE-6, T-AGS-45, T-AGOS-19, and the SWATH T-AGOS.

Analyses made by personnel from MIT and U. of Michigan relative to merits of the results obtained from these studies were also available to the team.

3.1.2 DDG-51 Producibility Studies

An analysis was conducted of the DDG-51 (DDGX) studies which were identified as producibility studies by the DDG-51 Project Office. These studies were previously summarized in Reference (2). This analysis is based upon a review of the data contained in that report and the review of selected studies from the DDG-51 Data Bank.

Six shipyards participated in the DDGX design program and were tasked to conduct the “producibility” studies covered in this report. They were

Bath Iron Works
General Dynamics (Quincy)
Ingalls Shipbuilding
Lockheed Shipbuilding
Newport News Shipbuilding
Todd Pacific

In the DDG-51 producibility studies, two of the shipyards were assigned to perform independent studies of each of an initial group of six subjects. The subjects were

1. Individual shipyard cost reduction and product improvement studies.
2. Space tightness and volume reduction studies.
3. Steel vs. Aluminum deckhouse trade-off studies.
4. Shipboard Multiplexing Data System studies.
5. Hybrid Metric Design Assessment.
6. Computerization of the Contract Data Design Package.

As can be clearly seen in the titles of the studies listed above, only #2, parts of #1 and possibly #3 would be classed as “producibility” issues, using the definition of producibility used herein. The remainder are design trade-off studies and studies of other issues related to cost and/or weight.

Further reinforcing the conclusion regarding the design trade-off nature of many of the studies, some of the studies labelled as “producibility" studies did not contain any direct reference to cost, despite the fact that producibility is clearly related to cost. Of the 61 studies identified in the referenced report as “producibility” studies, 15 did not address costs either directly or even indirectly. Further, of the remaining 46, only 26 of the studies contained what could be termed a detailed analysis of the estimated costs. Finally, where included, the cost estimates frequently applied overall cost factors which were neither explained nor supported in the study. Only a few of the studies included sufficient detail to permit a rudimentary evaluation of the results. This leaves the reader to assume that the factors are based upon the rior experience of the individual shipyard making the analysis. Since the shipyards did not include backup cost data, there is no way to determine what is included or omitted from the estimate *nor* the weighting of each item which is included in the overall factor. This makes comparison of the factors between shipyards difficult, if not impossible.

In addition to the lack of quantitative analysis, perhaps the most striking feature noted during this review is the divergence in approach and conclusions between shipyards. Each shipyard appeared to use its own approach (or the approach of the individual conducting the study) in performing the cost analysis. The reader is therefore unable to readily identfiy the underlying reasons for the conflicting results when two shipyards analyzing the same subject reach different conclusions.

It is clear that there is little to be gained from these producibility studies which can be adapted to an overall producibility evaluation system. However, it is also clear that unless a detailed analysis which identifies the factors considered is conducted, the results of any producibility study can not be used to reach reliable and accurate conclusions regarding costs.

In the DDG-51 program the producibility studies had only limited influence in the design. Reference (2) states that the studies of the six subjects listed above were not considered by the design team before the contract was awarded for the initial ship and that the results were not incorporated into the contract design.

In addition to the producibility studies, the referenced report also covers RCIAs on the DDG-51 program. Of the 1100 RCIAs at the time of the report, 279 were labelled as producibility items. Most of these however could be divided into the following categories:

Specification clarification
Specification and drawing corrections
Material/equipment substitutions
Operating/safety improvements

Reference (2) also comments on the producibility efforts associated with other programs, specifically the T-AO-187 and the AOE-6 in addition to the DDG-51.

3.1.3 T-AO 187

In theT-AO-187 program, the report states that an immature design was provided to six shipyards for a funded review. The shipyards submitted over 4000 comments in an unstructured format. Some of the comments were used to correct discrepancies but no major design changes were proposed or accepted.

3.1.4 AOE-6

In the AOE-6 program, the contract design package was delivered late to the shipyards for an unfunded review. Over 200 comments were submitted, some of which were incorporated. However, none of the proposed major design changes were made,reportedly because the design was set and schedule driven.

3.1.5 T-AGOS-19

Representatives from several shipyards were invited to review the design of this ship during its Contract Design stage. Their efforts resulted in numerous specific comments and suggestions, which are a mixture of design standards, design trade-offs, and weight reduction approaches in addition to many true producibility changes. Only a limited number of the studies included any quantitative analysis. The quantitative analyses which were included are rudimentary, with very little detail useful for developing relationships between work content and manhours or cost.

3.1.6 SWATH T-AGOS

Reference (3) provides the results of a producibility review of the Preliminary Design of the T-AGOS (SWATH "A"). This report provides general producibility principles, makes 29 recommendations for change and includes a estimate of cost savings for making significant changes in the structural design of the ship. Many of the recommended changes, particularly in the area of machinery rearrangements, were incorporated into the design, since the members of the review team worked directly with the NAVSEA designers as the design was being developed. Elements of this report were directly useful in the current project.

3.1.7 T-AGS-45 Producibility Study

The T-AG(X) Preliminary Design producibility study, Reference (4), was reviewed. The objective of the study was to enhance producibility considerations in the design. The report is divided into two main sections. The first is the preliminary design review and the second a comparative analysis of three alternative mid-ship framing designs.

The review of the preliminary design makes generic comments, overall observations, 22 suggested changes to the ship's structure, 17 suggested changes to the machinery and distributive systems and 3 comments regarding other systems. A proposed routing scheme for the distributive systems is included. Some of the changes are in the nature of design trade-offs but the majority are producibility items which generally confirm to the overall principles of producibtity. However, there were no quantitative analyses made of the cost impact of any of the suggested changes or comments. Therefore, the cost benefit associated with any or all of the changes could not be ascertained from this study.

The comparative analysis of the alternate framing systems did however, provide a quantitative approach to determining the cost of alternate designs. The approach builds upon that used in Reference(3), the producibility review of the SWATH T-AGOS. It considers the differences in the baseline midship design versus the three alternative designs for a selected section of the hull, in this case, a forty foot section. The work content of the five stages in structural fabrication were analyzed and the manhours for each of the steps were calculated. The stages used are Layout Time, Burning Time, Fitting Time, Welding Time and Grind/Chip Time. Unfortunately, the report only includes the detailed calculations for cutting and welding and even these sections include some factors which are not explained in the text. The source of the work measurement standards is only provided for the Layup manhour estimate table. The standards used in the other tables are not referenced. The Welding calculations do consider the length of weld, the type of weld (butt or fillet), the size of weld, the welding process, (submerged arc or shielded metal are), and the speed of welding. This approach is conceptually the same as the Cost Estimating technique developed for the current project.

3.1.8 Overall Evaluation

Review of the various design stage producibility studies revealed few discrete criteria useful for the purposes of this project. As has been stated earlier, most of the proposed changes studied involved use of different equipment of greater or lesser capability, reductions in requirements or other issues which more properly should be considered design trade-offs of the sort which are an inherent part of the early stage design process. The calculation of cost savings resulting from such alternatives were based on the weight of steel, fuel etc. which were eliminated from the baseline, multiplied by historical weight related cost factors from past shipbuilding efforts. The essence of these findings was that if no weight reduction was achieved, no cost savings could be anticipated. Results of this kind did not provide the team with useful data. The content and use of these studies clearly indicates the state of producibility in NavSea during the 1980s.

In conclusion a review of the existing approaches in the evaluation of producibility change proposals used by NavSea and the shipyards contacted to date has not disclosed a suitable alternate to the traditional bottom-up, engineering analysis approach.

3.2 DETAILED DESIGN PHASE PRODUCIBILITY STUDIES

During conversations with various representatives from the shipyards and Supervisors of Shipbuilding, the team was given information on both generalities and specific problems, many of which were not directly applicable *to our* task. The comments have been edited and included in the Appendix with no identification of the source.

The key observation made by many of the shipyard personnel is that the Navy does not appear to have considered either producibility or cost in their ship designs to date and therefore has a long way to go.

Our primary observation was that all of the yards appear to use a relatively informal unstructured system for evaluating most producibility changes. If it is “obvious” that there will be a significant net cost saving and the specifications do not have to be changed to accomplish it, personnel at appropriate decision making levels approve making the change.

One problem with this is that there seems to be little effort to evaluate the amount of saving in most such cases. Failure to recoup the manhours or dollars “saved” by reducing the manhours allocated to the task in the development of work authorizations *to the* trades will reduce the likelihood that the projected savings will be reflected in the final manhour expenditures.

One of the team’s purposes in the discussions held with shipyard personnel was to identfy the differences in cost between work done in the normal most desirable, stage and location and the same work accomplished at some later stage in the production process. The team did not obtain any specific, documented information on this subject. There are several “thumb rules” used by experienced personnel all of which were generally similar, ranging from 50% to 100% increase per stage. A factor of about 50% per stage, which is considered to be on the conservative side, has been used in this work The acceptability of the factors used was confirmed by the shipbuilders who participated in the Milwaukee Workshop which was a part of this project.

4.0 THE COST ESTIMATING COMPUTER PROGRAMS

4.1 GENERAL

This Chapter describes a technique for determthe cost, in manhours and dollars, to construct a product. The technique is based on a bottom-up production engineering approach. It considers how the proposed design would be most efficiently built, then develops the manhours expended during each step of that construction process and, finally, develops the costs of labor and material The technique lends itself equally well to obtaining the total cost of the work or to developing the differential cost of alternative designs. In many instances, only the differential cost is necessary.

Although the complexity of a total ship design might seem to be too great to allow this technique to be applied practically to the entire ship, it has been found that most studies of design alternatives involve discrete changes that can be effectively studied using this method. Further, cost estimates of major portions of a ship and even a complete ship are possible by applying this technique to a small part of the ship and expanding that to repetitive features of the design. For example, a cost estimate for a structural unit can be readily expanded to similar units throughout the ship.

In order to simplify and standardize the calculation of cost estimates using the techniques described in this chapter, a number of computer spreadsheet programs have been developed. Spreadsheets have been developed for estimating the shipyard construction costs for each of the types of shipyard work which normally contribute the major portion of construction costs. This initial group of cost estimating computer programs (CECOPS) has been prepared for the high cost effect trades involved; namely, Structural, Piping, Electrical and HVAC. Even in these trades, however, this initial group of programs is not all-inclusive. Programs have been prepared only for the major materials utilized in the work in these categories. For example, the structural program has been prepared only for mild steel, aluminum HY80 and HTS, the piping forms address only Schedule 40 and Schedule 80 pipe of the most common materials, and the HVAC program is limited to sheetmetal ducting.

These cost estimating computer programs represent the first step in developing a standardized format and methodology for estimating costs of ship construction and repair. As such the programs are intended to establish a common language between shipyards, Supervisors of Shipbuilding, NavSea and any other ship owners and/operators. Additional programs will be required to expand the coverage to those other aspects of the work normally performed in a shipyard. These cost estimating forms are only the first step in an evolving process to develop a standardized method of estimating costs in evaluating the producibility aspects of alternate designs.

The cost factors used in the CECOPS described herein are based upon data and engineering standards obtained from various sources. The contributions to this effort by the U.S. Naval Shipbuilding Scheduling Office are particularly appreciated. It is fully recognized, however, that the data contained in the current version of the programs provide only a reasonable starting point and that revisions and expansions can be expected after other organizations review and apply the programs.

1.2 BASIC CONCEPT

The basic concept of this technique is to estimate costs by identifying all of the discrete work processes to be used when constructing the design under consideration, to identify the quantity of work to be done in each process, and then to apply factors, from engineered standards and other data which determine the manhours required to accomplish each work process. The factors used take into account whether the work is accomplished during the most efficient work stage or at a later point in the construction process. The sum of the manhours required to complete all of the work processes involved, multiplied by the cost per manhour, generates the direct labor cost. By adding the support labor cost and material costs to the direct labor cost the *total* cost is obtained.

The steps in the process follow.

1. Select the design feature to be analyzed.
2. Identify the trades required to perform the work
3. Identify the shipyard work processes which would be used in the production of the design feature.
4. Determine and apply the engineered standards for each work process.
5. Apply a factor to reflect the increased difficulty of performing the work at a stage other than the ideal stage, on which the engineered standard is based.
6. Apply a factor for the support man-hours required.
7. Convert manhours to dollars.
8. Estimate material costs from the bill of material.
9. Total the cost for constructing the design.
10. Compare the cost with alternate design construction costs.

The differential method uses a simplified approach which considers only the differences in alternative designs and limits the analysis to those differences.

4.3 SPREADSHEET DESCRIPTION

The steps in the cost estimating process, as described above, can be accomplished without use of the computer programs which have been developed but the programs greatly facilitate the process and provide a guideline that should ensure that all pertinent factors are taken into account. Each of the cost estimating program spreadsheets is in a similar format which is illustrated in Table I. The following describes the primary elements of each.

The heading of each form defines the type of system and material covered by the form and provides fields for entering the size of the material to be used. In Figure 4-1, for instance, the heading identifies this as the Cost Estimating Form for Carbon Steel P2 Piping. Fields are provided for identifying the project and the specific design alternative under consideration. The fields for entering the pipe diameter and schedule are located at the right side of the heading.

The central portion of all of the forms include the same nine column headings; namely Work Process, Work Units, Process Factor, Unit Amount, Actual Stage, Standard Stage, Actual Factor, Standard Factor and Manhours Required. The data in all but the Unit Amount and Actual Stage columns is protected, so that the information in the protected columns cannot be modified without taking special steps to do so.

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SP-4                              COST  ESTIMATING  FORM  FOR  PIPING (P2)

FILEPIP2CFE             PROJECT : EXAMPLE #1 -FITTINGS     PIPE MATERIAL : CARBON STEEL
2/28/92                 FILE :    EXAMPLE1                 DIAMETER :             2 IPS
                                                           SCHEDULE :            40

  WORK PROCESS          WORK     PROCESS     UNIT ACTUAL STANDARD ACTUAL STANDARD MANHOURS
                        UNITS     FACTOR   AMOUNT  STAGE    STAGE FACTOR   FACTOR REQUIRED
                              (MNHRS/WK UNIT)
 1 OBTAIN MATERIAL
     RECEIPT & PREP     PIECE      1.00        4      1         1    1.0      1.0      4.0

 2 CUTTING
    MACHINE             CUT         .05       14      1         1    1.0      1.0       .7
    MANUAL              CUT         .50        0      2         2    1.5      1.5       .0

 3 BENDING
    MACHINE             BEND        .39        0      1         1    1.0      1.0       .0
    MANUAL              BEND       5.00        0      2         2    1.5      1.5       .0

 4 MARKING              PIECE       .10       15      2         2    1.5      1.5      1.5

 5 HANDLING (KITTING)
    STORAGE             PIECE       .10       15      2         2    1.5      1.5      1.5
    TRANSPORTING        PIECE      3.00        0      2         2    1.5      1.5       .0
    LIFTING             PIECE      5.00        0      2         2    1.5      1.5       .0

 6 WELDED JOINTS
    WELDING, BUTT       JOINT      1.70        0      2         2    1.5      1.5       .0
    WELDING, SOCKET     JOINT      1.20       14      2         2    1.5      1.5     16.8

 7 FIT UP, ASSEMBLE & INSTALL
    BUTT                JOINT      1.70        0      2         2    1.5      1.5       .0
    SOCKET              JOINT      1.40       14      2         2    1.5      1.5     19.6
    FLANGED             JOINT       .80        0      2         2    1.5      1.5       .0
    THREADED            JOINT       .50        0      2         2    1.5      1.5       .0
    SILBRAZED           JOINT       .32        0      2         2    1.5      1.5       .0
    THERMOFIT           JOINT      1.00        0      2         2    1.5      1.5       .0
    CRYOFIT             JOINT      1.50        0      2         2    1.5      1.5       .0
    MAP                 JOINT

 8 SURFACE PREP
    EXTERIOR            SQ FT       .10        0      3         3    2.0      2.0       .0
    INTERIOR            SQ FT       .20        0      2         2    1.5      1.5       .0

 9 COATING              SQ FT       .20        0      2         2    1.5      1.5       .0

10 INSTALLATION
    PIPE HANGERS        HANGER      .50        0      2         2    1.5      1.5       .0
    INSULATION          LN FT      1.14        0      4         4    4.0      4.0       .0

11 TESTING
    AIR                 OPENING     .10        0      6         6    7.0      7.0       .0
    HYDRO               OPENING     .96        0      6         6    7.0      7.0       .0
    AUDIOGRAM           LIN FT      .05        0      1         1    1.0      1.0       .0
    X RAYS              LIN FT      .10        0      1         1    1.0      1.0       .0

TOTAL TRADE MANHOURS                                                                44.1
TRADE SUPPORT MANHOURS  (35% OF TRADE MANHOURS)                                     15.4
TOTAL PRODUCTION MANHOURS                                                           59.5
LABOR COST (MNHRS X HRLY RATE)         20.00                                     1190.70
MATERIAL COST (FROM MATERIAL SCHEDULE)                                             67.10

TOTAL COST                                                                       1257.80

DIFFERENTIAL MATERIAL SCHEDULE
ELBOWS, SOCKET WELD, 90 DEG          4 ea.     10.76      43.04
ELBOWS, SOCKET WELD, 45 DEG          2 ea.     12.03      24.06
     TOTAL                                                67.10
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Figure 4-1 - Cost Estimating Form For P2 Piping

4.3.1 Work Process

All of the work processes which may be applied to the material covered by the form are listed in theWorkProcess column. Not all of the processes will be needed for the construction of every design product, but the intent is that all possible processes be listed, since any one of them may be needed for some specific application.

4.3.2 Work Unit

For each Work Process, there is a Unit of Work which determines the magnitude of effort involved in that process. These are listed under the heading "Work Units" in the second column. As can be seen by review of Figure 4-1, the work unit associated with cutting pipe is the number of cuts that must be made, while the work unit associated with Fit-up, Assembly and Installation is the number of joints.

4.3.3 Process Factor

The third column, headed “Process Factor", gives the faictor which must be applied to each work unit of the related work process in order to determine how many manhours are required for accomplishing each unit of that particular process. The values in this column of each form have come from discussions with individuals in shipyards, from estimates made by the team members or from estimating standards used in Naval Shipyards. This latter data was provided through the Navy’s Ship Scheduling Office in Philadelphia, PA. When the material size (for example, the IPS diameter and Schedule for the piping form used in Figure 4-1) is entered into the field at the top of the form, all of the values in the process factor column are automatically entered, from a cost estimating data "look up" table located in the same spreadsheet into which the engineered standards for each material size have been entered. Figure 4-2 shows the data included in the lookup table for the carbon steel piping form. Note that the value shown in Figure 4-1 for Work Process 2, Cutting, Machine, is obtained from the "Cut Pipe" column in Figure 4-2 for 2 inch pipe. Data for the other forms is given in the Manual, Reference (l).

4.3.4 Unit Amount

The Unit Amount Column in Figure 4-1 is to be filled in for each design alternative being considered. The initial values are all zero when the form is pulled up originally from the spreadsheet program.

4.3.5 Stages and Process Factors

Modern ship construction is based upon modular construction, with each module (or unit or block, depending upon the nomenclature chosen by a shipyard), passing through a series of stages, each of which is normally associated with specific work sites, where the process can be performed most efficiently. Many work processes can also be accomplished at later stages of the construction process, but the work then will be done less efficiently, and thus will require more manhours. The values which appear in the Process Factor column apply to work done most at the standard stage. For estimates made during early stage design, the standard values can be assumed. For estimates made after construction has started, these values may not be applicable. Thus, a column headed “Actual Stage” has been provided, where a stage later than the standard stage may be entered in order to generate more accurate cost estimates.

While diiferent shipyards use differing designations and vary the number of stages that they identify in their production process, the stages shown in Figure 4-3 have been selected for use in the CECOP forms. In Figure 4-3, the normal location of the work stage is also show

NSRP PANEL SP-4
FILE: PIP2CRES

COST ESTIMATING DATA FOR
PIPING (P21

MATERIAL: CRES
SCHEDULE 8U

COST ESTIMATING PROCESS FACTORS

PIPE sIZE IPS	1 CUT PIPE	2 BEND PIPE	3 (FiT BUTT	4 UP SOCKET	5 ASSEMBLE & FIANGE	6 AND THREAD	7 INSTALL) SILBRAZE	8 **PIPE** INSULATION	9 HYDRO TEST
0.25	0.02	0.25	0.8	0.6	0.5	0.3	0.22	0.91	0.27
0.50	0.02	0.25	1.0	0.7	0.6	0.3	0.23	0.91	0.41
0.75	0.03	0.25	1.1	0.8	0.6	0.4	0.24	0.91	0.55
1.00	0.03	0.25	1.2	0.9	0.6	0.4	0.27	0.91	0.68
1.25	0.04	0.25	1.2	1.1	0.7	0.4	0.28	1.14	0.75
1.50	0.05	0.25	1.5	1.2	0.7	0.4	0.30	1.14	0.82
2.00	0.05	0.39	1.7	1.4	0.8	0.5	0.32	1.14	0.96
2.50	0.06	0.39	1.9	1.6	0.8	0.5		1.14	1.09
3.00	0.06	0.39	2.2	1.9	0.9			1.23	1.23
3.50	0.07	0.39	2.5	2.2	1.0			1.33	1.23
4.00	0.08	0.39	2.7	2.4	1.0			1.41	1.36
5.00	0.08	0.39	3.1	2.7	1.0			1.49	1.50
6.00	0.09	0.39	3.6	3.2	1.1			1.71	1.64
8.00	0.15	0.72	4.5	4.0	1.1			2.30	1.77
10.00	0.21	1.61	5.5	4.9	1.2			2.58	
12.00	0.26	4.33	6.4	5.9	1.3			2.84	
14.00	0.32	4.33	7.4	6.8	1.4			3.13	
16.00	0.38	4.33						3.34	

WELD FACTORS

BUTT	2
SOCKET	5

SCHEDULEE PIPE SIZE IPS	40 WELD BUTT	80 **WELD** BUTT	160 WELD BUTT	**WELD** SOCKET	WELD SOCKET	160 **WELD** SOCKET
0.25	1.4	1.6	1.8	0.9	1.0	1.3
0.50	1.4	1.6	1.8	0.9	1.0	1.3
0.75	1.4	1.6	1.8	0.9	1.0	1.3
1.00	1.4	1.6	1.8	0.9	1.0	1.3
1.25	1.4	1.6	1.8	1.0	1.2	1.6
1 .!50	1.4	1.6	1.8	1.0	1.2	1.6
2.00	2.2	2.3	3.8	1.6	1.6	2.1
2.50	2.2	2.3	3.8			
3.00	2.2	2.3	3.8			
3.50	2.7	3.1	5.5			
4.00	2.7	3.1	5.5			
5.00	3.4	3.9	6.9			
6.00	4.2	4.8	8.5			
8.00	5.1	5.9	10.0			
10.00	6.1	7.0	12.0			
12.00	6.6	7.8	14.0			
14.00	7.7	8.7	16.0			
16.00	8.6	10.0	19.0			

Figure 4-2 - Cost Estimating Data For Piping (P2)

	Stage	Location	Difficulty Factor
1.	Fabrication	In Shop	1.0
2.	Pre-Paint Outfitting	On Platten - Hot work	1.5
3.	Paint	Paint Shop / Stage	2.0
4.	Post-Paint Outfitting	On Platten - Cold Work	3.0
5.	Erection	Erection Site	4.5
6.	On-Board Outfitting	Erection Site	7.0
7.	Waterborne	Pierside after Launch	10.0

Figure 4-3 - Construction Stages and Process Difficulty Factors

to clarify the stage definition and to facilitate the application of this technique to repair work as well as new construction.

4.3.6 Stage Process Factors.

To reflect the additional work caused by accomplishing work at other than the standard stage, a set of process difficulty factors have been selected. These factors have been used by the team based upon estimates received from numerous sources. All of the inputs could be classified as thumb rules. The team was not able to identify any hard data to support the numbers used. However, based on experience of many experienced shipbuilders, the difficulty factor between stages has been estimated at 1.5 to 2 times the effort required in the prior stage. The work stage difficulty factors provided in Figure 4-3 reflect an amalgam of the work stage difficulty data obtained from various sources. Revisions to the work stage factors, based on later and expanded measurements, are anticipated.

The work factors from figure 4-3 appear under the Actual Factor and Standard Factor columns in Figure 4-1, based upon the values which appear in the Actual Stage and Standard Stage, respectively. When a stage later than the standard stage is entered into the Actual Stage column for a process, the applicable stage difficulty factor is obtained automatically from ;he lookup table shown in Figure 4-3 and appears in the Actual Factor column.

4.3.7 Manhours Required

The data in the last column is calculated by the program, which multiplies the process factor by the unit amount and multiplies that product by the ratio of the Actual Factor to the Standard Factor. Values of the ratio of the Actual Factor to the Standard Factor of less than 1.0 are not permitted.

4.3.8 Cost Estimate

The lower portion of the form in Figure 4-1 shows the steps necessary to generate the final cost estimate. The program automatically adds up all of the manhours in the last column. An allowance for trade support manhours is determined based on a percentage figure which can be modified by each yard based on its own data. The total manhours are multiplied by the hourly rate for the associated trades to calculate the labor cost. Finally, the cost of material is added in order to determine the total cost of constructing the product.

4.4 DATA ENTRY.

Although the preceding description may seem quite extensive, the actual effort to fill in data in any CECOP form is quire simple. The only unprotected fields on this form, i.e., the only fields which can be changed by the operator who is entering data, are the Project Title, the File description, the material dimension data, and the fields in the Unit Amount and Actual Stage columns. The Actual Stage column default value in the original file is the same as the Standard Stage value. This entry should be changed by the operator as judged appropriate for the particular project. Thus, using the CECOP forms involves only the following steps.

1. Identifying each Work Process which will be involved in the construction of the design alternative being considered and entering, in the Unit Amount column, the number of work units required for that alternative,
2. Entering, in the Actual Stage column, the work stage during which the work is expected to be accomplished. The form already includes the Standard Stage value in this column, making it unnecessary to make any entry in this column unless the work will be accomplished at some other stage. This column normally will not need to be filled in except after ship construction has started, i.e., for analyses made during the detail design phase.
3. Entering material cost information.

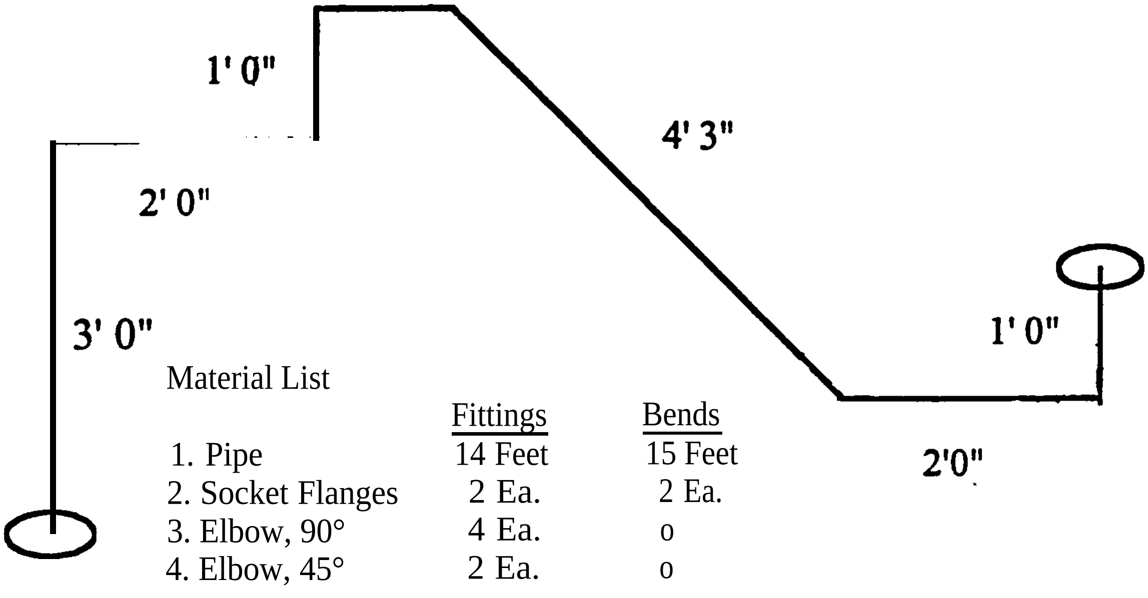
Accurate and detailed cost estimating has always been a difficult, complex and time consuming task. Now, much of the drudgery of preparing cost estimates can be performed by the computer. The next step is to use the programs, evaluate the accuracy of the results and adjust the computer programs as necessary.

4.5 APPLICATION

4.5.1 Pipe Fittings vs. Bending

As an example, the piping cost estimating computer program was applied to two alternative approaches to producing the simple section of piping shown in Figure 4-4. The differential cost of manufacturing the piping detail by the use of fittings for each change in direction

11011



Material List

	Fittings	Bends
1. Pipe	14 Feet	15 Feet
2. Socket Flanges	2 Ea.	2 Ea.
3. Elbow, 90°	4 Ea.	o
4. Elbow, 45°	2 Ea.	o

Figure 4-4 - Pipe Example

versus by bending the pipe with a pipe bending machine was estimated. The costs of identical material and work processes were ignored and only the costs of the different material and work processes were considered. Figure 4-1 illustrates the application to the Fittings alternative. The *cost* dfierential between the two alternatives was calculated to be $955 in savings for the bending approach.

4.5.2 Schedule Slippage

The difference in costs of manufacturing the pipe detail in Figure 4-4 at different stages in the construction schedule was also estimated, in order to evaluate the effects of late work. In both cases, the pipe detail was assumed to be fabricated with fittings. In the optimum case, the pipe detail is manufactured in the shop, stage 1, and installed in the module at stage 2, Pre-Paint Outfitting. In the alternate case, work was not accomplished until the ship is water-borne, undergoing final outfitting. Further, in this case the assumption was made that the pipe would have been cut in the shop, stage 1, but that assembly and welding on board in stage 6 would be required to fit the pipe section into place. This calculation concluded that 107 hours would have been required had the work been accomplished at stage 2, but that 460 hours would have been needed for the same work performed at stage 6. The delay in performing the work would have quadrupled the cost.

4.6 VALIDATION

Validation of the CECOP forms and their underlying data tables was attempted by applying them to producibility items that had actually been made by shipyards and comparing the results obtained using CECOP to the results calculated by the yards. Reasonably good correlation was obtained in the several studies that have been made.

However, these attempts demonstrated the difficulty in comparing producibility cost estimates prepared by different organizations. The key problem is determining what is included in the estimate and what functions are omitted. Specifically, many of the work processes considered in the CECOP forms, such as material handling processes, are not normally addressed in shipyard studies. Further, the work process factors used by each group may vary depending on how the factors were developed and the specific processes and equipment available to the yard. Obviously, once two organizations work together on generating estimates these differences will be highlighted and ultimately eliminated.

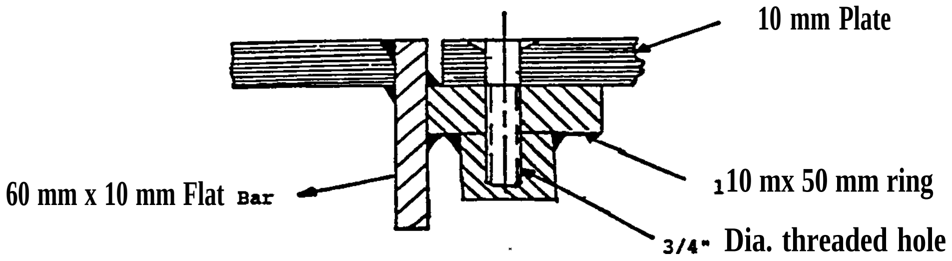
Finally, for want of better data, this validation is being made between two estimates, without the benefit of any actual cost data to confirm the accuracy of either estimate. Without the ability to compared estimates against actual return costs for any specific project, the estimating techniques used by either organization are open to question.

Nevertheless, the producibility cost estimates are all that are available and they do provide a tool for decision making. The use of standard cost estimating computer programs will allow for standardizing the process and permit the identification of the reasons for differences between the results obtained by diverse organizations.

4.6.1 Validation example 1

A producibility item applicable to handholes and manholes was used. The original method of fabricating handholes, as illustrated by "Current Design" in Figu 4-5, consisted of welding a 20 mm flat ring to the inside of a 10 mm circular flat bat which was welded into the opening in the deck. Round bar stack with a diameter of 32 mm was cut to 38 mm lengths to

CURRENT DESIGN



PROPOSED DESIGN

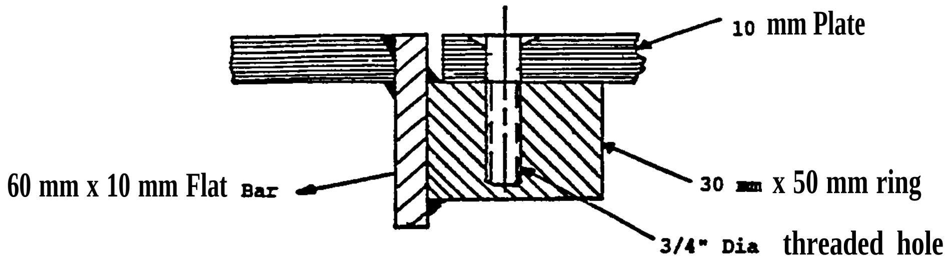


Figure 4-5 - *Manhole* Design Alternatives

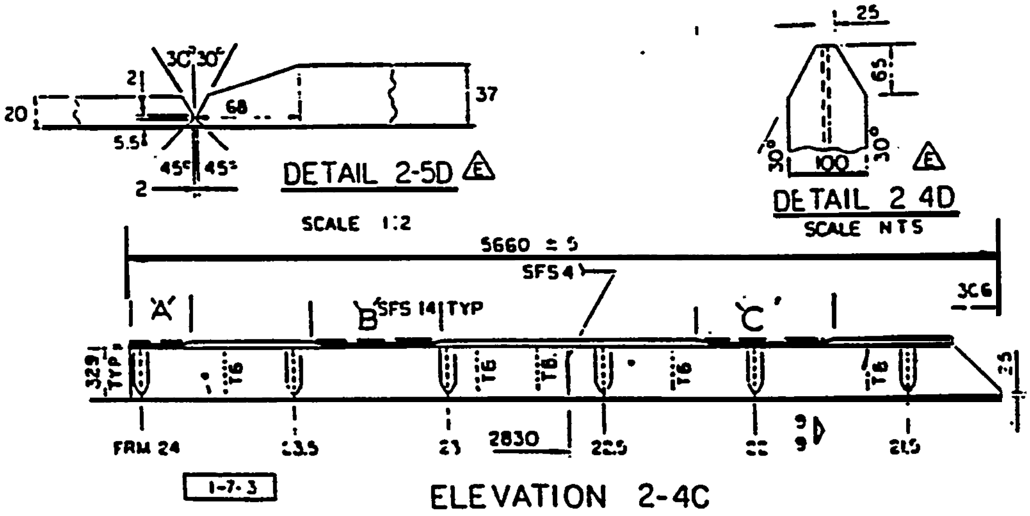


Figure 4-6 - Generator Seat Configuration

form studs. These studs were welded to the underside of the flat ring, drilled and tapped to accept 19 mm (3/4 inch) hold down bolts. The proposed producibility improvement substituted a 30 mm flat ring for the 10 mm ring. The bolt holes were therefore drilled and tapped into the ring without the installation of the studs. The shipyard estimated that the old method required 28 manhours per manhole and that the new method would result in a 40% saving in manhours, or 11 man-hours. Data was not available to support either the estimate of current manhours or the percentage of savings.

The application of the CECOP structural form to this producibility item gave essentially the same results as the shipyard estimate of the savings.

4.6.2 Validation example 2

A producibility proposal applicable to fabricating Diesel Generator Seats also was used. The original method of fabricating the seats consisted of fitting and welding six sections of plating, alternating in thickness between 20 and 37 mm. The plates were welded together by double sided butt welds, as shown in Figure 4-6. Each joint required edge preparation with two bevels for each plate. Further, the 37 mm thick plate required a longer bevel to reduce the thickness to 20 mm at the joint. Overall, each seat was 390 mm wide and 5660 mm long when completed. The proposed producibility improvement was to use a single 37 mm thick plate and machine the thinner areas to the required 20 mm thickness. The length of the three areas to be machined to 20 mm were 336 mm, 719 mm and 719 mm.

The shipyard estimated the manhour cost savings per seat for machining compared to the use of either manual Shielded Metal Arc Welding (SMAW) procedures or automated Flux Core Arc Welding (FCAW) procedures. Although the shipyard's description of the savings to be obtained included mention of savings in handling and straightening, these savings were not quantified.

The CECOP estimate of the savings to be obtained by use of the modified construction procedures was close to those estimated by the shipyard. Savings in the joint preparation, fitting, welding and cutting were considered. Savings in handling and straightening were omitted, to permit ready comparison with the shipyard analysis. A work stage factor of 1 was applied. A separate sheet of the CECOP form was used for each of the two different material thicknesses and the estimates were added to obtain the final value for each process. The following estimates resulted.

Process	MH FCAW	MH SMAW
Joint prep	1	1
Fit up	4	4
Welding	7	23
cutting	1	1
support	5	11
Total Reduction	18	40

In calculating the increase in manhour costs for the proposed method, data for the work process factor for machining were not available, Therefore, the shipyard's manhour estimate for the machining was used to develop a preliminary work process factor for machining. The total machining effort was calculated to be the sum of 16 hours for machining and 5 support hours, for a total estimate of 21 manhours.

Thus, the final CECOP results showed that the machining approach would result in an increase of 3 manhours over the automatic welding process, and in a saving of 19 manhours over the manual process. These compare with the yard's estimates of a 6 manhour saving over automated welding and 29 manhours over manual welding. These results indicate that the CECOP analysis essentially confirms the shipyard's conclusion that there is little to be gained in changing the current method of fabricating the generator seats when automatic welding is considered. However, there is an appreciable savings to be gained when compared to manually welding the plates. Further, when the savings in shipping, handling and straightening of the welded plates are considered, the savings to be gained from the machined diesel generator seats will increase.

4.7 FINDINGS

The correlations achieved in these two validation tests of the CECOP forms demonstrate the potential value of this method in estimating costs of producibility improvement proposals. Future development of the forms and refinement of their backup data should improve the accuracy and reliability of the results which can be obtained.

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5.0 RELATIVE PRODUCIBILITY EVALUATION

5.1 GENERAL

The analytical technique described in the previous section requires a significant amount of detailed information about the product and about how it can or will be constructed. The major advantage of that technique is that it specifically considers the actual work content of the product and provides a realistic cost estimate for the construction effort.

However, during the course of this project, the authors found another technique for evaluating the producibility of ship designs to have great value. Although this alternative method provides only a relative comparison of various design alternatives, as opposed to the absolute quantitative valuation described in the previous section, it may be accomplished when less detailed data are available. This "relative” producibility method may be used as a preliminary test to determine whether to proceed with the “absolute” method.

This second method is an application of the Analytic Hierarchy Process (AHP) developed by Prof. Thomas L. Saaty of the University of Pittsburgh Reference (5). The AHP allows effective decisions to be made concerning complex issues by following several discrete steps.

The first step involves breaking down the situation to be evaluated into those criteria which affect the process under evaluation. Each of these criteria are further broken down into the subcriteria which affect them. This process continues until the most basic elements which control the criteria are identified. In this way, the hierarchic order of all of the significant variables are determined.

In the next step, the relative weight to be given to each of the variables is determined. This is accomplished by pairwise comparisons of related criteria, as described in more detail later. In accomplishing this step, the intuitive knowledge of experienced individuals is taken into account, as well as the specific information available.

These first two steps need to be accomplished only once at each design stage for any shipbuilding program. Once the controlling producibility criteria and subcriteria have been identified and their relative weighting values determined, they will be used for all evaluations of the producibility of design alternatives. Thus the development of a specific hierarchy is, at most a one-time effort for each project. It is reasonable to assume that a single hierarchy will be adequate for most shipbuilding programs, since the construction processes in all shipyards are essentially common.

The third and fourth steps in the process are the only steps that are needed for comparing two or more design alternatives. They involve making a pairwise comparison of each of the design alternatives for each of the subcriteria at the lowest level of the hierarchy and then multiplying these results by the subcriteria weights determined in step 2 and adding up the results. The process will be described by example in later paragraphs.

5.2 ADVANTAGES

There are several very important advantages to the use of the AHP method. One is that this technique has a rigorous methodological basis. Reference (5) provides further information on this matter. This reference also provides a detailed description of the AHP process as a framework for application to many different areas, including areas not explored by Professor Saaty. However, the examples in the book demonstrate that application of the method to different types of problem requires at least some minimal system engineering effort to structure the problem appropriately.

Another advantage of the AHP is that this process can make use of “hard”, numerical data when it is *available.* For instance, when specific data, such as the length of piping of alternative design configurations, is known, this data may be used directly. But if hard data is not available or if the different attributes that must be considered cannot be measured in common units, this technique is still effective.

5.3 SHIPBUILDING APPLICATION

In carrying out the first step of the AHP for shipbuilding program applications, the authors obtained reports from producibility studies that had been carried out on several recent shipbuilding programs. The attributes that were used in each of them for making decisions relative to the selection of preferred design alternatives were compiled. The authors also visited numerous shipyards to learn about the methods that were used at the yards when making producibility related decisions, with particular attention to the criteria that contributed to their decision making process. Using the data thus obtained, influenced by their own experience, the authors developed a hierarchy of characteristics which control the relative ease of difficulty of constructing the systems of which a ship is comprised.

The parameter tree which has been developed for producibility aspects of a shipbuilding program is described in the following paragraphs. Although this hierarchy has been identified through interviews of personnel at all levels of the design and construction processes, it can be expected that experience with the methodology will lead to additions and or deletions.

5.4 TOP LEVEL PRODUCIBILITY CRITERIA

The criteria in the following list were found to be the top level parameters which control the cost of building a ship.

Arrangements
Simplicity
Material
Standardization
Fabrication /Assembly requirements

As may be noted from some of these choices, the positive, or most enhancing aspect of the criterion, was selected to describe the criterion whenever possible. Thus, Simplicity was used in preference to Complexity. In this way of thinking, the greater value is assigned *to the* attribute which leads to the least construction effort and cost. This is not always possible when dealing with hard numerical data such as the length of piping or length of welding, but weighting values are appropriately adjusted in such cases.

5.5 UNDERLYING SUBCRITERIA

5.5.1 Arrangements.

By arranging the structural details of a ship in ways that enhance modular instruction breaks, and arranging the equipment within spaces to minimize the length of runs of distributive systems, etc., it is possible to eliminate unnecessary welding, lengths of piping, ventilation ducting, and many other sources of production cost. All of these efforts will result in a reduction of manhours, material cost and construction time, with resultant reduction in recurring construction costs.

Experience has shown (3) that equipment arrangements that were made during the early stages of design often were carried through detail design without any attempt at optimization. When comparing the relative producibility of various design alternatives, the arrangement of structure, equipment and distributive systems can make a major contribution. The next lower tier - the elements which directly affect the producibility of an arrangement - have been identified to be those in the following list.

Enhanced packaging of components
Direct routing of distributive systems
Interference avoidance
Volumetric density.

5.5.2 Simplicity

The next lower tiers of elements under the primary criterion of Simplicity areas follows.

Shape of pieces
Flat plate
Simple curvature
Rectangular configuration
Number of pieces
Accessibility.

5.5.3 Material/Equipment/Facilities

Use of different types of material, even if more expensive, can lead to fewer construction manhours, (as well as reduced service life maintenance requirements) with net overall reduction in construction cost. No lower tier elements were identified under this criterion during the development of weighting factors for producibility criteria, since it was held that the relative merits of various designs could be adequately evaluated at this level. However, should it be found desirable to do so for any specific application, material and equipment costs could be broken down by system type, such as structural, piping, propulsion machinery, etc., and specific facilities to be used or considered could be identified.

5.5.4 Standardization

Use of standard parts, standard processes, etc., has been found to reduce construction costs. Thus it is important to identfy the degree of standardization of competing design alternatives when considering their relative producibilities. The lower tier parameters for standardization were established as shown below.

- Component standardization
- Structural
  - Plate thickness
  - shapes
  - Sizes
- outfitting
- Equipment
- Process standardization.

5.5.5 Fabrication/Assembly Requirements.

The hierarchy of parameters which affect the actual construction processes involved during fabrication and assembly of a ship's equipment and material could be very extensive. The listing which follows is believed to be sufficiently comprehensive to yield valid results for relative producibility evaluations, without being so extensive as to require unnecessary detail in order to carry out the evaluations.

- Welding considerations
  - Process required
    - Automation achievable
    - Position optimization
    - Heat treatment
  - Configuration
    - Weld length
    - Weld type
    - Fillet configuration
      - Plate bevel angles
      - Number of passes
- Sheetmetal considerations
  - Configuration
  - Process required
- Machinery considerations
  - Use of common foundations
  - Mounting details
  - Installation
- Pipefitting considerations
  - Pipe size
  - Length
  - Material type
  - Piping support needs
  - Process
    - Use of bends vs. fittings
    - Connection type
- Electrical/Electronic considerations
  - Wireways
  - Connections/hookups
  - Cable
  - Length
  - Size
- HVAC considerations
  - Ducting
    - Size
    - Length
    - Material
    - Configuration changes
  - Equipment installation
  - Insulation

5.6 WEIGHTING FACTORS

The weighting factors to be used for each of the criteria identified above are obtained by a method of pairwise comparison of each element of a higher level of the hierarchy. Thus, for instance, each of the three first level parameters listed under HVAC (Ducting, Equipment installation, Insulation) would be compared with the other two, and each of the four under "Ducting" would be compared with the other three. In doing each pairwise comparison, a scale of 1 to 9 is used, where a 1 means both parameters are equally important and a 9 means that the corresponding parameter is very much more important than (actually, 9 times as important as) the other. A questionnaire format has been prepared for accomplishing these comparisons. The format of one element of the questionnaire is shown in Figure 5-1.

Which of the two parameters below has the greatest influence on construction cost? A 9 indicates very much greater, 7 much greater, 5 moderately greater, 3 somewhat greater, 1 equal influence

Ducting Size Ducting Length

9 . . ..8 . . ..7 . . ..6 . . ..5 . . ..4 . . ..3 . . ..2 . . ..1 . . ..2 . . ..3 . . ..4 . . ..5 . . ..6 . . ..7 . ...8....9

Figure 5-1 - PairWise weighting questionnaire element

Persons familar with the influence of the factors identified are asked to circle the numerical value which indicates their considered opinion. A copy of the questionnaire used for developing the data presented in this report is included as an Appendix. A computer program has been developed to capture the data presented in each questionnaire. The same program can be used for direct entry individual responses to the questions contained in the questionnaire. A second computer program has been developed to combine the results of each individual response into a single weighting factor for each of the parameters of the entire hierarchy.

Figure 5-2 presents the weighting factors derived from the responses received from those who answered the questionnaire. The values for each series of elements from each level of the hierarchy will add up to 1.0, as can be demonstrated by adding all of the values in Level 1, all of the values for the Arrangement subcriteria of Level 2, etc. The composite figures listed in the last column are obtained from multiplying the factor for each individual subcriterion by the values for each element located above it in the hierarchy. Only those elements of the hierarchy whose composite factors are shown in the column headed "Use" are used when comparing the producibility of design alternatives. Again, it is emphasized that this process need be accomplished only once for a specific ship project and design phase. Once the criteria to be evaluated have been determined, and their weighting values calculated, as in the Use column, they are used for evaluating each set of design alternatives.

5.7 EVALUATING DESIGN ALTERNATIVES

In order to determine the relative producibility of two or more competing design proposals, a process similar to that used to determine the performance criteria weighting factors is followed. The difference is that each alternative ship design proposal is compared with each of the other competing design alternatives for each of the lowest tier producibility parameters, again using the 9 to 1 to 9 rating scale. The comparison of the alternative designs can be carried out

		<------------LEVEL------------>					
	USE	1	2	3	4	5	COMP
*RECURRING PRE-D*ELIVERY CONSTRUCTION COST							
Arrangement		.2419					.24190
Enhanced Packaging of Components	**.06451**		.2667				.06451
Direct Routing of Distributive Systems.	04115		.1701				.04115
Interference Avoidance	.08769		.3625				.08769
Volumetric Density	.04855		.2007				.04855
simplicity		.2239					.22390
Shape of Pieces			.2402				.05378
Flat Plate	.02705			.5030			.02705
Simple Curvature	.00952			.1770			.00952
Rectangular *Configurations*	.01721			.3200			.01721
Accessibility	.10714		.4785				l 10714
Number of Pieces	.06298		.2813				.06298
Material	.08000	.0000					.08000
standardization		.2220					.22200
Component *Standardization*			.6380				.14164
Structural				.2067			.02928
Plate Thickness	.00709				.2421		.00709
Shapes	.01385				.4732		.01385
Sizes	.00833				.2847		.00833
Outfitting	.0S106			.3605			.05106
Equipment	.06131			.4329			.06131
Process Standardization	.08036		.3620				.08036
fabrication/Assembly Requirements		.2323					.23230
welding Considerations			.2271				.02953
Process Required				.5825			.01720
Automation Achieved	.00877				.5099		.00877
Position Optimization	.00375				.2279		.00375
Heat Treatment	.00466				.2722		.00468
configuration				.4175			.01233
Fillet configuration					.3345		.00412
Plate Bevel Angles	.00175					.4243	.00175
Number of Passes	.00237					.5757	.00237
Weld Length	.00326				.2648		.00326
weld Type	.00494				.4007		.00494
Sheetmetal Consideration			.0609				.01415
Configuration	.00626			.4427			.00626
l Process Required	.00788			.5573			.00788
Machining Considerations			.2118				.04920
Use of Common Foundations	.01503			.3054			.01503
Hounting Deatails	.01440			.2926			.01440
Installation	.01978			.4020			.01978
Pipefitting Considerations			.2057				.04778
Process				.3404			.01627
Use of Bends vice Fittings	.00902				.5544		.00902
Connection Type	.00725				.4456		.00725
Pips Size	.00627			.2312			.00627
Length	.00615			.1286			.00615
Material Type	.00811			.1698			.00811
Piping support Needs	.01099			.2300			.01099
Electrical/Electronics Considerations			.2176				.05055
Cable				.2560			.01294
Length	.00641				.4955		.00641
size	.00653				.5045		.00653
Connections/Hookups	.02100			.4154			.02100
Wireways	.01661			.3286			.01661
HVAC Considerations			.1769				.04109
Ducting				.4013			.01649
Size	.00320				.1943		.00320
Length	.00324				.1962		.00324
Material Type	.00291				.1765		.00291
Configuration Changes	.00714				.4330		.00714
Equipment Installation	.01439			.3501			.01439
Insulation	.01022			.2486			.01022
Sum of weighting Factors	1.00001	1.0001	4.0000	8.0001	6.0000	1.0000	

Figure 5-2 - Survey Weighting Factors for Producibility Evaluation quite quickly, using questionnaiire forms prepared for this purpose. The general format of the questionnaire is as shown in Figure 5-3.

> Which of the two design alternatives has the smaller HVAC DUCTING SIZE, and what is the degree of difference? A 9 indicates very much smaller, 7 much smaller, 5 moderately smaller, 3 somewhat smaller, 1 equal
>
> Alternative A   Alternative B
>
> 9 . . ..8 . . ..7 . . ..6 . . ..5 . . ..4 . . ..3 . . ..2 . . ..l . . ..2 . . ..3 . . ..4 . . ..5 . . ..6 . . ..7 . ...8....9

Figure 5-3 - Comparison of Design Alternatives for One Criterion

Several knowledgeable persons should evaluate the same design alternatives. The data from each person's evaluation will be entered into computer programs which will generate a combined score for each design for each criterion. The sum of the values for each design is provided by the program. Since these amounts represent relative values and the more producible design is given the higher score for each criterion, the largest sum will identify the most producible (least costly) design alternative. In order to determine the dollar value of cost savings to be expected, one would then proceed to the "absolute" evaluation described previously.

A simple spreadsheet form, for use when only two alternatives are being compared, is shown in Figure 5-4. When evaluating alternative designs using this form, both alternatives are compared for each of the producibility evaluation criteria shown. A value of 1 to 9 is given to the alternative that is more producible, with the value indicating the degree of improvement, exactly as if the scale shown above was being used. The other alternative receives a value of 1.

When hard data is available, it can be entered directly, taking care to enter the data in such a way that the preferred alternative receives the higher value.

Whenever possible, more than two alternative ship design configurations should be compared, since a consistency factor can then be obtained for confidence verification. Thus it is helpful to have information about a baseline ship against which a new ship's basic design characteristics and those of a proposed alternative both may be compared.

5.8 EXAMPLE.

In Figure 5-4, values reflecting the pipe fitting vs. bend analysis shown in Figure 4-4 have been entered. Using fittings requires a total of 15 pieces while bending the pipe yields only 3. To give the higher relative value to Alternative 2, the bending approach the value of 15 has been entered under Alt. 2 and 3 under Alt. 1. The work to cut the pipe and assemble the joints also will be significantly reduced for the bending case. The ratio of manhours for the two alternatives is estimated to be in the order of 3 to 1. Thus the value of 3 is entered under the Relative Merit column of Alt. 2. As a result of having entered these values, the sum of weighted values for the two design alternatives becomes .4774 for Alternative 1 and .5226 for Alternative 2. Based on the larger value for Alternative 2, it would be concluded that Alternative 2 is the more producible design.

RECURRING PRE-DELIVERY CONSTRUCTION COST					
Arrangement					
Enhanced Packaging of Components	1	1	.06451	.03225	.03225
Direct Routing of Distributive Systems	1	1	.04115	.02007	.02007
Interference Avoidance	1	1	.08769	.04384	.04384
Volumetric Density	1	1	.04855	.02427	.02427
Simplicity					
Shape of Pieces					
Flat Plate	1	1	.02705	.01353	.01353
Simple Curvature	1	1	.00952	.00476	.00476
Rectangular Configurations	1	1	.01721	.00860	.00860
Accessibility	1	1	.10714	.05357	.05357
Number of Pieces	3	14	.06298	.01111	.05187
Material	1	1	.08000	.04000	.04000
Standardization					
Component Standardization					
Structural					
Plate Thickness	1	1	.00709	.00354	.00354
Shapes	1	1	.01385	.00693	.00693
Sizes	1	1	.00833	.00417	.00417
Outfitting	1	1	.05106	.02553	.02553
Equipment	1	1	.06131	.03066	.03066
Process Standardization	1	1	.08036	.04018	.04018
Fabrication/Assembly Requirements					
Welding Considerations					
Process Required					
Automation Achieved	1	1	.00877	.00438	.00438
Position Optimization	1	1	.00375	.00187	.00187
Heat Treatment	1	1	.00468	.00234	.00234
Configuration					
Fillet Configuration					
Plate Bevel Angles	1	1	.00175	.00087	.00087
Number of Passes	1	1	.00237	.00119	.00119
Weld Length	1	1	.00326	.00163	.00163
Weld Type	1	1	.00494	.00247	.00247
Sheetmetal Considerations					
Configuration	1	1	.00626	.00313	.00313
Process Required	1	1	.00788	.00394	.00394
Machining Considerations					
Use of Common Foundations	1	1	.01503	.00751	.00751
Mounting Details	1	1	.01440	.00720	.00720
Installation	1	1	.01978	.00989	.00989
Pipefitting Considerations					
Process					
Use of Bends vice Fittings	1	3	.00902	.00226	.00676
Connection Type	1	1	.00725	.00362	.00362
Pipe Size	1	1	.00627	.00313	.00313
Length	1	1	.00615	.00307	.00307
Material Type	1	1	.00811	.00406	.00406
Piping Support Needs	1	1	.01099	.00550	.00550
Electrical/Electronics Considerations					
Cable					
Length	1	1	.00641	.00321	.00321
Size	1	1	.00653	.00326	.00326
Connections/Hookups	1	1	.02100	.01050	.01050
Wireways	1	1	.01661	.00831	.00831
HVAC Considerations					
Ducting					
Size	1	1	.00320	.00160	.00160
Length	1	1	.00324	.00162	.00162
Material Type	1	1	.00291	.00146	.00146
Configuration Changes	1	1	.00714	.00357	.00357
Equipment Installation	1	1	.01439	.00719	.00719
Insulation	1	1	.01022	.00511	.00511
		SUMS:	1.00000	.47740	.52260

Figure 5-4 - Producibility Evaluation Sheet; Two Design Alternatives

6.0 THE DECISION MAKING PROCESS

6.1 GENERAL

Although it is important to know the non-recurring cost of construction of a design alternative, that knowledge in itself is not sufficient to justify a decision to build that alternative. A final decision to approve or disapprove the implementation of any design change involves answering the following questions.

How much will it cost (or save) to implement this change?
How will the schedule be impacted?
What risk is involved?
How will the ship's performance be affected?

Getting good answers to these questions is not simple, but the most difficult task in making the decision is in evaluating the answers, or more correctly, in properly weighting and balancing the answers, since the answers are not normally expressed in comparable units of measures. Because the AHP process is precisely designed to accomplish this type of decision making, the authors proceeded to develop the necessary hierarchy and weighting factors.

6.2 IDENTIFICATlON OF CRITERIA

Cost, Schedule and Risk. The cost, schedule and risk elements were relatively simple to determine, but performance parameters represented a greater difficulty, since there have been so many prior efforts with significantly different results. The lower level criteria for cost, schedule and risk were selected from those used in several past shipbuilding programs, based on the authors' experience.

6.2.1 Cost Criteria.

The cost criteria related to shipbuilding programs are listed below.

- Recurring Predelivery Costs (Producibility)
  - See Figure 5-2
- Nonrecurring Predelivery Costs
  - Program management
  - Design and engineering
  - Production planning
  - Production aids
  - Disruption
  - Delay
- Postdelivery costs
  - Operational costs
  - Consumables
  - Personnel
  - Maintenance
  - Growth/upgrade costs

6.2.2 Schedule Criteria

The following list identifies the lower tier elements of the Schedule criterion.

- Design/Engineering Schedule
- Procurement Schedule
- Construction Schedule

6.2.3 Risk Criteria

The risk criterion is described by the following list of lower tier criteria.

- Maturity of Technology
- Yard Experience
- Degree of development required
- Confidence in Cost estimate
- Confidence in Schedule estimate

6.2.4 Performance Criteria

An initial listing of the lower level elements of a hierarchy of performance criteria was prepared and circulated among numerous individuals who have been directly involved in naval ship design programs, including line officers in requirement setting billets, personnel in ship acquisition program offices and ship design managers. That first listing was revised in response to the comments received and the revised listing was recirculated. Although there was not total agreement, the revised listing was generally accepted. The performance criteria selected are listed below. Certain of these, such as payload carrying capacity, would likely have several lower level tiers, particularly for warships.

- Operational capability
  - Payload carrying capacity
  - Payload effectiveness
- Mobility
  - Speed
  - Endurance
  - Maneuverability
- Availability
  - Reliability
  - Maintainability
  - Ability to operate in extreme environments
- Survivability
  - Ability to avoid detection
  - Ability to operate after damage
- Operational efficiency
  - Manning
  - Habitability
  - Safety
- Future growth margin
  - Weight margin
  - KG margin
  - Volume margin (Density)
  - Modularity

6.3 CRITERIA WEIGHTING

6.3.1 Cost, Schedule and Risk.

Having established the hierarchy, the next step in the process was to determine weighting factors for each of the elements in each tier. The cost, schedule and risk criteria were included in a questionnaire similar to that represented by Figure 5-1, in order *to* obtain the

	USE	<-----LEVEL-----> 1	2	3	COMB
1. COST		.1731			.17310
1.1 Recurring Predelivery Construction Cost			.3334		.05771
1.2 Non-Recurring Costs; predelivery			.3333		.05769
1.2.1 Design and Engineering	.04327			.7500	.04327
1.2.2 Production planning	.00577			.1000	.00577
1.2.3 Production Aids/Tooling	.00288			.0500	.00288
1.2.4 Disruption	.00288			.0500	.00288
1.2.5 Delay	.00288			.0500	.00288
1.3 Postdelivery Costs			.3333		.05769
1.3.1 Operational Costs	.01442			.2500	.01442
1.3.2 Consumables	.01442			.2500	.01442
1.3.3 Personnel	.01442			.2500	.01442
1.3.4 Maintenance	.01442			.2500	.01442
2. SCHEDULE CRITERIA		.1076			.10760
2.1 Design/Engineering Schedule	.03159		.2936		.03159
2.2 Equipment/Material Procurement Schedule	.02369		.2202		.02369
2.3 Construction Schedule	.05232		.4862		.05232
2.4 Test and Trials Schedule	.00000		.0000		.00000
3. RISK CRITERIA		.3200			.32000
3.1 Maturity of Technology	.12867		.4021		.12867
3.2 Yard Experience	.09539		.2981		.09539
3.3 Confidence in Cost Estimate	.05114		.1598		.05114
3.4 Confidence in Schedule Estimate	.04480		.1400		.04480
4. PERFORMANCE CRITERIA	.39940	.3994			.39940

Figure 6-1 - Decision Making Weighting Factors

factors. The results from the questionnaires were fed into computer programs that were developed to analyze the data. Since not all of the individuals who received the questionnaire were asked to identfy the ship type or design phase to which their answers referred, the figures provided in Figure 6-l represent an overall weighting for ships in general. The value of 0.0000 is shown for the weighting of test and trials schedule because that criterion was not included in the questionnaires, but was later recognized as a one that should have been included. A copy of the questionnaire used is contained in the Appendix. Copies of the programs used to analyze the data are provided in Reference (l).

6.3.2 Performance.

The weighting for the Performance criteria was obtained in a separate questionnaire, distributed at a different time horn that for the other criteria. The distribution list was the same one that was used to develop the Performance hierarchy. The respondents to this questionnaire were asked to identfy the ship class and design phase to which their answers were applicable. Since virtually all of the respondents were involved in the early stages of the ship

SHIP PERFORMANCE CRITERIA	CVN	DD	FFG	SHALL COMBATANT	AMPEIS	MGM5	AMY	RGM6
Operational Capability	.7009	.5971	.4947	.3326	.2326	.5205	.6074	.5399
Operational Efficiency	.2020	.2106	.3808	.5278	.0543	.2564	.3033	.2665
Future Growth Margin	.0971	.1924	.1246	.1396	.7131	.2231	.0893	.1936
Operational Capability								
Payload Carrying Capacity	.0666	.1293	.0971	.2093	.0563	.1057	.1252	.1095
payload Effectiveness	.3252	.3030	.3090	.2474	.3021	.3138	.3509	.3222
Mobility	.0362	.1194	.1178	.1629	.0373	.0838	.0766	.0832
Availability	.1814	.2516	.3483	.2460	.3021	.2752	.3404	.2874
Survivability	.3907	.1967	.1279	.1344	.3021	.2215	.1069	.1977
Mobility								
Speed	.4444	.3174	.2444	.4891	.2326	.3468	.2120	.3216
Endurance	.4444	.5110	.5070	.3296	.7131	.5103	.6280	.5318
Manouverability	.1111	.1716	.2486	.1813	.0543	.1429	.1600	.1466
Availability								
Raliability	.6047	.5508	.5677	.3041	.5589	.5570	.5082	.5495
Maintainability	.1047	.1393	.2377	.1206	.3829	.1929	.2583	.2029
Ability/Environn Extremes	.2906	.3099	.1946	.5753	.0582	.2501	.2334	.2477
Survivability								
Ability/Avoid Detection	.2743	.7306	.6667	.7388	.5000	.5870	.4654	.5671
Ability/Operate Damaged	.7257	.2694	.3333	.2612	.5000	.4130	.5346	.4329
Operational Efficiency								
Manning	.7142	.3768	.4396	.6042	.4040	.5220	.3479	.4929
Habitability	.1429	.2066	.1118	.0729	.0687	.1173	.1083	.1169
Safety	.1429	.4166	.4486	.3229	.5273	.3607	.5439	.3902
Future Growth Margin								
weight Margin	.3214	.2460	.1824	.2557	.0763	.2184	.1852	.2151
KG Margin	.3214	.1582	.4206	.2733	.6097	.3628	.2995	.3558
Volume Margin (Density)	.3214	.2060	.2157	.2292	.1294	.2370	.1501	.2223
Modularity	.0357	.3898	.1813	.2417	.1846	.1818	.3652	.2068

Figure 6-2 - Performance Criteria Weighting Factors By Stip Type

design process, (when performance variation tradeoffs may still be made) the results are most representative of those phases. Figure 6-2 provides the results of this effort. Values were obtained for Aircraft Carriers (CVN), Destroyer/Cruisers (DD), Frigates (FFG), Small Combatants and Amphibious ships, as well as for "any" ship. The column headed NGM5 contains the normalized geometric mean of the values given in the first 5 columns. The column headed NGM6 includes the values in the "Any" column as well.

6.4 APPLICATION

Once the hierarchy that is appropriate to the ship type has been established, and the weighting factors have been determined, the choice between competing design alternatives becomes a matter of evaluating each alternative against each criterion in the hierarchy and selecting the alternative which achieves the highest overall weighting factor. In most cases, there will be relatively few criteria that actually are involved, and the process will be very simple.

Despite the fact that it is preferable to have more than two alternatives to evaluate simultaneously, it is most likely that only two wilI exist. Simple spreadsheet forms have been

		SUPERIORITY FACTORS		FINAL WEIGHTS	
CRITERIA	WEIGHTING FACTOR	PIPE FITTINGS	PIPE BENDING	PIPE FITTINGS	PIPE BENDING
COST					
Recurring Cost (Producibility)	.0577	.4774	.5226	.0275	.0301
Non-Recurring Pre-Delivery Cost					
Design and Engineering	.0293	1.0000	1.5000	.0117	.0176
Production Planning	.0163	1.0000	1.1000	.0078	.0085
production Aids/Tooling	.0024	.5000	.5000	.0012	.0012
Disruption	.0042	.5000	.5000	.0021	.0021
Delay	.0055	.5000	.5000	.0028	.0028
Service Life Cost					
Personnel	.0150	.5000	.5000	.0075	.0075
Consumables	.0189	.5000	.5000	.0094	.0094
Maintenance	.0238	1.0000	2.0000	.0079	.0159
SCHEDULE					
Design/Engineering Schedule	.0297	.5000	.5000	.0149	.0149
Equipment/<aterial Procurement School	.0218	.5000	.5000	.0109	.0109
Construction Schedule	.0504	.5000	.5000	.0252	.0252
Test and Trials Schedule	.0056	.5000	.5000	.0028	.0028
RISK					
Maturity of Technology	.1287	.5000	.5000	.0643	.0643
Yard Experience	.0954	.5000	.5000	.0477	.0477
Cost Estimate Confidence	.0511	.5000	.5000	.0256	.0256
Schedule Estimate Confidence	.0448	.5000	.5000	.0224	.0224
PERFORMANCE	.3994	.5000	.5000	.1997	.1997
	1.0000			.4914	.5086

Figure 6-3 - Design Selection Calculation Sheet

developed for comparing two or three (1). It would be simple to generate similar forms for evaluating additional alternatives simultaneously. Figure 6-3 illustrates the use of the form for evaluating two alternatives, namely the decision to use pipe fittings or to bend the pipe.

Although the pipe bending approach was identified as the more producible, the other criteria which control the decision making process must be considered. The factors for recurring cost have been taken from the results of the producibility evaluation, Figure 5-2.

Given that the ship's performance will *not* likely be noticeably affected by either choice, the evaluation is limited to the other factors. The non-recurring cost of modifying drawings, equipment lists, and work instructions to reflect the change from fittings to bending must be assessed against the bending method, but since these costs will be spread over many manholes and several ships, the allocated cost to any one ship will be small. A factor of superiority of 1.5 has been assigned to the fitting method, Alternative 1, for design and engineering, and a factor of 1.1 for production planning. If estimates of cost had been made, that "hard" data could have been used to generate the factors used.

More joints exist in the fitting method, making it more likely that a maintenance problem will occur during the service life of the ship. A factor of 2 was assigned to Alternative 2. If several persons had been asked to make judgments on these criteria, their combined values would have been determined before being entered into the form in Figure 6-3.

With these data entered into the form, the overall values for Fittings and Bending, shown at the bottom of the form in Figure 6-3, become .4914 and .5086, respectively, making the bending choice the preferred alternative from the overall perspective as well as from the standpoint of producibility alone.

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7.0 CONCLUSIONS AND ACKNOWLEDGMENTS

7.1 CONCLUSIONS

The authors consider that the methods presented herein are logical, straightforward and easy to use. The validation tests have yielded results that are consistent with the findings of the shipyards from which the design alternatives were obtained. While the quantitative data has not been sufficiently tested to conclusively prove the degree of accuracy which the methods provide, the data is considered to be of at least first order accuracy. Requests from shipyards for comments have not yielded any negative responses.

The techniques have been used only on rather elemental evaluations to date. Their application to these has proven very easy to accomplish and the results have been apparently accurate. Although an application of either technique to a large scale ship design alternative has not yet been tried, it is expected that the larger scale problems will be found to be made up of numerous elements, each of which can be treated with the techniques presented herein.

A familiarity with ship production processes is certainly helpful when using the CECOP programs, but the questions that must be answered are explicitly stated on the forms. It seems apparent that even a novice user would quickly gain familiarity with the information needed to fill in the forms, and thus that the forms will be useful to designers and managers involved with early design stage decision making as well as during the detail design process.

The authors have found that there are individuals in most organizations who have at least some degree of familiarity with the AHP method. The computer programs that accompany Reference (1) will allow the necessary calculations to be made at any desk top or laptop computer. Should any questions arise in applying these techniques to specific shipbuilding, overhaul or repair projects, it will be easy to find sources of solutions.

7.2 ACKNOWLEDGMENTS

The authors are indebted to Mr. and Mrs. Kenneth Borchers for their initial development of the questionnaires used to perform the pairwise comparisons, from which the weighting factors are obtained, and for the initial development of the Basic programs used for evaluating the results from the questionnaires. The support and participation of each of the shipyards which provided producibility study data for evaluating the methods proposed are also acknowledged, with particular thanks to Ingalls Shipbuilding Division, Bath Iron Works and Saint John Shipbuilding Ltd. Finally the authors wish to express great appreciation to the many individuals in shipyards, NavSea, SupShips offices, SP-4 and elsewhere, who answered the questionnaires, and provided suggestions and guidance during the course of this effort.

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APPENDIX A

COMMENTS FROM

SHIPYARD AND SUPSHIPS PERSONNEL

DURING VISITS

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COMMENTS FROM SHIPYARD AND SUPSHIPS PERSONNEL DURING VISITS

1. This shipyard makes producibility change proposals when they are advantageous to this shipyard as a whole and not simply to the current program. This shipyard has to consider schedule impacts and other projects when reviewing producibility changes.
2. This shipyard only prepares detailed producibility change cost estimates for claims and formal change orders. Internal producibility changes are not estimated in detail.
3. This shipyard is not required to and does not submit the majority of producibility changes which they make to the Navy.
4. NavSea's many approval layers for producibility changes frustrates and chokes off many ideas.
5. NavSea response times are excessively slow.
6. NavSea needs a better system for incorporating improvements suggested by the shipyards in future ship designs.
7. NavSea doesn't listen to input from the shipyards regarding schedule or producibility.
8. Value Engineering is the kiss of death.
9. The best way to incorporate producibility is to include production early in the contract and detail design stages.
10. Producibility is a dead issue when the drawings are due at the production trades.
11. There are two levels of producibility. The macro consisting of the overall design during contract (and preliminary) design and the micro during the detail design.
12. Thorough evaluation of producibility requires detailed cost estimates of alternative methods of construction.
13. Suggested Criteria for evaluating producibtity alternatives are
    a. Is development in-house or by subcontractor required?
    b. Which alternative requires the least time?
    c. Is the work to be done off ship or on board?
    d. Which represents the lowest schedule risk?
    e. Which represents the lowest cost risk?
    f Have cost estimates prepared by cost estimators, not engineers. (Engineer's estimates are always too optimistic.)
    g. Which is the lowest cost?
14. The greatest savings in producibility would flow from national standards for shipbuilding. Now shipyards prepare standards individually but standards prepared by an overall body such as the SNAME Standards Panel is preferable. This would require Navy acceptance and support, but the savings would be considerable.
15. CAD systems help production move into design as they allow production to use the engineering drawings to prepare sketches and provide direct feedback to engineering.

16. NavSea should either carry ship designs to greater detail or pull back. The Navy is in the worst position now by specifying *too* much but not carrying the design far enough to remove all of the errors. For noncombatants, NavSea should reduce design time and the level of detail and shift to shipyard design.
17. NavSea designs to absolute minimum weights. This prevents standardization% and leaves no margin to handle errors.
18. NavSea structural designs include too many small parts.
19. NavSea designs specifying T-bars cut from I's are wasteful of both material and the labor to cut and then straighten the webs. NavSea should shift to bulb shapes. NavSea is in a position to shift to bulb shapes by either pressuring or encouraging the US steel industry to provide them by a large government purchase and then providing them as GFM to the shipyards or by asking Congress to permit the use of imported bulb shapes.
20. Light plating is costly due to distortion caused by welding. NavSea should either use heavier plating or intermittent welding to reduce costs.
21. NavSea should maximize automatic welding by reducing the variations in shell plating thickness.
22. NavSea should design for decreased weld lengths. Studies at Burmeister Wain demonstrated a marked reduction in costs accompanying engineering efforts aimed at reducing weld lengths.
23. This shipyard is using alternate fillet sizes based upon a Newport News study *to* reduce 60 degree bevels to 15 degrees and thereby reduce multiple passes, weld metal weight, grain grow the size of the heat affected zone and distortion. However, the yard has had to get NavSea approval to use the welding procedure on each project.
24. NavSea should design arrangements for more unit outfitting by grouping equipment and piping into units.
25. NavSea repair personnel do not accept new construction techniques developed *on* construction projects.
26. NAVSEA designers are structure rather than process oriented. There is a need for concurrent engineering in NAVSEA.
27. A shipyard must balance the cost of making a producibility change against the total anticipated savings.
28. An expanded and improved reference system on the structure reduces costs of construction, improves accuracy and identifies mistakes early in the process. NAVSEA should make it a contract requirement.
29. NAVSEA should design to reduce the number of different parts, including chocks, clips and pipe sizes.
30. Design for automatic welding.
31. Design for piping units.
32. The testing required by many MilSpecs is excessive. Why are there two specs for certifying welders, MilSpec and ABS?
33. There are too many meetings.

34. Dimensional tolerances are misapplied.
35. The NAVSEA cost model grossly misjudged the effects on construction costs of lowering the deck heights on ship X.
36. Machinery packages and distributive system designs were flops on ship X.
37. Rectilinear bulkheads on ship X were a producibility success. This initiative is a very synergistic “win-win”. Teamwork with NAVSEA and the shipyards involved did it.
38. SSES (Ship Systems Engineering Standards for VLS) application on ship X failed. Everyone went hog wild with over-specified combat system tolerances which were totally unneeded.
39. Steel-space-steel “secondary sheathing” failed in producibility. No one apparently took the time to see the whole process of installation!
40. Pet peeve Lack of class-to-class standardization. Prime examples: switchboards, foundation attachments. Designers must look at previous ships harder!
41. Success Stories: The DDG mast, the collective protective system, transverse stiffeners on top of deck in radar room, general structural design, foundation designs on FFG-7.
42. Trust the shipbuilder input earlier.
43. Develop institutional memory: Standardize components much more.
44. Prove out any new designs with the vendor community with USN research.
45. If you can combine everyone’s perspective, it can be kept *a* simple design.
46. There is no such thing as improved producibility by adding on; adding on is not simple design, it is patchwork.
47. Never call for copper pipe, use copper-nickel.
48. Different factors affect producibility such as the stage of the project, the available equipment and the training level of the workers. The best way to reduce costs is to use the type of construction favored by the shipyard. NAVSEA should simplify the design to reduce costs such as using fewer plate thicknesses in the hull design.
49. A producibility suggestion can represent disruption and has to be analyzed from the performance aspect to see if it is really as good as the baseline and if there are enough benefits to warrant going through the ABS and Navy approval process.
50. NAVSEA lacks production knowledge.
51. No one in the NAVSEA design team is responsible for cost. The only career threat to NAVSEA designers is if something breaks, not how much is spent to avoid failure. An example is the titanium pumps in the ship’s specs.
52. NAVSEA optimizes the design by individual systems, not by the whole ship. The complete ship design should be integrated and optimized.
53. NAVSEA specs try to paraphrase ABS and USCG specs in lieu of simply referencing the specs which are known to all shipyards. Frequently, the paraphrasing creates errors in or omits parts of the original specs.
54. NAVSEA should plan distributive system runs to insure that they can be run and are not causing needless expense.

55. The level of detail in NAVSEA contract design is uneven. The structural design goes to too great a level of detail while distributive systems do not include enough.

56. The offshore industry provides the shipyard with a complete set of working drawings. NAVSEA should try to have working drawings prepared under contract before the construction contract is bid and awarded.

57. The equipment available affects producibility and costs. For example, the ship's piping design was limited to 5D bends. While this may be a limitation in some yards, this requirement increases the number of fittings and small pieces which must be used and thereby increases costs. Other yards save piping costs by the use of a 2D bending machine.

58. NAVSEA should review the standard drawings to improve producibility of the designs. Some of the drawings require very costly construction techniques when cheaper ones will do as well. Some examples: the design of gratings for the anchor chain locker, the Multi Purpose Gas Cylinder Storage Racks, Drawing No. 518427, and ammunition (pyrotechnic) lockers.

59. A rule of thumb to evaluate the cost of fabricating an item is to double the cost at each operation on a piece part.

60. NAVSEA should require a build strategy from every competing shipyard based ***on the* preliminary** design. Then multiple contracts for the contract design should be awarded and the construction contract awarded to the best.

61. Fiber optics can save costs but won't be fully effective until a standardized control system language is adopted which will permit a common bus to be used.

62. The shipyard has problems with corporate memory for material items such as the use of CRES pipe for lube oil and hydraulic oil to save on flushing costs.

63. NAVSEA should standardize the number and types of nuts and bolts specified.

64. Shipyards may be able to improve productivity by changes in working schedules to keep the yard operating seven days a week.

6.5. It is sometimes difficult to get the shipyard's engineering people to change when a better (cheaper) way to design something is proposed by operations. The shipyard engineering people have adopted NAVSEA attitudes.

66. You can't get a cost saving ECP through the system.

67. The yard is receiving about 2000 changes per week.

68. The steel-space-steel protective system on the ship has a serious impact on costs due to the difficulty of fastening other items to the bulkheads.

69. The bow compartment on the ship is so high that the lights must be mounted on long legs which require special bracing.

70. The tight spaces for routing the distributive systems are driving up costs.

71. This shipyard uses larger unit sizes, which reduces welding and allows for more preoutfitting.

72 Shipyard has found that cost is not dependent on steel weight in the novel hull form.

73 Shipyards are having trouble in coordinating the efforts of various subcontractors to avoid interferences. One yard has recently gone from field routing of 2 inch and below to field routing of piping 3 inches and below. In addition, yard installed the ducting first and now has to run piping around it.

74 NAVSEA apparently did not make a distributive system design and may not have realized that the extremely restrictive bulkhead penetration specifications make the routing problem very diflicult. This has increased the construction cost of the ship.

75. The lack of production knowledge by the designers is the basic problem. CAD systems aggravate the problem. The design data can flow directly to the shops from the designers, but the CAD computer can’t think. Designers, through lack of experience are designing parts which cannot be built or are needlessly expensive to fabricate.

76. The primary solution is to have the designs reviewed by personnel with production knowledge. NAVSEA however, doesn’t allow enough time between the issuance of the specs and the start of construction for a producibility review. Personnel from the Supervisor of Shipbuilding offices and the repair facilities should attend NAVSEA spec reading sessions.

77. NAVSEA’s corporate memory resides in individuals. With the turnover in NAVSEA, memory is lost. It is important for the NAVSEA designers to know the roots of the equipment and designs they are specifying to avoid repeating mistakes. Know the past history, problems encountered and fixes. Don't blindly copy past mistakes.

78. Many of NAVSEA’s specifications and standard drawings date from World War II. They need to be updated to reflect current production processes and capabilities.

79. NAVSEA designers should meet with vendors to identify cheaper, faster designs or equipment. When buying equipment, buy the technology as well. No vendor lives forever.

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APPENDIX B

PRODUCIBILITY CRITERIA SURVEY

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PRODUCIBILITY
CRITERIA SURVEY

AUGUST 16,1990

WILKINS ENTERPRISE/COASTAL TECHNOLOGY ASSOCIATES
BORCHERS & ASSOCIATES

PART 1: INSTRUCTIONS

This survey asks a series of questions which when analyzed, will assist the industry in developing weighted criteria fo the evaluation of the producibility aspects of ship design and *construction. Exhibit 1* presents a hierarchy of the overal parameters which bear on ship design and construction. This survey will focus on the producibility segment of the Producibility hierarchy. Follow-on studies will develop the other segments

EXHIBIT 1
PRODUCIBLITY CRllERIA

- 3. PRODUCIBILITY PARAMETERS
  - 3.1. Arrangement
    - 3.1.1. Enhanced Packaging of Componants
    - 3.12. Direct Routing of Distributive Systems
    - 3.1.3. Interference Avoidanoe
    - 3.1.4. Volumetric Density
  - 3.2. Simplicity
    - 3.2.1. Number of Pieces
    - 3.2.2. shape of Pieces
      - 3.2.2.1. Flat Plate
      - 3.2.22. Simple Curvature
      - 3.2.2.3. Rectangular Configurations
    - 3.2.3. Accessibility
  - 3.3. Material
  - 3.4. Standardization
    - 3.4.1. Component Standardization
      - 3.4.1.1. Structural
        - 3.4.1.1.1. Plate thickness
        - 3.4.1.1.2 Shape
        - 3.4.1.1.3. Sizes
      - 3.4.12. Outfitting
      - 3.4.1.3. Equipment
    - 3.4.2 Process Standardization

EXHIBIT 1 (CONTINUED)

3.5. FabrioaIion/Assembly Requirements
- 3.5.1. Welding Considerations
  - 3.5.1.1. Process Required
    - 3.5.1.1.1. Automation Achieveved
    - 3.5.1.1.2. Position Optimization
    - 3.5.1.1.3. Heet Treatment
  - 3.5.1.2. Configuration
    - 3.5.1.2.1. Weld Length
    - 3.5.1.2.2. Fillet Configuration.
      - 3.5.1.2.21. Plate Bevel Angles
      - 3.5.1222. Number of Passes
    - 3.5.1.23. Weld Type
- 3.5.2 Sheetmatal Considerations
  - 3.5.2.1. Configuration
  - 3.5.2.2 Process Required
- 3.5.3. Machining Considerratlons
  - 3.5.3.1. Use of common foundations
  - 3.5.3.2. **Mounting Details**
  - 3.5.3.3. Installation
- 3.5.4. Pipefitting Considerations
  - 3.5.4.1. Pipe Size
  - 3.5.4.2. Length
  - 3.5.4.3. Material
  - 3.5.4.4. Process
    - 3.5.4.4.1. Use of Bends vs Fittings
    - 3.5.4.4.2 Connection Type
  - 3.5.4.5. Piping Support Needs

EXHIBIT 1 (CONTINUED)

3.5.5. Electrical/Electronics Considerations
    3.5.5.1. WireWays
    3.5.5.2 Cable
        3.5.52.1. Length
        3.5.5.2.2 Size
    3.5.5.3. Connections/Hookups
3.5.8. HVAC Considerations
    3.5.6.1. Ducting
        3.5.6.1.1. Size
        3.5.6.1.2 Length
        3.5.0.1.3. Material
        3.5.6.1.4. Configuration Changes
    3.5.6.2 Equipment Installation
    3.5.6.3. Insulation

The general format is **to** present definitions of the attributes which will be evaluated, followed by a form on which **you** are **asked** to make judgements. Often, reference back *to* the producibility **hierarchy, Exhibit 1, Will answer questions you may have during the evaluation.**

The survey asks you to compare two attributes and make an “expert" judgement as to which is most beneficial in term: of benefit and/or cost to the ship. Definition of the exact emphasis is given in each case just above the area you will mark

Following are three examples which compare the same two attributes to illustrate three differing judgments. The two attributes used in the examples, which will be evaluated from the standpoint of producibility, are Arrangement and Standardization.

Arrangement

> **Those characteristics of the basic design which through elective placement of systems and components contribute to lower and/or more efficient use of production resources. Including manpower, equipment, material, facilities, and schedule. Next tier elements are: ENHANCED PACKAGING OF COMPONENTS, DIRECT ROUTING OF DISTRIBUTIVE SYSTEMS, INTERFERENCE AVOIDANCE, and VOLUMETRIC DENSITY.**

Standardization

> **Those characteristics of design which contribute to**greater standardization **within** *a single* ship design. **Next tier elements are: COMPONENT STANDARDIZATION and PROCESS STANDARDIZATION.**

Example No. 1

In this first example, your judgement is that the two attributes are equal in terms of their contribution to PRODUCIBILITY. You should circle the-[l] in the center of the form.

Whgich of the following criteria is
more important for Producibility trade-off studies
Please circle your judgement which reflects
the degree of difference on each line.

More Important <————————> **No Difference** <————————> **More Important**

Standardization 9——8——7——6——5——4——3——2——[✓ [1]]——2——3——4——5——6——7——8——9 **Arrangement**

Example No. 2
You are comparing the same two activities.
in this example, it is your opinion that Standardization is a more important attribute. You believe that it should be giver **greater 'Weight' than Arrangement in trade-off studies. Also, you believe there is a great** degree of difference between the two attributes. **In** this case, **you identiffy that difference by a circle of the** -7- closest to the attribute Standardization.

More Important <————————> No Difference <————————> More Important

Standardization 9——8——[✓ 7]——6——5——4——3——2——1——2——3——4——5——6——7——8——9 Arrangement

Example No. 3
You are **comparing the same two attributes**
In this example, it **is your judgement that** Arrangement is more important for producbility trade-off studies. However, you also believe that the degree of difference is very slight. You indicate this with **a circle of** -2-, closest to the attribute Arrangement

More Important <————————> No Difference <————————> More Important

Standardization 9——8——7——6——5——4——3——2——1——[✓ 2]——3——4——5——6——7——8——9 Arrangement

You should now be ready to begin the survey. You must mark each comparison to indicate where an attribute has greater value, or contributes greater benefit, to the Producibility of the design **and/or construction process. Should yo have a question as to the meaning of a term, you can refer to the definition and/or the overall hierarchy. It is important that you mark every line. Absence of a judgement will be assumed to indicate that you have considered the two attributes equal**

PART 2: SURVEY QUESTIONNAIRE

Producibility Criteria

L Arrangement

Those characteristics of basic design which through elective Placement of systems and components contribute to lower and/or more efficient use of production resources, including manpower, equipment, material, facilities, and schedule. Next tier elements are: ENHANCED PACKAGING OF COMPONENTS, DIRECT ROUTING OF DISTRIBUTIVE SYSTEMS, INTERFERENCE AVOIDANCE, and VOLUMETRIC DENSITY.

2. Simplicity

Those characteristics of the basic design which simplify its construction. Next for elements are: NUMBER OF PIECES, SHAPE OF PIECES, AND ACCESSIBILITY.

3. Material

The cost of procuring the materials specified, structural materials, outfit materials and equipment

4 Standardization

Those characteristics of design which contribute to *greater standardization* within a single ship design. Next tier elements are: COMPONENT STANDARDIZATION and PROCESS STANDARDIZATION.

5. Fabrication/Assembly Requirements

Those characteristics of the basic design which contrubute to lower or more efficient use of production resources to l accomplish fabrication and/or assembly of equipments,systems, or ship modules. Mest tier elements are: WELDING CONSIDERATIONS, SHEETMETAL CONSIDERATIONS, MACHINING CONSIDERATIONS, PIPEFITTING CONSIDERATIONS, ELECTRICAL/ELECTRONIC CONSIDERATIONS, and HVAC CONSIDERATIONS.

Producibility Criteria Survey

**Which of the following criteria is
more important for trade-off studies which focus on Producibility?
Please circle your judgement which reflects
the degree of difference on each line.**

	More Important <————> No Difference <————> More Important	
Arrangement	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	Simplicity
Arrangement	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	Material
Arrangement	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	Standardization
Arrangement	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	Fab/Assembly
Simplicity	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	Material
Simplicity	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	Standardization
Simplicity	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	Fab/Assembly
Material	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	Standardization
Material	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	Fab/Assembly
Standardization	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	Fab/Assembly

L Arrangement

Those characteristics of the basic design which through elective placement of systems and components contribute to lower and/or more efficient use of production resources, including manpower, equipment, material, facilities, and schedule. Next tier elements are: ENHANCED PACKAGING OF COMPONENTS, DIRECT ROUTING OF DISTRIBUTIVE SYSTEMS, INTERFERENCE AVOIDANCE, and VOLUMETRIC DENSITY.

1.1 Enhanced Packaging ofComponents

Those characteristics ofthe arrangement of equipment which enhance the ability of the shipyard to assemble and to related system components as a unit on a common foundation in a ship, and then to install thisunit onboard as a single assembly.

1.2. Direct Routing ofDistributive Systems

The characteristics of design which contribute to more direct routing of distributive systems. Dedication of specific volume to specified systems and location of equipment are examples which affect routing.

1.3. Interference Avoidance

Those characteristics of system arrangement which minimize the potential interference between structural elements, equipments, and/or components.

1.4. Volumetric Density

Those characteristics of design which result in the most effective use of volume, taking installation and maintenance requirements into consideration. Too high a volumetric density will degrade producibility. This is related to other criteria such as interference avoidance but is distinguishable as an estimated ratio of available space to filled space for a give modular element

Producibility Criteria Survey

Which of the following criteria is
more important for trade-off studies which focuson Arrangement?
Place circle your judgement which reflects
the degree of difference on each line.

	More Important <————————> No Differences <————————>	More Important
Enhanced Packaging	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	Direct Routing
Enhanced Packaging	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	Interference Avoidance
Enhanced Packaging	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	Volumetric Density
Direct Routing	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	Interference Avoidance
Direct Routing	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	Volumetric Density
Interference Avoidance	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	Volumetric Density

20 Simplicity

Those characteristics of the basic design which simplify its construction. Next tier elements are: NUMBER OF PIECES, SHAPE OF PIECES, AND ACCESSIBILITY.

2.1. Number of PIeces

Those characteristics of design which minimizethe number of place partswhich have to be manufactured, tracked, assembled, and installed.

2.2 Shape of PIeces

Those characteristics of the basic hull design which contribute to the simplest shape consistent with providing the required operational and hydrodynamic performance. Next tier elements are: FLAT PLATE, SIMPLE CURVATURE, an RECTANGULAR CONFIGURATIONS.

2.21. Flat Plate

Those characteristics of the design which maximize the use of flat plate.

2.2.2. Simple Curvature

Those characteristics of the design which provide minimum, simple curvature, straight runs of distrubutive system: simple transitions, etc. For example: many hul lines can be straight in one direction and there for avoid double curvature surfaces in hull plating.

2.2.3. Rectangular Configurations

Those characteristics of the structure which maximize the use of right angle Intersection of pieces.

2.3. Accessibility

Those characteristics of the design which provide access for production and maintenance functions.

Which of the following criteria is more important for Producibility trade-off studies which focus on SIMPLICITY? Please circle your judgement which reflects the degree of difference on each line.

	More Important <————> No Difference <————> More Important	
Number of Pieces	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	Shape of Piece
Number of Pieces	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	Accessibility
Shape of Pieces	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	Accessibility

Which of the following criteria is
more important for trade-off studies which focus on Simplicity
with regard to the SHAPE OF PIECES?
Place circle your judgement which reflects
the degree of difference on each line.

	More Important <————————>	No Difference	<————————> More Important	
Flat Plate	9—8—7—6—5—4—3—2—	1	—2—3—4—5—6—7—8—9	Simple Curvature
Flat Plate	9—8—7—6—5—4—3—2—	1	—2—3—4—5—6—7—8—9	Rectangular Configurations
Simple Curvature	9—8—7—6—5—4—3—2—	1	—2—3—4—5—6—7—8—9	Rectangular Configurations

4. Standardization

Those characteristics of design which contribute to greater standardization within a single ship design. Next tier elements are: COMPONENT STANDARDIZATION and PROCESS STANDARDIZATION.

4.1. Component Standardization

Those characteristics of design which contribute to greater standardization of components. Next tier elements are: STRUCTUAL, OUTFITTING, and EQUIPMENT.

4.1.1. Structural

Those characteristics of design which contribute to greater use of common sizes and shape of components and equipment. Next tier elements are: PLATE THICKNESS, SHAPES, and SIZES.

4.1.1.1. Plate thickness

Those characteristics of design which contribute to greater use of standardized structural material. In this case the number of different plate thicknesses should be minimized.

4.1.1.2. Shapes

Those characteristics of design which result in less variety of plate shapes and maximize the use of standardized plate shapes.

4.1.1.3. Sizes

Those characteristics of design which result in less variety of plate sizes and maximize the use of standardized plate sizes.

4.1.2. Outfitting

Those characteristics of the overall design which maximize the use of standardized outfitting equipment, tools, procedures, and processes.

4.1.3. Equipment

Those characteristics of the overall design which maximize the use of standardized equipments. Examples of areas which are usually candidates are, pumps, motors, valves, etc.

4.2. Process Standardization

Processes those characteristics of design which maximize use of standard shipbuilding industry processes.

Which of the following criteria is
more important for Producibility trade-off studies which focus on Standardization
Please circle your judgement which reflects
the degree of difference on each line.

	More Important <———————>	No Difference	<———————> More Important	
Component Standardization	9—8—7—6—5—4—3—2—	1	—2—3—4—5—6—7—8—9	Process Standardization

Which of the following criteria is
more important for Producibility trade-off studies which focus on COMPONENT STANDARDIZATION?
Please circle your judgement which reflects
the degree of difference on each line.

	More Important <———————>	No Difference	<———————> More Important	
Structural	9—8—7—6—5—4—3—2—	1	—2—3—4—5—6—7—8—9	Outfitting
Structural	9—8—7—6—5—4—3—2—	1	—2—3—4—5—6—7—8—9	Equipment
Outfitting	9—8—7—6—5—4—3—2—	1	—2—3—4—5—6—7—8—9	Equipment

Which of the following criteria is
more important for Producibility trade-off studies which focus on STRUCTURAL STANDARDIZATION?
Please circle your judgement which reflects
the degree of difference on each line.

More Important <——————> No Difference <——————> More Important

Plate Thickness 9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9 Shapes

Plate Thickness 9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9 Sizes

Shapes 9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9 Sizes

5. Fabrication/Assembly Requirements

Those characteristics of the basic design which contribute to lowerormore efficient use of production resources to accomplish fabrication and/or assembly of equipments, systems, or ship modules. Next tier elements are: WELDING CONSIDERATIONS, SHEETMETAL CONSIDERATIONS, MACHINING CONSIDERATIONS, PIPEFITTING CUNSIDERATIONS, ELECTRICAL/ELECTRONIC CONSIDERATIONS, and HVAC CONSIDERATIONS.

5.1. Welding Considerations

Those characteristics of design which minimize the resources required to accomplish production welding functions: manpower, material, time, etc.. Next tier elements are: PROCESS REQUIRED, and CONFIGURATION.

5.2. Sheetmetal Considerations

Those characteristics of design which result in less need to use sheetmetal resources, including shop space,shop equipment, and trade labor. Next tier elements are: CONFIGURATION, and PROCESS REQUIRED.

5.3. Machining Considerations

Those characteristics of design which result in less need to use machining resources, including shop space,shop equipment, and trade labor. Next tier elements are: USE OF COMMON FOUNDATIONS, MOUNTING DETAILS, and

5.4. Pipefitting Considerations

Those characteristics of design which result in less need to use pipefitting resources, including shop space,shop equipment, and trade labor. Next tier elements are: PIPE SIZE, LENGTH, MATERIAL, PROCESS and SUPPORT NEEDS.

5.5. Electrical/Electronics Considerations

Those characteristics of design which result in less need to use electrical / electronic resources, including shop space,shop equipment, and trade labor. Next tier elements are: WIREWAYS, CABLE, and CONNECTIONS/HOOKUPS.

5.6. HVAC Considerations

Those characteristics of design which result in less need to use HVAC resources, including shop space,shop equipment, and trade labor. Next tier elements are: DUCTING, EQUIPMENT INSTALLATION, and INSULATION.

Producibility Criteria Survey

Which of the following criteria is
more important for Producibility trade-off studies which focus on
FABRICATION/ASSEMBLY REQUIREMENTS?
Please circle your judgement which reflects
the degree of difference on each line.

More Important <————————> No Difference <————————> More Important

Welding 9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9 **Sheetmetal**

Welding 9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9 **Machining**

Welding 9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9 **Pipefitting**

Welding 9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9 **Elec/Electronic**

Welding 9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9 **HVAC**

Sheetmetal 9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9 **Machining**

Sheetmetal 9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9 **Pipefitting**

Sheetmetal 9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9 **Elec/Electronic**

Sheetmetal 9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9 **HVAC**

Machining 9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9 **Pipefitting**

Machining 9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9 **Elec/Electronic**

Machining 9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9 **HVAC**

Pipefitting 9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9 **Elec/Electronic**

Pipefitting 9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9 **HVAC**

Elec/Electronics 9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9 **HVAC**

5.1 Welding Considerations

Those characteristics of design which minimize the resources required to accomplish production welding functions: manpower, material, time, etc.. Next tier elements are: PROCESS REQUIRED, and CONFIGURATION.

5.1.1. Process Required

Those characteristics of design which minimize the resources of the process required to accomplish production welding functions. Next tier elements are: AUTOMATION ACHIEVED, POSITION OPTIMIZATION, and HEAT TREATMENT.

5.1.1.1. Automation Achieved

Those characteristics of design which maximize the shipyard's ability to use processes for welding .

5.1.1.2. Position Optimization

Those characteristics of design which optimize the welding position to be used, with the order of preference being either automated or manual.

5.1.1.3. Heat Treatment

Those characteristics of design which result in minimized requirements for pre and post weld heat treatment as part of the specified welding process.

5.1.2. Configuration

Those characteristics of design which define and limit the welding process requirements: Next tier elements are: WELD LENGTH ,FILLET CONFIGURATION, and WELD TYPE.

5.1.2.1. Weld Length

Those characteristics of design which minimize the weld length required.

5.1.2.2. Fillet Configuration

Those characteristics of design which minimize the fillet size required. Next tier elements are: PLATE BEVEL ANGLES, and NUMBER OF PASSES.

5.1.2.2.1. Plate Bevel Angles

Those characteristics of design which enhance the use of simple welding procedures.

5.1.2.2.2. Number of Passes

Those characteristics of design which minimize the number of passes required for welding the design configuration.

5.1.2.3. Weld Type

Those characteristics of design which enhance use of more efficient use of welding types..

Which of the following criteria is
more important for Producibility trade-off studies which focus on WELDING?
Please circle your judgement which reflects
the degree of difference on each line.

	More Important <————> No Difference <————>	Mom Important
Process Required	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	**Configuration**

Which of the followingcriteria is
more important for trade-off studies which focus on Welding
with regard to the PROCESS REQUIRED?
Please circle your judgement which reflects
the degree of difference on each line.

	More Important <————> No Difference <————>	More Important
Automation Achieved	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	**Position Optimization**
Automation Achieved	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	**Heat Treatmen**
Position Optimization	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	**Heat Treatmen**

Which of the following criteria is
more important for Producibility trade-off studies which focus on Welding
with regard to the CONFIGURATION?
Please circle your judgement which reflects
the degree of difference on each line.

	More Important <——————> No Difference <——————>	More Important
Weld Length	9——8——7——6——5——4——3——2——1——2——3——4——5——6——7——8——9	Fillet **Configuration**
Weld Length	9——8——7——6——5——4——3——2——1——2——3——4——5——6——7——8——9	weld Type
Fillet Configuration	9——8——7——6——5——4——3——2——1——2——3——4——5——6——7——8——9	Weld Type

Which of the following criteria is
more important for Producibility trade-off studies which focus on Welding
FILLET CONFIGURATION?
Please circle your judgement which reflects
the degree of difference on each line.

	More Important <——————> **No Difference** <——————>	**More Important**
Plate Bevel Angles	9——8——7——6——5——4——3——2——1——2——3——4——5——6——7——8——9	**Number of Passes**

.2 Sheetmetal Considerations

Those characteristics of design which result in less need to use sheetmetal resources, including shop space, shop equipment, and trade labor. Next tier elements are: CONFIGURATION, and PROCESS REQUIRED.

5.2.1. Configuration

Those aspects of design which simplify the sheetmetal configuration.

5.2.2. Process Required

Those aspects of design which maximize use of most efficient processes for sheetmetal work, including cutting, forming, assembly and installation.

Which of the following criteria is
more important for Producibility **trade-off studies which focus on**
SHEETMETAL CONSIDERATIONS?
Please circle your judgement which reflects
the degree of difference on each line.

	More Important <----------------->	No Difference	<-----------------> More Important	
Configuration	9-------8-------7-------6-------5-------4-------3------2-----1	1	1-----2-------3-------4-------5-------6-------7-------8------- 9	**Process Required**

5.3. Machining Considerations

Those characteristics of design which result in less need to use machining resources, including including shop space, shop equipment, and trade labor. Next tier elements are:. USE OF COMMON **FOUNDATIONS, MOUNTING** DETAILS, and **INSTALLATION.**

5.3.1. Use of common foundations

Those characteristics of design which allow the use of common structural elements for mounting of several **equipment components.**

5.3.2 Mounting Details

Those characteristics of design which minimize the complexity of mounting details, including need for secial fasteners, need **for special** tools, number of **fasteners, etc.**

5.3.3. Installation

Those characteristics ofdesign which minimizethe complexity of the installation process for an equipment, system, or module.

Which of the following criteria is
more important for trade-off studies which focus on
MACHINING CONSIDERATIONS?
Please circle your judgement which reflects
the degree of difference on each line.

	More Important <——————> No Difference <——————> More Important	
Use **of Common Foundations**	9——8——7——6——5——4——3——2——1|1——2——3——4——5——6——7——8——9	**Mounting Details**
Use of Common **Foundations**	9——8——7——6——5——4——3——2——1|1——2——3——4——5——6——7——8——9	**Installation**
Mounting Details	9——8——7——6——5——4——3——2——1|1——2——3——4——5——6——7——8——9	**Installation**

5.4. Pipefitting Considerations

Those characteristics of design which result in less need to use pipefitting resources, including shop space, shop *equipment, and trade labor. Next tier elements are: PIPE* SIZE LENGTH, MATERIAL, PROCESS and SUPPORT NEEDS.

5.4.1. Pipe Size

Those characteristics of design which minimize the pipe size consistent with meeting requirements.

5.4.2. Length

Those characteristics of design which minimize the pipe length consistent with meeting requirements.

5.4.3. Material

Those characteristics of design which minimize the pipe material requirements consistent with meeting requirements.

5.4.4. Process

Those characteristics of design which allow the use of the most efficient pipefitting processes. Next tier elements are: USE OF BEND VS. FITTINGS, AND CONNECTION TYPE

5.4.4.1. Use of Bends vs Fittings

Those characteristics of design which minimize the need for pipefittings through the use of bends, consistor with the requirement for installation and maintenance of the piping systems.

5.4A.2 Connection Type

Those characteristics of design which allow the use of the least complex type of connection.

5.45. Piping Support Needs

Those characteristics of design which minimize the need for complex pipe hangers or other piping support Components.

Producibility Criteria Survey

Which of the following criteria is
more important for trade-off studies which focus on Sheetmetal
with respect to PIPEFITTING
Please circle your judgement which reflects
the degree of difference on each line.

	More Important <——————> No Difference <——————> More Important	
Pipe Size	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	Pipe Length
Pipe Size	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	Material
Pipe Size	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	Process
Pipe Size	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	Support Needs
Pipe Length	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	Material
Pipe Length	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	Process
Pipe Length	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	Support Needs
Material	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	Process
Material	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	Support Needs
Process	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	Support Needs

Which of the following cirteria is
more important for Producibility trade-off studies which focus on sheetmetal
pipefitting consideration with regard to PROCESS?
Please circle your judgement which reflects
the degree of differences on each line.

More Important <————————> No Difference <————————> More Important

Use of Bends vs. Fittings 9——8——7——6——5——4——3——2——1——2——3——4——5——6——7——8——9 **Connection Type**

5.5. Electrical/Electronics Considerations

Those characteristics of design which result in less need to use electrical/electronic resources, including shop space, shop equipment, and trade labor. Next tier elements are: WIREWAYS, CABLE, and CONNECTIONS/HOOKUPS.

55.1. Wireways

Those characteristics of design which minimize the number and length of wireways.

5.5.2. Cable

Those characteristics of design which minimize the size, length and/or cables required. Next tier elements are: LENGTH, and SIZE.

5.5.2.1. Length

Those characteristics of design which minimize the cable length.

5.5.2.2. Size

Those characteristics of design which minimize the cables size.

5.5.3. Connections/Hookups

Those characteristics of design which minimize the electrical connections for the equipment or system under evaluation, or simplifies their connections.

Producibility Criteria Survey

Which of the following criteria is
more important for Producibility trade-off studies which focus on
ELECTRICAL/ELECTRONIC CONSIDERATIONS?
Please circle your judgement which reflects
the degree of difference on each line.

	More Important <————> No Difference <————> More Important	
Wireways	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	Cable
Wireways	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	**Connections/ Hookup**
Cable	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	Connections/s Hookup

hich of the following criteria is
more important for Producibility trade-off studies which focus on electrical/electronics
with regard to the CABLE?
Please circle your judgement which reflects
the degree of differences on each line.

	More Important <————> No Difference <————> More Important	
Cable Length	**9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9**	**Cable Size**

5.6. HVAC Considerations

Those characteristics of design which result in less need to use HVAC resources, including shop space,stmp equipment, and trade labor. Next tier elements are: DUCTIiNG, EQUIPMENT INSTALLATION, and INSULATION.

5.6.1. Ducting

Those characteristics of design which result In less need for HVAC ducting. Next tier elements are: SIZE, and LENGTH.

5.6.1.1. Size

Those characteristics of design which minimize the size of HVAC ducting.

5.6.1.2. Length

Those characteristics of design which minimize the length of HVAC ducting.

5.6.1.3. Material

Those characteristics of design which allow the use of materials which require less labor for facilities to use it fabrlcation and/or assembly.

S.6.1.4. Configuration Changes

Those characteristics of design which minimize the number of size orshape changes throughout the ducting routing.

5.6.2 Equipment Installation

Those characteristics of design which simplify the HVAC installation, including need for special tools, trade skill *requirements, and trade labor..*

5.6.3. Insulation

Those characteristics of design which minimize the requirements for HVAC insulation, including insulation materia installation requirements, requirements for non-standard tools, non-standard processes, and special trade skills.

Which ofthe following criteria is
more important for trade-off studies which focus on
HVAC CONSIDERATIONS?
Please circle your judgement which reflects
the degree of difference on each line.

	More Important <————> No Difference <————> More Important	
Ducting	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	**Equipment Installation**
Ducting	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	**Insulation**
Equipment Installation	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	**Insulation**

Which of the following criteria is

Producibility Criteria Survey

Which of the following criteria is
more important for Producibility trade-off studies which focus on HVAC
DUCTING considerations?
Please circle your judgement which reflects
the degree of difference on *each line.*

	More Important <————> No *Difference* <————> More Important	
Size	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	*Length*
Size	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	Material
Size	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	Configuration Changes
Length	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	**Material**
Length	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	**Configuration Changes**
Material	9—8—7—6—5—4—3—2—1—2—3—4—5—6—7—8—9	**Configuration Changes**

APPENDIX C

SHIP SYSTEM PERFORMANCE ~ SURVEY

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SHIP SYSTEM PERFORMANCE PARAMETERS

0PERATIONAL CAPABILITY (EFFECTIVENESS)

- Payload Carrying Capacity
  - Individual Payloads Based on mission

- Payload Effectiveness
  - Effectiveness Measures
  - Onload/Offload Capability

- Mobility
  - Speed
  - Endurance
  - Maneuverability

- Availability
  - Reliability (HTBF)
  - Maintainability (MTTR)
  - Ability to Operate in Environmental Extremes
    - Seakeeping
    - Temperature Extremes
    - Other Conditions
      - Fog
      - Sandstorms

- Survivability
  - Ability to Avoid Detection
    - Various Signature Levels
  - Ability to Operate When Damaged
    - Damaged Stability
    - Shock Hardening
    - System Redundancy
    - Vital System Separation

OPERATIONAL EFFICIENCY

- Manning
- Habitability
- Safety

FUTURE GROWTH CAPABILITY

- Weight Margin
- KG Margin
- Volume Margin (Density)
- Modularity

SHIP PERFORMANCE PARAMETERS

Which of each of the pairs of Ship Performance parameters compared below has greater influence on the ship's ability to meet the mission requirements (is of more value to the ship's owner)? A 9 indicates very much greater, 7 much greater, 5 moderately greater, 3 somewhat greater, 1 equal value:

Operational Capability Operational Efficiency

9...8...7...6...5...4...3...2...1...2...3...4...5...6...7...8...9

Operational Capability Future Growth Capability

9...8...7...6...5...4...3...2...1...2...3...4...5...6...7...8...9

Operational Efficiency Future Growth Capability

9...8...7...6...5...4...3...2...1...2...3...4...5...6...7...8...9

Definitions:

Operational Capability describes a ship's ability to accomplish various missions. The elements to be considered within this parameter are the ship's payload carrying capability, the effectiveness with which that payload is delivered, the availability of the ship for accomplishing its missions, its survivability in various environments, the ship's onload/offload capability and its mobility.

Operational Efficiency describes the efficiency, in the use of resources, with which the ship's mission(s) is(are) carried out. The elements of operational efficiency are the manning level required, the habitability required and the safety by which the missions can be carried out.

Future Growth Margin describes the ease or difficulty with which a ship may be modified in the future in order to improve the existing operational capability or efficiency.

OPERATIONAL CAPABILITY

Which of each of the pairs of ship Operational Capability parameters compared below has greater influence on the ship's ability to meet the mission requirements (is of more value to the ship's owner)? A 9 indicates very much greater, 7 much greater, 5 moderately greater, 3 somewhat greater, 1 equal value:

Payload Carrying Capacity — Payload Effectiveness
9...8...7...6...5...4...3...2...1...2...3...4...5...6...7...8...9

Payload Carrying capacity — Mobility
9...8...7...6...5...4...3...2...1...2...3...4...5...6...7...8...9

Payload Carrying Capacity — Availability
9...8...7...6...5...4...3...2...1...2...3...4...5...6...7...8...9

Payload Carrying Capacity — Survivability
9...8...7...6...5...4...3...2...1...2...3...4...5...6...7...8...9

Payload Effectiveness — Mobility
9...8...7...6...5...4...3...2...1...2...3...4...5...6...7...8...9

Payload Effectiveness — Availability
9...8...7...6...5...4...3...2...1...2...3...4...5...6...7...8...9

Payload Effectiveness — Survivability
9...8...7...6...5...4...3...2...1...2...3...4...5...6...7...8...9

Mobility — Availability
9...8...7...6...5...4...3...2...1...2...3...4...5...6...7...8...9

nobility — Survivability
9...8...7...6...5...4...3...2...1...2...3...4...5...6...7...8...9

Availability — Survivability
9...8...7...6...5...4...3...2...1...2...3...4...5...6...7...8...9

Definitions:

Payload Carrying Capacity: The quantities of various cargos (mission related systems) carried. This category includes systems that are available for loading and unloading cargo. For warships, this would be the numbers of various weapon launchers (missile launchers, guns, torpedo tubes, etc.), the number of weapons (missiles, shells, torpedoes, etc.), the number of sensors of various types, the number of various communication systems, etc.

Payload Effectiveness: The Effectiveness of the cargos carried for the purpose intended. For commercial carriers, this would be the profitability of the various cargos carried, the speed of loading and unloading cargos, etc. For warships this would be the ability of each weapon system to accomplish its functions which could be measured in terms of probability of acquisition at a range of interest, probability of hit, etc. Ability to load and unload supplies, particularly while underway, would be included within this parameter.

Availability: The probability of the involved elements of the ship system to function successfully at the time they are required to function for successfully accomplishing each intended mission. Sub elements of Availability include Reliability, Maintainability and Ability to Operate in Environmental Extremes.

Survivability: The ability of the ship to function in various environments, including in a damaged condition. The sub-elements of Survivability are Ability to Avoid Detection and Ability to Operate When Damaged.

Mobility: The performance characteristics that relate to the degree of mobility of the ship, including Speed, Endurance, and Maneuverability.

MOBILITY

Which of the pairs of ship Mobility parameters compared below has greater influence on the ship's ability to meet the mission requirements (is of sore value to the ship's owner)? A 9 indicates very much greater, 7 much greater, 5 moderately greater, 3 samewhat greater, 1 equal value:

Speed   Endurance
9...8...7...6...5...4...3...2...1...2...3...4...5...6...7...8...9

Speed   Maneuverability
9...8...7...6...5...4...3...2...1...2...3...4...5...6...7...8...9

Endurance   Maneuverability
9...8...7...6...5...4...3...2...1...2...3...4...5...6...7...8...9

Definitions:

Speed: The speed of the ship. The sub-elements of this parameter are Maximum Speed, Cruising Speed and Most Economical Speed.

Endurance: The ability of the ship to operate independently. The sub-elements are Fuel Storage Capacity, Oil Storage Capacity, Water Capacity (Storage and Production), Food Storage Capacity and Maintenance Capacity (Shops and Stores).

Maneuverability: The ability of the ship to maneuver, in order to maintain control; avoid danger. Sub-Elements include Turning Radii, Turning Diameters and, for submersibles, Depth Change Rates at various speeds, as well as Wind and Current forces which can be tolerated when operating in ports and harbors.

AVAILABILITY

Which of the pairs of ship Mailability parameters compared below has greater influence on the ship's ability to meet the mission requirements (is of more value to the ship's owner)? A 9 indicates very much greater, 7 much greater, 5 moderately greater, 3 somewhat greater, 1 equal value:

Reliability	Maintainability
9...8...7...6...5...4...3...2...1...2...3...4...5...6...7...8...9	

Reliability	Ability to Operate in Environmental Extremes
9...8...7...6...5...4...3...2...1...2...3...4...5...6...7...8...9	

Maintainability	Ability to Operate in Environmental Extremes
9...8...7...6...5...4...3...2...1...2...3...4...5...6...7...8...9	

Definitions:

Reliability: The probability that all elements of the ship's systems that are required to accomplish a specific mission operate as required. This measure is controlled by the Mean Time Between Failure (MTBF) of each of the ship's equipments, their usage rate and the degree of redundancy of equipment.

Maintainability. Normally measured by the time necessary to get ship's systems back into full operational condition after an element of the system becomes degraded or inoperable in performance (the Mean Time To Repair (MTTR)).

Availability to Operate in Environmental Extremes: The ability to maintain the desired degree of readiness/performance in extremes of the environment in which the ship is *required* to operate. The sub-elements of this parameter are Seakeeping Ability, Operation in Temperature Extremes (Ice, Tropics) and Operation in other Conditions, such as Fog, Sandstorms, etc.

SURVIVABILITY

Which of the pair of ship Survivability parameters compared below has greater influence on the ship's ability to meet the mission requirements (is of more value to the ship's owner)? A 9 indicates very much greater, 7 much greater, 5 moderately greater, 3 somewhat greater, 1 equal value:

Ability to Avoid Detection **Ability to Operate When Damaged**

9...8...7...6...5...4...3...2...1...2...3...4...5...6...7...8...9

Definitions:

Ability to Avoid Detection: The sub-elements of this parameter would include each of the various signatures of the ship that are subject to detection by other forces.

Ability to Operate When Damaged: The characteristics of a ship that permit the ship to continue to operate, even if at some lesser degree of capability, after damage. The sub-elements of this parameter include Damaged Stability, Shock Hardening, System Redundancy and Vital System Separation.

OPERATIONAL EFFICIENCY

Which of each of the pairs of ship Operational Efficiency parameters compared below has greater influence on the ship's ability to meet the mission requirements (is of more value to the ship's owner)? A 9 indicates very much greater, 7 much greater, 5 moderately greater, 3 somewhat greater, 1 equal value:

Manning Habitability
9...8...7...6...5...4...3...2...1...2...3...4...5...6...7...8...9

Mlanning Safety
9...8...7...6...5...4...3...2...1...2...3...4...5...6...7...8...9

Habitability Safety
9...8...7...6...5...4...3...2...1...2...3...4...5...6...7...8...9

Definitions:

Manning: The personnel necessary to perform all operations for all missions of the ship. Subelements *are* the manning requirements for different operational scenarios such as Normal Underway Watchstanding, General Quarters, Special Sea Detail, Maintenance, Linehandling Details, etc.

Habitability: The degree of furnishings *or* environmental conditions required to obtain the required degree of performance from the personnel on board.

Safety: The degree of safety with which each of the missions of the ship can be accomplished.

FUTURE 6ROWTH CAPABILITY

Which of each of the pairs of ship Future Growth Capability parameters compared below has greater influence on the ship's ability to meet the mission requirements (is of more value to the ship's owner)? 6 9 indicates very much greater, 7 much greater, 5 moderately greater, 3 somewhat greater, 1 equal value:

Weight Margin KG Margin
9...8...7...6...5...4...3...2...1...2...3...4...5...6...7...8...9

Weight Margin Volume Margin
9...8...7...6...5...4...3...2...1...2...3...4...5...6...7...8...9

Weight Margin Modularity
9...8...7...6...5...4...3...2...1...2...3...4...5...6...7...8...9

KG Margin Volume Margin
9...8...7...6...5...4...3...2...1...2...3...4...5...6...7...8...9

KG Margin Modularity
9...8...7...6...5...4...3...2...1...2...3...4...5...6...7...8...9

Volume Margin Modularity
9...8...7...6...5...4...3...2...1...2...3...4...5...6...7...8...9

Definitions:

Weight Margin: The amount of weight that can be added to a ship without exceeding the stability or strength of the ship.

KG Margin: The amount by which the Center of Gravity of the ship may be raised by modifications to the ship without exceeding the stability requirements of the ship.

Volume Margin (Density): The amount of internal volume of the ship which can be taken up by future modifications without exceeding the clearances necessary for normal ship operational functions, including maintenance and equipment removal.

Modularity: The degree to which systems have been installed in a modular manner, allowing the systems to be removed and replaced as an entity when necessary to modify the ship's performance capability.

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