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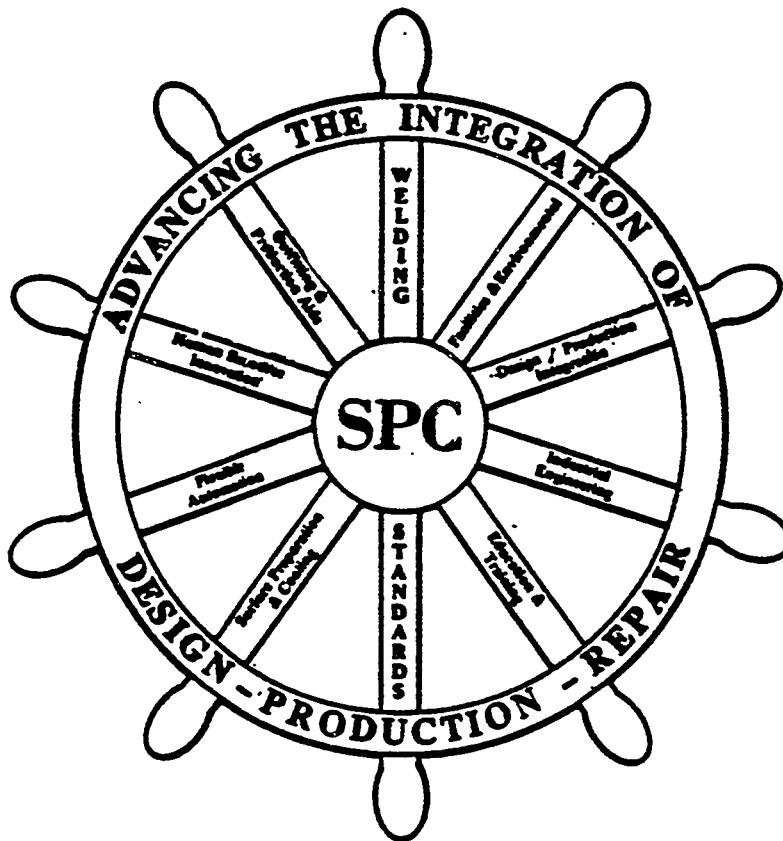
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Computer Integration of SEAWOLF Class Submarine Life Cycle Functions

CDR Blaine R. Brucker, USN, Member and CDR K.J. Merrill, USN, Visitor
SEAWOLF Program, Naval Sea Systems Command, Washington, D.C.

ABSTRACT

The application of computers in acquisition and logistics support is a major requirement of future weapons systems acquisitions. Although the design of the SEAWOLF preceded most new DOD sponsored requirements, the program incorporated many initiatives that will serve as prototypes for future acquisitions.

The SEAWOLF Program is employing computer technology to integrate the design, production and logistic support functions of the ship's life cycle. The transportability of electronic data from the design phase to construction, and on to logistics is key to improving efficiency and more closely linking designer, shipbuilder and maintainer.

SEAWOLF is an important step in the overall effort to improve weapons system acquisition efficiency. Lessons learned by SEAWOLF will be valuable in preparing other acquisition programs to take advantage of the integration of computer data bases that can bring greater success in the execution of design, production and logistics support phases.

INTRODUCTION

The life cycle of a ship or any weapons system in general is divided into many phases. These phases extend from the first drawing that defines the ship at the highest level during conceptual design to the day when the last unit completes its final mission. One constant that has existed for centuries is the need to transfer information. In early ship construction a scale model constructed in wood may have been the only vehicle necessary to transfer the designer's knowledge to the shipwright. The next step, and the one we are for the most

part living with today, is the transfer of information from designer to constructor to operator and

logistician using paper as the medium. Today, the information takes the form of drawings, specifications, maintenance plans and standards, technical publications, piece part support, allowances and a seemingly infinite number of variations. The desire to better control the life cycle functions of a ship has led to the proliferation of huge volumes of paper at each point of the process. The wasteful part of this process is the fact that we constantly recreate data that undoubtedly a person associated with some previous part of the life cycle has had at their fingertips.

The practical application of managing the data created during a ship (or any other weapons system) life cycle is an immense task. Figure 1 depicts a very high level summary of the major interfaces. There are many points of transfer and each one has its own specific requirements that must be satisfied. For example, the interface between design and construction is a particularly important one in the SEAWOLF Program today.

The shipbuilder must be provided an array of design products, the largest volume of which is drawings and associated material information. Conventionally, this point of data transfer has been strictly limited to the delivery of reproducible paper drawings. However, the ability of a program to provide that information in a data transfer medium other than paper is in today's increasingly computer oriented environment not only an attractive option, but in the near future will be a requirement.

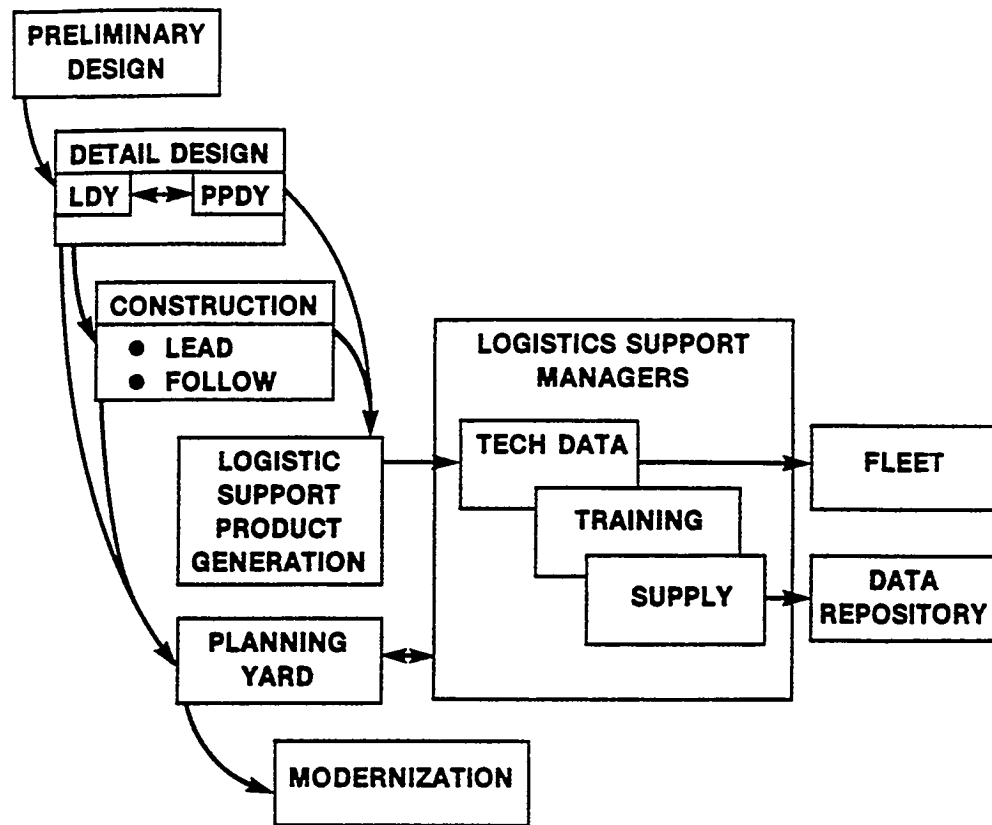


FIGURE 1. LIFE CYCLE DATA INTERFACES

Today's program manager must be expected to understand the methodology of managing data. The program manager will look at the Department of Defense specifications, the capability of potential prime contractors and mandate contractual language to implement design, construction and ILS requirements. There are many key decision points within an acquisition program concerning the vehicles by which data will be created, stored and exchanged. The most critical decisions, from the SEAWOLF experience, are the decisions made during the preliminary phases of design and implemented in the detail design contract. The detail design phase creates large amounts of data, and a later change of course would in all likelihood be expensive and difficult to execute. Therefore, the topic of creating and utilizing electronic data bases in weapons system acquisition will receive increasing visibility at high level forums, such as the ship production symposium.

EARLY SEAWOLF INITIATIVES

The SEAWOLF Program preceded most DOD initiatives to improve the methods in which life cycle information is handled. Sufficient technology was available at both submarine design yards, Newport News Shipbuilding (NNS) and General Dynamics, Electric Boat Division (EB Div), to establish the contractual mandate that the EB Div/NNS design be entirely CAD based. We believe that history will support that this forward looking decision is one of the single most important milestones in the Program's history.

To support a competitive acquisition strategy, the Program's plan to go forward with a digitally based design had to deal with the difficult problem of developing the capability to transfer design products between the two submarine design yards, and eventually to a shipbuilder. The incompatibility of the design yard CAD systems left serious doubts as to whether or not the EB and NNS design data could be transferred cost

effectively. There were three options explored to solve this problem: 1) direct both design yards to use the same CAD system, 2) Develop a direct translator between the two existing systems, or 3) work with a neutral format translation process, specifically the Initial Graphics Exchange Specification (IGES).

The first option would have incurred a very large expense. The second option was regarded as being too inflexible since data from a third system may not be usable and future upgrades of existing software at either design yards could necessitate revisions to the direct translator. The third option had the potential to be cost effective and flexible, however, it was recognized that large scale IGES transfers in shipbuilding had not been done before. The program selected the IGES option and accepted the task to go through the development effort necessary and make this medium of transfer an effective vehicle. In addition to the two and three dimensional graphics information that IGES would handle the need to transfer processible or "field" type text data was necessary. In 1985 the SEAWOLF Program organized data transfer working groups to bring EB Div and NNS people together and provide the framework for transferring, in most cases in parallel with the hard copy deliverable, three types of data:

- o Drawings (2D Graphics)
- o Product Model (3D Data)
- o Processible Data Elements

A working group was assigned to each of these data types with the goals of specifically defining what contract deliverables would be transferred, developing the written transfer procedures, and thoroughly testing the transfer process to validate the procedures. The charter of these working groups was to bring electronic data transfer from a goal to a reality. Additionally, the procedures developed had to be rigorous and clear for the digital product to be made a deliverable in the SEAWOLF Construction Contract.

SEAWOLF DIGITAL DATA TRANSFER WORKING GROUPS

The philosophy behind the working groups was that knowledgeable personnel from Electric Boat and Newport News, with guidance from NAVSEA, were capable of developing the tools necessary to transfer SEAWOLF

data electronically. Although the management at both companies set the course, the working group's efforts for the most part were undertaken by Computer Aided Design (CAD) support engineers, for the IGES type transfer, and material specialists, in the processible text transfer. The groups met about once a month and devised their own methods of developing the products required by the detail design contract. The statement of work of the contract required the design yards to develop and refine procedures for the conversion, storage, validation, and exchange of design information (processable text, drawings and product model including piping and structural information) in digital form. In addition, as part of the Contract Data Requirements List (CDRL) the delivery of procedures was required. These procedures (see Figure 2) would become the basis of data transfer and invoked in future contracts.

1. DIGITAL DRAWING EXCHANGE
- 2 DATA ELEMENT DICTIONARY
3. PROCESSIBLE DATA EXCHANGE
4. STRUCTURE EXCHANGE
5. PIPING DATA EXCHANGE
6. NON.PROCESSIBLE TEXT EXCHANGE
7. DIGITAL PRODUCT DATA CONTROL
8. DIGITAL DATA TEST SET

FIGURE 2 SEAWOLF DATA EXCHANGE PROCEDURES

Drawing Transfer

The successful exchange of drawings within the SEAWOLF Program from design yard to construction yard allows the shipbuilder to have a computer usable (vector notation) drawing available. The utility of being able to work with a drawing with the same capability as if it had been created on ones own CAD system is significant. Additionally, the option to create a SEAWOLF data base at another site, such as a planning yard, is achievable.

The transfer of drawings using IGES as the vehicle is a complex process. The complexity is the result of the methods in which individual CAD vendors represent the many visual devices that convey information. Something as simple as the width (or font) of a line can create a thorny translation problem. Although IGES translators were available from each of the CAD vendors whose products were involved in SEAWOLF design, the initial attempts to transfer data resulted in drawings at the receiving site that did not resemble the original drawing. The major reasons for these drawing exchange difficulties were rooted in four areas:

- o Translator Problems
- o IGES
- o System Differences
- o User Errors

Each problem was documented and categorized by priority and method of solution. Translator problems were resolved by feeding back information to the CAD vendor who provided the translator. Both vendors involved (IBM and CV) were very receptive to the requests from the SEAWOLF Data Transfer working groups for improvements in the translator software and most problems have been solved. Recommendations to change IGES were referred to the IGES committee and the National Bureau of Standards (now National Institute of Standards and Technology). This process, although slower than working through the CAD vendors, resulted in useful changes that improved the translation process. Working with the CAD vendors and IGES had the advantage of not being a direct cost to the government. The feedback provided by the SEAWOLF working groups to the CAD vendors and the IGES committee provided a basis for a significant product improvement to the vendors translators and IGES.

In the event a solution to a problem was required prior to being addressed in the translator or IGES, an interim solution to most problems was resolved by creating "work around" software at the sending or receiving site. System differences and user errors were corrected through the institution of internal procedures within each company to provide uniform CAD products and a SEAWOLF drawing transfer procedure to govern exchanges of drawings between sites. In addition, a standard set of test cases was developed to check translator integrity when a new revision of CAD Software was introduced by either design yard. The program to improve

drawing transfer has been very successful. The SEAWOLF effort has achieved a consistently accurate transfer of information with only minor problems that are well documented and easily corrected at the receiving site, as part of the drawing validation process.

Future Acquisition Programs must decide what medium is required to transfer drawings. The SEAWOLF Program chose IGES as the medium to provide computer usable drawings at various sites. Options other than IGES, i.e., raster images, can provide improved transfer, storage and retrieval capability, but without the virtue of being CAD usable. A Raster image is a series of dots that can be electronically stored to represent a 2D graphic. The advance of technology in converting Raster to vector may someday allow the Raster transfer to become the 2D transfer medium of choice.

Product Model Transfer

The transfer of product model or 3D information is an important function, particularly from the standpoint of manufacturing. The accurate 3D description of parts that comprise a ship is the entry point for advanced manufacturing systems. A hallmark of the SEAWOLF Program is the contractual requirements for both design yards to deliver piping and structural product model information to the shipbuilder.

Moving information through a manufacturing process is a complex procedure. In most cases the time to create the paper or software products that support the fabrication of each piece takes many times longer than the actual time to manufacture. The need to reduce fabrication costs has driven most shipbuilders to implement producibility enhancement programs that reduce the time and complexity of the manufacturing process. One method revolves around bringing numerical control machinery onboard and interfacing them with computers. A generic computer integrate manufacturing system is depicted in Figure 3. To take full advantage of a systems potential, the maximum amount of information is transferred electronically from computer to computer through direct links. Down loading to paper at any point in the process and then recentering the data into another data base represents failure. The front end of the system is the CAD station work station that originates the designer's description of the piece to be fabricated, whatever it may be. In the case of

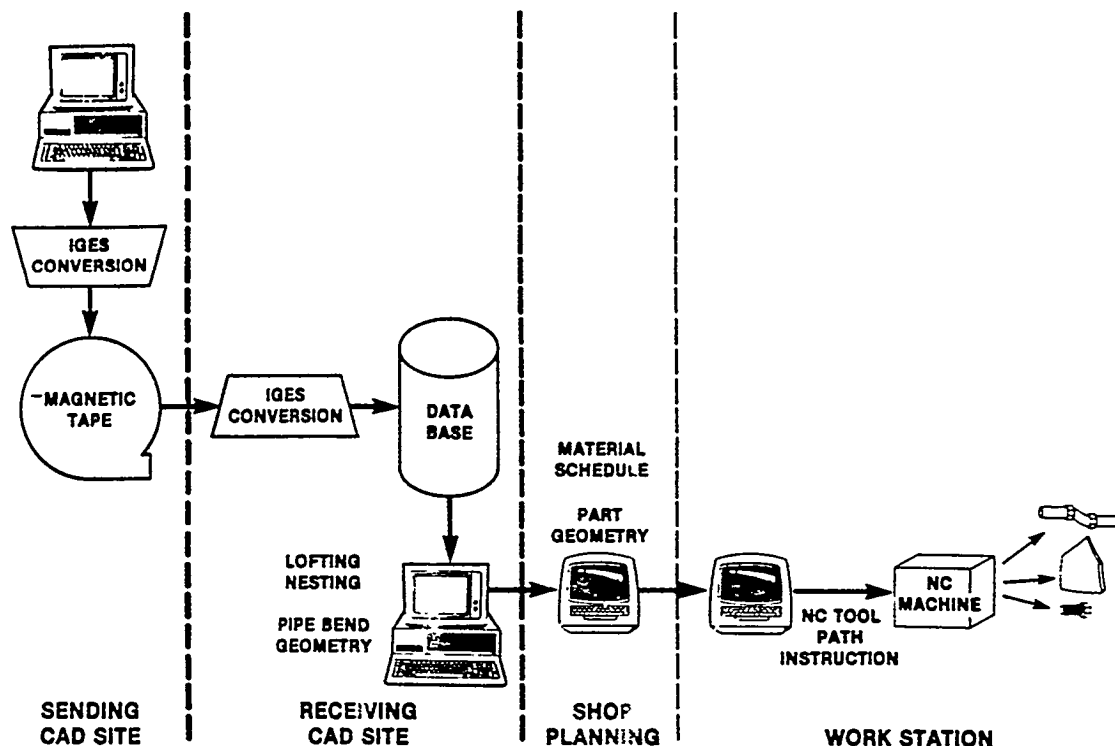


FIGURE 3. ADVANCED MANUFACTURING SYSTEM

SEAWOLF that piece may be designed at either NNS or EB. In order to electronically link the design data base to the manufacturing system of the shipbuilder, the SEAWOLF program developed and is continuing to develop the procedures to utilize IGES based transfer of product model data.

A working group, similar to the drawing transfer working group, developed a procedure to guide the process of moving structural and piping product model data from design yard to shipbuilder. In addition to the procedure development, considerable testing and resolution of problems that the testing brought out took place. The final step in the development phase has been to transfer data from designer to manufacturer and use that data to cut steel or bend pipe.

In a weapons system acquisition, the program manager must determine if the transfer of product model type information is required to support the manufacture of the system. The program should require sufficient procedure development and testing to insure that design data will fully support construction. An understanding of the manufacturing

capabilities and requirements of potential manufacturers is essential to making the correct decisions. Although the up front implementation of a data transfer program as part of design is an additional design expense, in reality it is a high leveraged investment that will make the weapons system more affordable over the life cycle.

Processible Text Transfer

The text information transferred with the drawings using the IGES process is not computer usable. In other words, information such as parts data cannot be electronically pulled from the drawings to access other computer files. Although future data exchange standards (notably PDES) plan to offer this capability, at present intelligent or processible text data must be transmitted separately in a relational data base that utilizes a data element dictionary (DED). The DED is simply a definition of the data element necessary to transmit information. The data element definition is extensive. Each element requires a field name, number of characters, data code, references, description, input instructions, examples, edit/screening provisions and data structure.

as in drawings and product model transfer, a working group was formed to develop the guidelines necessary to exchange processible text. This effort included assembling the elements of the data element dictionary and preparing the procedure

to guide the actual transfer. The most difficult activity was the large quantity of elements that had to be identified and then individually defined. An example of a data element is shown in Figure 4.

FIELD NAME:

ND Matrix

NUMEER OF CHARACTERS

1 each

DATA CODE:

PNC129A,B,C,D, E, and F

REFERENCES

(a) Table 47, NDT Codes

DESCRIPTION:

Identifies applicable non-destructive test requirements (i.e. VT, RT, PT, UT,MT, and MN) performed on the item (DAPN).

The Codes (Y/N) in these fields relate to tests listed in Reference (a).

INPUT INSTRUCTIONS:

- o Enter the letter "Y" if the particular test applies to the item, or enter "N" if not required.
- "Blank" indicates NDT consideration not made/not applicable.
- Test designation sequence:
VT RT PT UT MT and MN

EDIT/SCREENING PROVISIONS: (Performed by-)

0 Computer- Reject Code other than Y,N,or blank.

TYPE	V	R	P	U	M	M
TEST	T	T	T	T	T	N
Applicable(Yes/No)	Y	Y	N	N	N	N

EDIT/SCREENING PROVISIONS (Performed by-)

p Computer - Reject Code other than Y,N,or blank.

DATA STRUCTURE:

A(1) each (Alphabetic)

FIGURE 4. EXAMPLE OF SEAWOLF PROCESSIBLE TEXT DATA ELEMENT

The working group further defined the categories of data to be transferred. A list of the more common data reports exchanged is shown in Figure 5. As people working in the fields of procurement, manufacturing, non-destructive testing, weight control and most notably logistics support understand the utility of the computer in their jobs; the importance of data exchange increases so that the re-input or re-creation of data received from another source is not required.

SEAWOLF: A MAJOR MILESTONE IN DATA TRANSFER

The effort of the SEAWOLF working groups have brought the state of data transfer to the point where the program is contractually supporting the transfer of production information from design yard to shipbuilder. The culmination of this effort is very much like a commencement exercise. The door has been opened and the desirability of expanding the scope of the data transfer effort is apparent. The working groups have been tasked to develop the procedures and conduct the testing to facilitate a future transfer of ventilation and electrical cabling design data. The working groups will look at transferring data that is directly available from the data base such as cable routing information and tabular listing of ventilation shapes and their dimensions. Further, the groups will explore the transfer of the 3D product model of ventilation and electrical system geometry. The end result will be similar to the structure and piping programs, as the ventilation and electrical construction drawings are issued, a parallel package of electronic data will be issued to support the manufacturing and planning operations.

Beyond the present program of providing data which represents the transfer of design information is the desire to increase the scope of the transfer to include manufacturing type information. For example, the SEAWOLF plate cutting facility takes the transferred design or "neat" part and adds information such as the bevel required for a specific welding process and any extra stock necessary for final fit up. If commonality between manufacturing sites can be reached in the methodology of preparing a design part for manufacture, then the information added by the manufacturing planner will be required only one time during the life of that part.

DATA EXCHANGE DOCUMENT

1. ENGINEERING PARTS LIST
2. LOGISTIC SUPPORT ANALYSIS CONTROL NUMBER MASTER FILE
3. STOWAGE INFORMATION
4. MACHINERY MATERIAL HISTORY
5. PREFERRED PARTS SELECTION LIST
6. SHIP'S DRAWING SCHEDULE
7. HIGH IMPACT SHOCK QUALITY DATA
8. RADIOGRAPHIC SHOOTING SKETCH DATA
9. PROCUREMENT SUMMARY INDEX
10. WEIGHTS AND MOMENTS
11. NON-DESTRUCTIVE TEST DATA

FIGURE 5. SELECTED PROCESSIBLE TEXT REPORTS SUPPORTED BY THE SEAWOLF DATA ELEMENT DICTIONARY

INTEGRATION OF DESIGN AND LOGISTICS SUPPORT

The integration of the SEAWOLF design and construction has been well documented in prior presentations. The creation of the modular build strategy, formalized by planning and sequence documents and presented in the SEAWOLF sectional construction drawings represents a major achievement in the practical application of concurrent engineering. The availability of the SEAWOLF electronic data base was key in making the transition from the system to zone design possible. The utility of the data base is also being exploited to make early inroads into the many products required for the logistics support of the ship. Design is the first phase of logistics support. As the designer creates the ship, the individual components are chosen to meet the requirements of the system. These components become the foundation of the effort required to maintain the ship in a proper condition of readiness. The design data base is the key resource from which the initialization of logistics support systems can be accomplished. The SEAWOLF logistics group, in cooperation with the design yards, is putting into place the systems to electronically extract information from the design data base and create the computer driven systems that will in turn create the products necessary to support the SEAWOLF class submarine throughout its life cycle. The systems that will fulfill this function have been integrated under the umbrella system known as SAILSS.

The creation and utilization of a computer based logistics effort represents a milestone as important in the logistics phase as the digital data transfer effort has been in the construction phase of the life cycle.

SEAWOLF AUTOMATED INTEGRATED LOGISTIC SYSTEM

Integrated Logistic Support (IIS) is a process concerned with capturing the configuration of the ship and producing and maintaining the logistic products (maintenance plans and standards, piece part support and allowances, technical manuals, etc.) that support the ship's operation. Because these products have historically been developed and maintained utilizing independent data bases, the information contained in them is often not in agreement. For example, piece part requirements can differ between the ship's allowance list, the technical manual and the repair standard. The lack of integration with the ship's logistic products results in wasted man hours and a high degree of frustration for the people performing maintenance.

To improve the efficiency and effectiveness of Integrated Logistic Support (IIS) for the SEAWOLF Class Submarine, PMS350 early in the development process sought to integrate the various ADP systems that provide this support. The historic disconnects that have existed between the various logistic products could only be corrected by integrating the systems that produce and maintain these products. This need led to the development of the SEAWOLF Automated Integrated Logistic Support System (SAILSS). SAILSS will provide an automated IIS system that will support the class during both the acquisition and operation phases.

SAILSS is being designed as a distributed data base (information resides in more than one ADP system) developed and dedicated to the logistic support of the class. The system is being designed as a composite of individual subsystems (See Figure 6), linked by common data elements, software and a telecommunication network with controls to prevent access of unauthorized individuals. NNS is the system developer and has responsibility for the design, development, testing and associated documentation of the system.

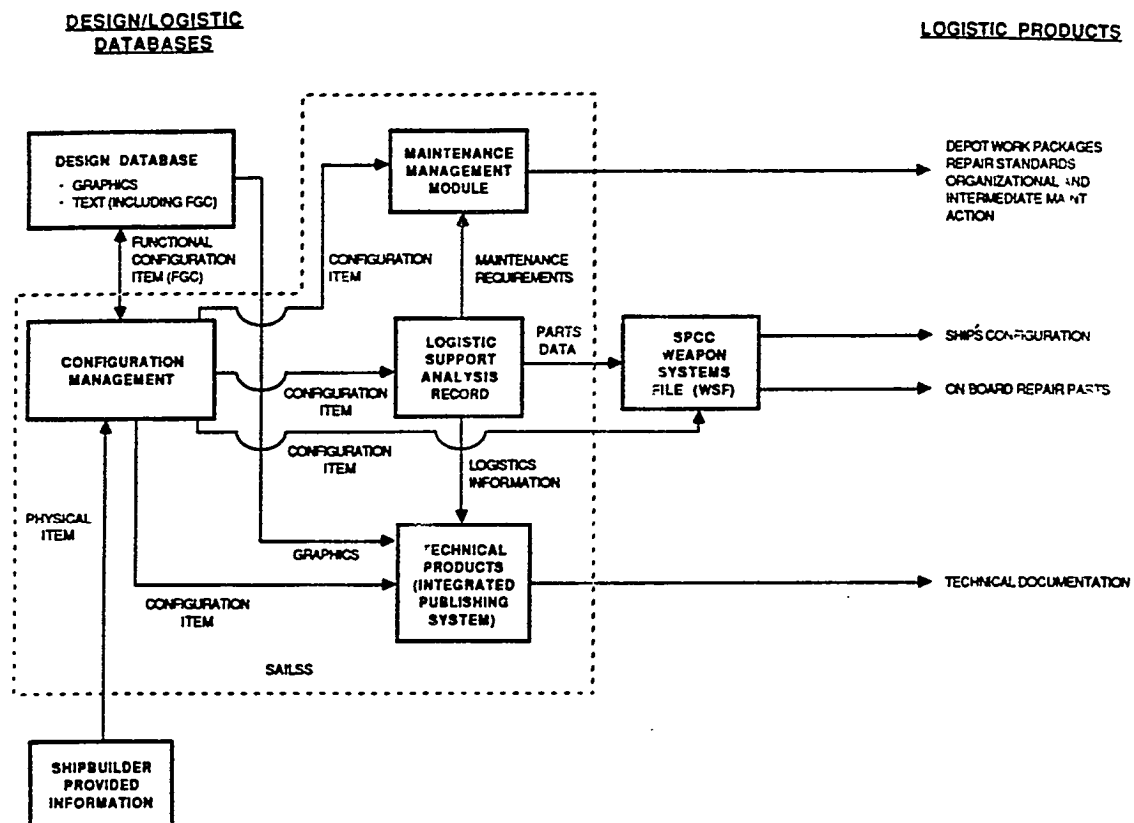


FIGURE 6. SEAWOLF AUTOMATED INTEGRATED LOGISTICS SUPPORT SYSTEM

Early in the development it became apparent that a methodology was needed that would provide commonality between the various SAILSS data bases. Additionally, since logistics is concerned with the ship's configuration, a link common to both SAILS and the design data base was required. SEAWOLF utilizes the Functional Group Code (FGC) for this linkage. The code provides an indexing system that establishes the basis for the structuring the configuration records. An example of a FGC is contained in Figure (7).

Configuration Management Sub-system

The primary sub-system within SAILSS supports the configuration management process. The purpose of this subsystem is to capture the functional configuration (generated during the design process) and to build upon this baseline by adding the physical configuration (an item identified to a specific vendor that satisfies the function) information identified during the construction process.

The following is a very simple outline of the **configuration** process and how FGC is involved in the process. As systems are developed the design engineer determines that an item is required in the system to perform a specific function, e.g., pump water. These items are added to the system drawing, a file in the design data base. The system drawing is reviewed by the system engineer who assigns a FGC to the individual functional items. This information is loaded into both the design and Configuration Management data bases. The physical configuration items are later identified by the shipbuilder and electronically transferred to the corresponding FGC in the configuration management sub-system.

Currently, a prototype that electronically links SAILSS and the design data base is being developed to take advantage of the fact that the FGC, **as well as** other logistic related information, is in the form of processible text. During the analysis phase of this project it became apparent that information that is important to the designer may not be important to the logistician and vice versa. For example, bulkheads and other structural items are not normally considered as a configuration items by the logistician but are by the designer. Because of these differing views of the submarine, a review by the logistics engineer in the initial integration of the two systems will be required. However, once the systems are linked, the capability to compare configuration information between the two data bases will exist. This ability ensures that changes in the design are captured by the logistician.

The Configuration data base electronically provides configuration information to the various sub-systems within SAILSS, as well as external data bases. Use of these interfaces will allow sharing of data and will increase the accuracy of the data.

Logistic Support Analysis Sub-system

Logistic Support Analysis (LSA) is a process that documents the engineering rationale on which the maintenance concept (repair activity capability, periodicity, and technical requirements) is based and stores source data from which individual logistic products are developed. Since the LSA process utilizes a data base that is linked to other SAILS sub-systems, consistency with the analysis and other ILS products is assured.

FGC	FUNCTIONAL NOMENCLATURE
420	NAVIGATION SYSTEM
423	ELECTRONIC NAVIGATION SYSTEMS, RADIO
4231	DIRECTION FINDER SET AN/XXXX
42311	ANTENNA ASSEMBLY AS-XXXX
42312	RECEIVER-PROCESSOR R-XXXX
42313	CONTROLLER-INDICATOR C-XXXX
42314	SWITCH-MULTIPLE ROTARY
4232	NAVIGATION SYSTEM, OMEGA
42321	RECEIVER-COMPUTER
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FIGURE 7. FUNCTIONAL GROUP CODE (FGC) INDEXING CONCEPT

The SEAWOLF project was the first to utilize the unified data base (UDB) software, which was developed by the Air Force, as the means to automate the LSA record (LSAR). The Naval Sea Systems Command Logistics Center (NAVSEALOG) has been designated as the custodian of this software. It is also planned that the UDB will be enhanced to include NAVSEA specific data elements not currently defined in MIL-STD-1388.

The LSAR is designed to utilize control numbers to identify the component undergoing analysis. SEAWOLF uses the FGC as the **Control** number, which will be electronically transferred to the LSAR from the Configuration Management Sub-system. This ensures all configuration items identified during the design/construction process are analyzed for logistic support requirements. Additionally, logistics support data produced by the LSA process will be distributed electronically between this system and other sub-systems of SAILS, as well as external data bases, for the actual production of logistic products.

Integrated Publishing System

The Integrated Publishing System (IPS) is a computer based system designed specifically to produce and maintain a wide variety of technical documentation. The system, which is a sub-system within SAILSS, consists of a combination of state of the art hardware and software which provides for technical matter publication and life-cycle maintenance.

IPS provides the speed and power to achieve high level of performance by replacing manual production tools and methods with computer function. The sub-system provides for the electronic tools to assist in the collection of source data, including IGES transfer of drawings from the design data base and interfaces to scanners for reading in hard copy drawings. The capability to transfer data directly from LSAR to the system will be developed. Additionally, other time consuming tasks such as page composition have also been automated. The merging of text and graphics, once a time consuming task, is now automated and the composition of a camera ready page is now a relatively simple task.

SUMMARY

There is a large body of organizations, government and industry, that are studying the concept of information transportability throughout a weapons system life cycle. The conclusions being reached, almost universally, are the free flow of data from one phase of the acquisition to another represents the greatest potential to reduce life cycle cost and improve the overall performance of the system.

However, in today's world there appears to be too much information and too little experience in structuring a long term program that utilizes the envisioned potential. Beyond the challenges of capital investment, cultural shock in the work force and the need to restructure traditional phases of acquisition, the very basic questions of "how do I structure my program and where do I go for help?" do not have clear answers. The SEAWOLF program was driven by necessity to search for the answers concerning data base structuring and utilization. The simply stated problem of "how do I transfer CAD data between NNS and EB Div" has taken a significant effort to resolve. The SEAWOLF Program has made steady progress in utilizing the design data base to improve the efficiency of the other phases of the ship's life cycle.

The Program Manager of any future weapons system acquisition will be charged with the responsibility to implement a strategy that more completely integrates ship design, construction and logistics. The only method to affordably accomplish that task is to create and utilize snared electronic data bases. The achievement of an essentially "paper less" environment that supports a free flow of data between life cycle phases is a significant goal that successive programs should undertake as a principal requirement. The Department of Defense has recognized the need for computer aided acquisition and logistic support systems and has formulated policy that mandates the creation of government accessible electronic data bases. The Program Manager must require, as part of the contract, the tasking to create and utilize data bases in a program tailored to support the life cycle. The lessons learned by the SEAWOLF program in this field are a major milestone in the effort to more fully realize the potential of advanced ship production techniques.

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No. 2

Producibility in U.S. Navy Ship Design

Hans A. Hofmann, Member, M. Rosenblatt & Son, Inc., Washington, D.C., Raymond S. Grant, Visitor and Siu Fung, Member, Naval Sea Systems Command, Washington, D.C.

ABSTRACT

Recent NAVSEA studies of a twin skeg hull form design applied to a T-AO type ship indicated many areas of possible improvement in producibility.

This paper reviews the findings of producibility studies and attempts to indicate specific areas where an improvement in producibility and attendant cost savings for Navy ships are possible without any degradation in ship performance and survivability.

Most available studies on producibility have an inherent trait of elaborating on details of shipyard producibility. This paper attempts to confine itself to the producibility aspect of the design phase, ending with the completion of contract design. While it is of course necessary for the Navy ship designer to know about producibility details of prospective building yards, he must be careful not to incorporate any details that may be restrictive on some of the prospective builders and thereby hinder competition.

Although the application of a twin skeg hull form to the ongoing T-AO program was determined by NAVSEA not to be practicable because of the advanced status of the ship acquisition program, it was determined that the concept of the producible, designed-to-build ship was worth further investigation for incorporation into future designs because of potential cost savings.

The paper concludes with recommendations for a method of application of producibility to the Navy ship design process for MSC-operated T-Ships.

INTRODUCTION

Producibility is defined as the capability to manufacture, build or assemble goods in a most cost-efficient manner. For this paper, producibility in the pure sense will have to be subdivided as required for the unique characteristics of naval ship design. The normal approach to the design of highly efficient details of construction cannot always be fully applied to naval ship design since the Navy's design activity stops at Contract Design completion, and it is not known at this point which of the prospective shipbuilders will be awarded the contract. The application of producibility to naval ship design is further complicated by the fact that there are usually fixed, and unchangeable mission requirements which are taboo and cannot be modified for any reason.

This paper examines which aspects of producibility are applicable equally to the range of prospective builders and can therefore be incorporated in a Navy ship design. The application of producibility is discussed in three segments: Feasibility Studies, Preliminary Design, and Contract Design.

PRODUCIBILITY FOR NAVAL SHIPS

Applying producibility to U.S. Navy ships is different than the application to commercial ship designs, considering that any Navy ship design must comply with the procurement methods and rules that have to be followed by government agencies. This means that the technical configuration and data in a bid package must permit all prospective builders to bid on the procurement in a fair and even competition. Maximum producibility would require a ship to be designed for construction in a specific predetermined production facility.

Producibility for Surface Combatants

A naval combatant's primary functions have priority over normal economy and producibility considerations in order not to degrade mission effectiveness. For example, high-speed small size and advanced naval surface combatants are usually weight sensitive and cannot normally tolerate the small weight increases associated with producibility considerations without a deterioration in their mission effectiveness. For these ships, it is, therefore, of the utmost importance to consider producibility and the attendant benefits and penalties during the earliest feasibility study phases. This approach minimizes performance decline and makes it possible to develop some general guidelines for the application of tempered producibility for these vessels.

Producibility for T-Ship Designs

T-ships are usually designed to commercial requirements with the exception of certain "fenced" areas for mission-critical systems. These areas depend on the ship type and mission, and are usually invoked by very detailed specification language. T-ships are usually relatively slow speed vessels (20 knots or less) which are somewhat akin to comparable commercial vessels and are therefore not as sensitive to the slightly greater weight usually associated with a producible ship design. The Navy's damaged stability criteria, as applied to T-ships, not conducive to producibility due to limitations on compartment length.

Producibility in General

Primarily, this paper primarily investigates the application of producibility to commercial-like, "T-Ship design," since that is apparently the area where the most benefit may be obtained. To apply producibility, one must obviously first know the number of ships to be built, since the design effort expended to obtain a producible ship varies directly with the number of ships to be built. Only a minimal effort is justified when one ship is built from the design and a much larger effort can be made as the number of units to be built increases until the economy of scale curve levels off. The discussion of producibility is subdivided into Feasibility Studies, Preliminary Design, and Contract Design phases. The most benefit can be gained in the early feasibility stage and the

least benefits are obtained in the later phase of Contract Design. The maximum effort must therefore be expended in the early design stages. In other words, the return for producibility efforts is **maximum in the beginning** of the design project and declines to a minimum as the design matures at the end of Contract Design. The return from producibility efforts increases again during the Detail Design effort due to shipyard applied erection joints and details of assembly. A possible general approach to producibility in naval ship design would be:

- 1) determine the number of ships to be built;
- 2) determine the possible range of prospective U.S. shipbuilders and their individual production methodology and facilities; and
- 3) determine ship size and compartmentation by evaluating stability, mission requirements, and producibility considerations such as -frame spacing, plate thickness, and possible erection joint locations to suit all prospective builders.

PRODUCIBILITY IN NAVSEA

Background

The Naval Sea Systems Command (NAVSEA) has a long history of considering producibility in conjunction with ship design. For example, producibility improvement has been a serious concern in the design stages for the T-AO 187 and DDG 51. As recently as 1985, the NAVSEA Naval Architecture Subgroup (SEA 55W) proposed a Twin-Skeg Integrated-Hull design concept (2) (references are listed at the end of the paper) as an alternate ship design for the T-AO 187 program. This alternate design incorporated some unique hull form characteristics and certain design-to-build features. The producibility features considered were as follows:

- o Maximized areas of flat plate.
- o Maximized areas of single curvature, for remaining shell plating.
- o Increased frame spacing and reduced numbers of piece parts in structural assemblies.

- o Standardized brackets and web frames, and use of bilge brackets in lieu of longitudinal stringers in the bilge turn area.
- o Carefully arranged erection joints.

The intent of the Twin-Skeg Integrated Hull Design for the T-AO was to achieve procurement cost savings with an integrated hull form, basic arrangement, and structural configuration which were aimed at improved producibility. Simultaneously, the Twin-Skeg T-AO design provided equal (or better) ship performance and intact and damaged stability characteristics, relative to that achieved with the existing T-AO 187. The evaluations presented below emphasize the analyses of the producibility concepts which may affect the ship general naval architectural characteristics and performance, particularly in the areas of intact and damaged ship stability, and the producibility "lessons learned." The hydrodynamic performance of the Twin-Skeg T-AO design (including powering/fuel consumption, and seakeeping and maneuvering performance) is the subject of another paper (1) and is not discussed herein.

Twin-Skeg T-AO Design & General Description

The same general constraints and requirements that applied to the T-AO 187 were also applied to the Twin-Skeg T-AO hull. These constraints included general hull parameters, namely length, depth, draft, beam, speed/power, cargo capacity, deck arrangements, and major watertight subdivision. The Top Level Requirements (TLR) for the T-AO 187 was also applied to the Twin-Skeg T-AO configuration.

The T-AO 187 Class Fleet Oiler has been designed with the maximum utilization of commercial standards except for the following systems areas, which were subject to U.S. Navy design standards:

- o UNREP
- o Cargo Handling
- o VERTRHP
- o Degaussing
- o Navy Communications
- o Electrical Distribution Philosophy
- o Steering Gear
- o Nixie
- o Helicopter Platform
- o Helicopter Control Station

The application of the proposed alternate hull form to the -T-AO 187 Class Fleet Oiler program had to be accomplished in a relatively short time. To save time, NAVSEA decided to utilize the existing deckhouse, weatherdeck arrangements and UNREP arrangement, and concentrate efforts in the areas affected by the proposed alternate hull form.

DESIGN CONSTRAINTS

Hull Form Design and Appendages

The final hull form of the Twin-Skeg T-AO design was basically derived from the material presented in (3), with the addition of a NAVSEA-designed bulbous bow. The proposed Twin Skeg T-AO design has the following distinctive features when compared to the existing T-AO 187 design:

Maximum utilization of flat or single curvature plating, except for the bulbous bow and the twin skegs;

Twin side skegs, extending from near amidships to about station 19;

Two 26-foot diameter, slow turning (60 rpm) skewed propellers;

A large, Nabla-type bulbous bow;

A relatively large stem radius and soft shoulder;

A wave-knife stem;

Larger frame spacing;

Use of flat bars where possible in lieu of angles or tees.

The final version of the Proposed Twin-Skeg T-AO hull form is depicted in Figure 1, which compares the Twin-Skeg T-AO and the T-AO 187 body plans. Table 1 lists the principal characteristics of both hull types.

The Twin-Skeg T-AO design concept concentrates not only on the producibility aspect but also on the hydrodynamic performance (1). With respect to the producibility aspect, the Twin-Skeg T-AO hull form incorporates significant amounts of flat hull surface and single curvature shell plating. The producibility concept of the Twin-Skeg T-AO resulted in a fuller and flatter forebody

TABLE 1 COMPARISON OF HULL FORM CHARACTERISTICS
TWIN-SKEG T-AO VS. T-AO 187

	TWIN-SKEG T-AO	T-AO 187
LOA	675'-6"	675'-6"
LBP	648'-0"	650'-0"
Beam, molded	97'-6"	97'-6"
Draft, DWL	34'-6"	34'-6"
Displacement, DWL	41,073 LT	40,140 LT
C _b	0.656	0.643
C _p	0.669	0.655
C _x	0.981	0.982
LCB, aft of midship	1.11 FT	1.75 FT
LCF, aft of midship	28.58 FT	27.23 FT
Station of max. area	10.50	10.00
Wetted Surface	90,858 FT ²	78,870 FT ²

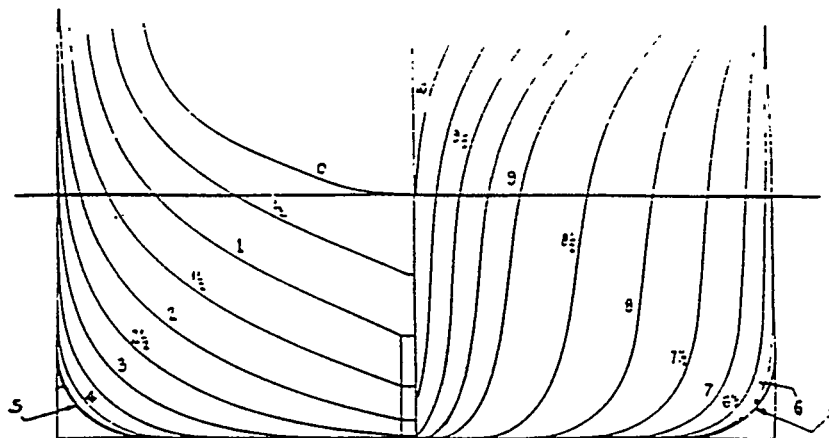
Note that all the above data is at the Design draft of 34 feet 6 inches (molded).

sectional area curve than the existing conventional T-AO 187. The sectional area curves of the

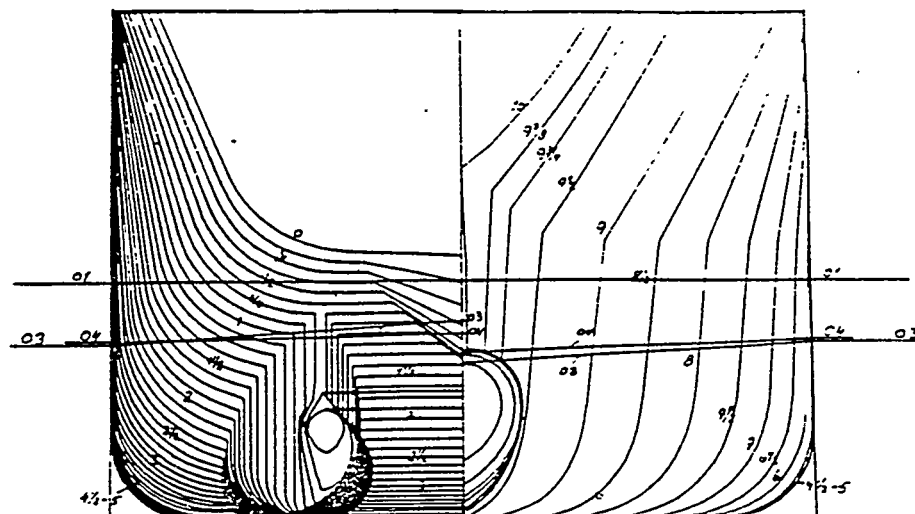
T-AO 187 and Twin-Skeg T-AO are presented in Figure 2.

The second objective of the Twin-Skeg T-AO design was to develop a hull form with equal or better hydrodynamic performance at design speed compared to the existing T-AO 187 design. Therefore, the fuller forebody of the Twin-Skeg T-AO is traded for a softer shoulder than the T-AO 187. This trend is clearly shown in Figure 2, particularly from stations 5 to 10.

Usually, at high speed, the softer shoulder tends to reduce the forward shoulder wave. However, the fuller bow section will increase the bow wave size, negating any resistance reduction related to the forward shoulder wave. The original design was intended to have the



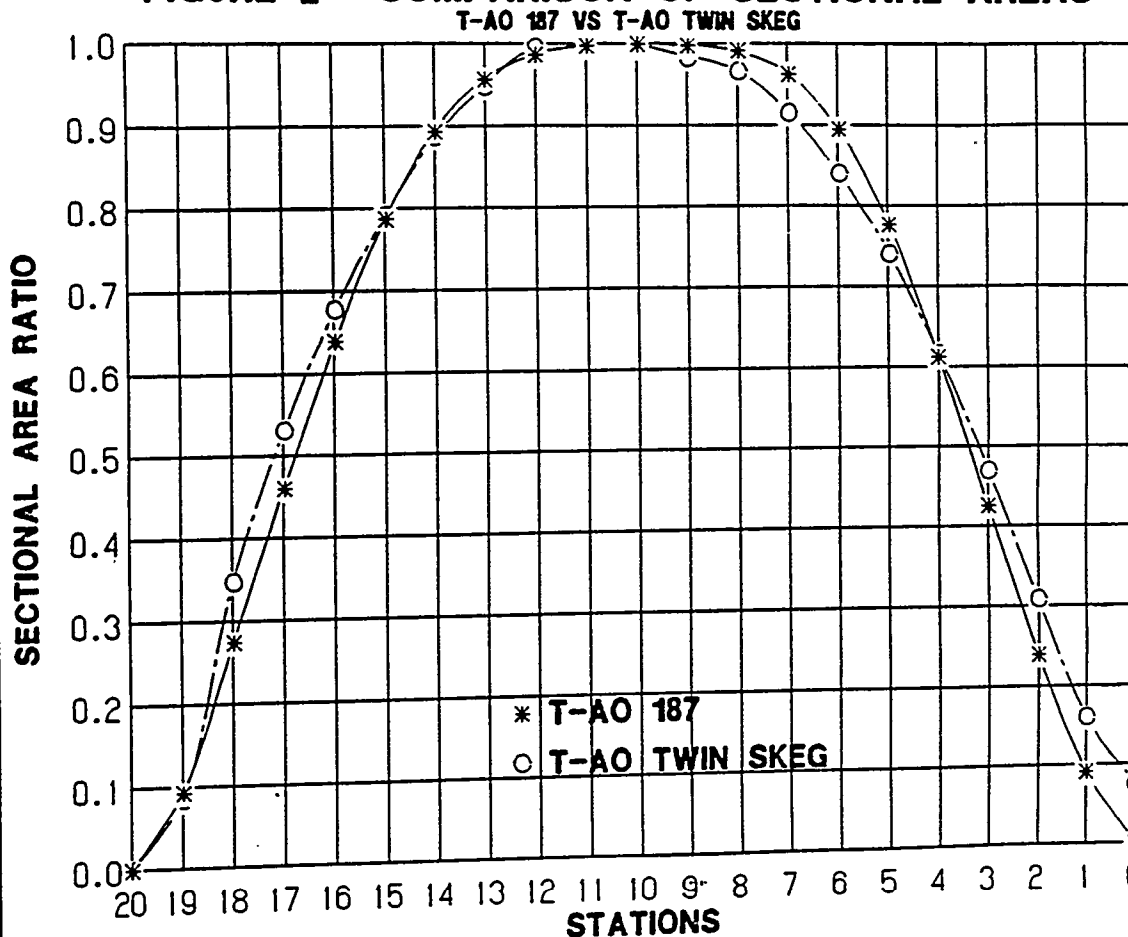
T-AO 187



T-AO TWIN-SKEG

FIGURE 1 BODY PLANS

FIGURE 2 COMPARISON OF SECTIONAL AREAS



optimum hydrodynamic performance at design speed rather than at the speed at which the ship, according to the peacetime speed-time profile from the TLR, operates for the majority of its time (greater than 75 percent). In order to cancel the bow wave which is generated by the relatively blunt bow (note that the Twin-Skeg T-AO entrance half-angle is 16 degrees, whereas that of the T-AO 187 is 10 degrees), the original Twin-Skeg hull form was equipped with a relatively large bow bulb. This bulb resulted in a very good powering characteristic high speed but also a relatively high fuel consumption penalty at off design (ballast condition) drafts, particularly at low speed. Subsequently, the originally designed bow bulb was replaced with a smaller, NAVSEA-designed bulbous bow (1).

The original Twin-Skeg T-AO had a large Nabla (inverted triangle) type bulbous bow, with the top of the bulb at the design waterline. This bulb resulted in a significant fuel consumption penalty at off-design drafts, particularly at low speed (12 to 14 knots).

The final Twin-Skeg T-AO hull has a NAVSEA-designed bulbous bow which is optimized for the ballast condition, and the top of which is about 24 feet above baseline versus a 34 feet 6 inch design draft.

The Twin-Skeg T-AO hull form has more "flat plate" content than the T-AO 187 and most of the Twin-Skeg T-AO "curved shell" plates are single curvature. The forebody has a distinct knuckle line where the side shell plate changes from a near vertical lower hull into the bow-flare of the upper hull.

The Twin-Skeg T-AO hull has two large 26-foot diameter, four-bladed, skewed CRP propellers. The propeller shafts are supported and enclosed by two asymmetric side skegs extending from near amidships. These skegs are of substantial cross section and are designed as box girders, continuous through the shell in order to serve as propulsion machinery foundations. The skegs have planar outboard sides and bulbous inboard sides, and are shaped to create pre-swirl for the

propellers. The skegs are toed in aft at an angle of 2.29 degrees with respect to the ship centerline.

At the extreme stern is a Vee-shaped centerline skeg. It functions primarily to protect the relatively flat bottom under the stern overhang from slamming damage. A more detailed description may be found in (1).

Two horn type rudders of relatively large size, with an area of about 395 square feet each, are fitted. These require a steering gear capable of producing a total of 18 million inch-pounds of torque to operate both rudders. By comparison the T-AO 187 has a rudder area of 295 square feet for each rudder and a steering gear capable of a total of 12 million inch-pounds of torque.

The forebody of the twin-skeg hull form consists of rather extreme U-shaped sections with nearly vertical sides, except for the small knuckle portion at the upper ends. The afterbody inboard of the skegs consists of straight line sections parallel to the baseline.

Structure

The structural configuration is intended to maximize producibility through the reduction of the number of piece parts. The web frame spacing of the Twin-Skeg T-AO is 14 feet 6 inches throughout the longitudinally framed cargo-area, vice 10 feet in the T-AO 187. The bow and stern areas are transversely framed, with 36-inch frame spacing compared to 24-inch spacing in the T-AO 187.

The depth of the floors and of the centerline vertical keel in the cargo area is 10 feet 0 inches in the Twin-Skeg T-AO, compared to 7 feet 6 inches and 4 feet 6 inches, respectively, in the T-AO 187. On the Twin-Skeg T-AO these members are fitted with a large face bar and form a level surface on which to land the upper hull structure modules.

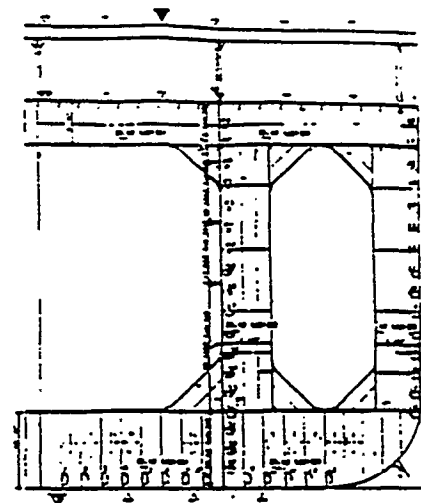
There are no transverse struts fitted in the wing tanks. Deeper, slightly heavier web frame sections are used instead to reduce the number of structural pieces.

The bilge area has no longitudinal frames, resulting in relatively heavy, 1-1/4-inch bilge plates to resist buckling. In lieu of longitudinal, bilge brackets, Figure 3, are fitted every 4 feet 10 inches. This results in two bilge brackets

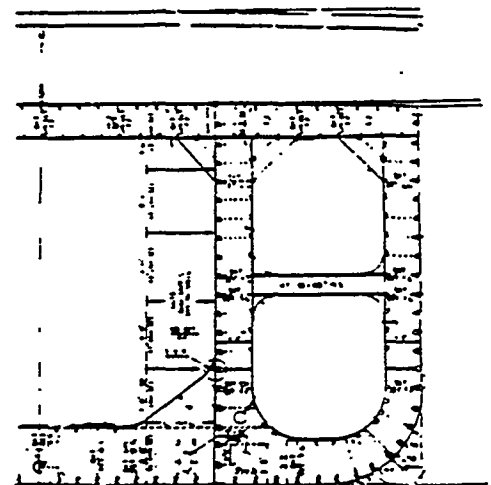
per side between every two web frames. Transition strakes are provided as appropriate to transition between the heavy bilge plating (1-1/4 inch) and the side and bottom shell plating thickness (5/8 inch).

Flat bar longitudinals are used at the main deck. At the side and bottom shell, and at the longitudinal bulkhead, longitudinals are angle sections all with 4-inch flanges, with only the depth of the web and weight varied to suit the location.

All effective longitudinal plating and members are of ABS grade higher strength steel AH-36 or AH-32, except the stringer and sheer strakes and the bilge strake, which are of more notch tough ES-36 to

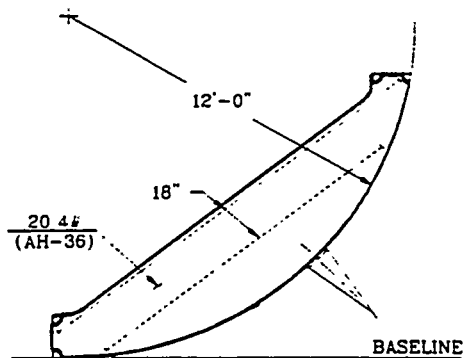


T-AO TWIN-SKEG



T-AO 187

FIGURE 3 MIDSHIP SECTION



SPACING 4'-10" (36 REQ)

FIGURE 4 BILGE BRACKET

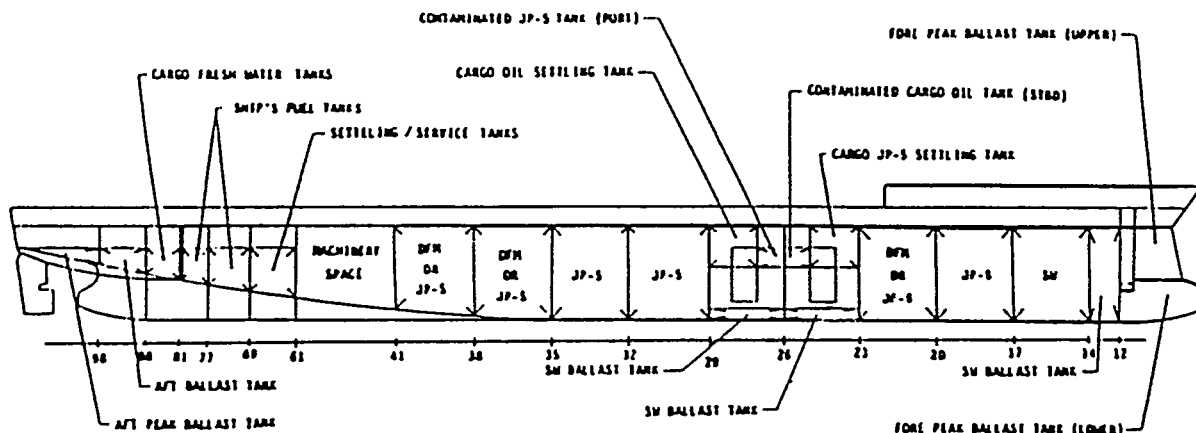
serve as crack arrestor strakes. The maximum permissible still water bending moment is 450,000 foot-tons, based on a calculated maximum still water bending moment of 434,561 foot-tons compared to the T-AO 187 with a permissible still water bending moment of 411,000 foot-tons based on a calculated maximum still water bending moment of 349,782 foot-tons.

The bulkhead spacing in the cargo tank area of the Twin-Skeg T-AO is 43 feet 6 inches, compared to 40 feet for the T-AO 187. This results in fewer bulkheads, and fewer web frames per compartment, although each individual web frame is somewhat heavier.

Figure 3 depicts the midship sections of the Twin-Skeg T-AO and, for comparison, the T-AO 187. Figure 4 shows the bilge bracket.

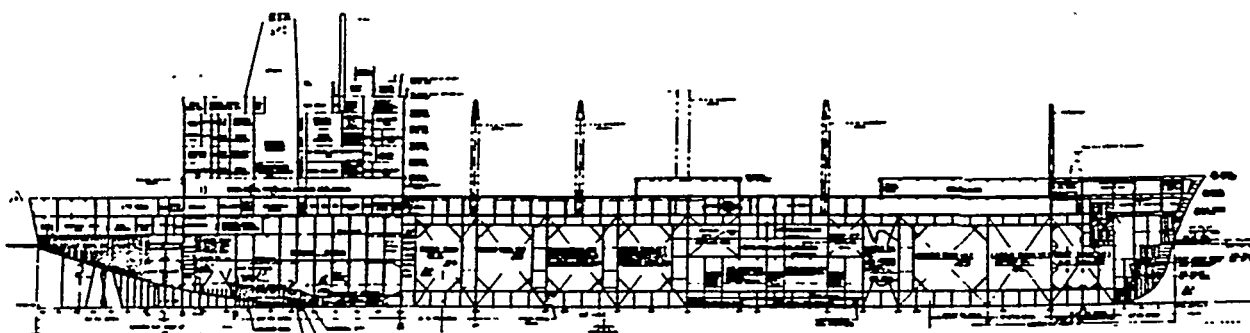
Compartmentation

The subdivision of the Twin-Skeg T-AO is determined by the desired cargo capacity, the necessary selectivity of product, the availability of segregated ballast to negate trim and minimize bending moment, and the damaged and intact stability requirements. The limitation of product outflow for IMO requirements is not a driving factor since the compartment/tank size required for stability and cargo flexibility is much smaller than the IMO tank size limitation for outflow (pollution) restriction.



NOTE: Same superstructure as T-AO 187

T-AO TWIN-SKEG



T-AO 187

FIGURE 5 INBOARD PROFILE

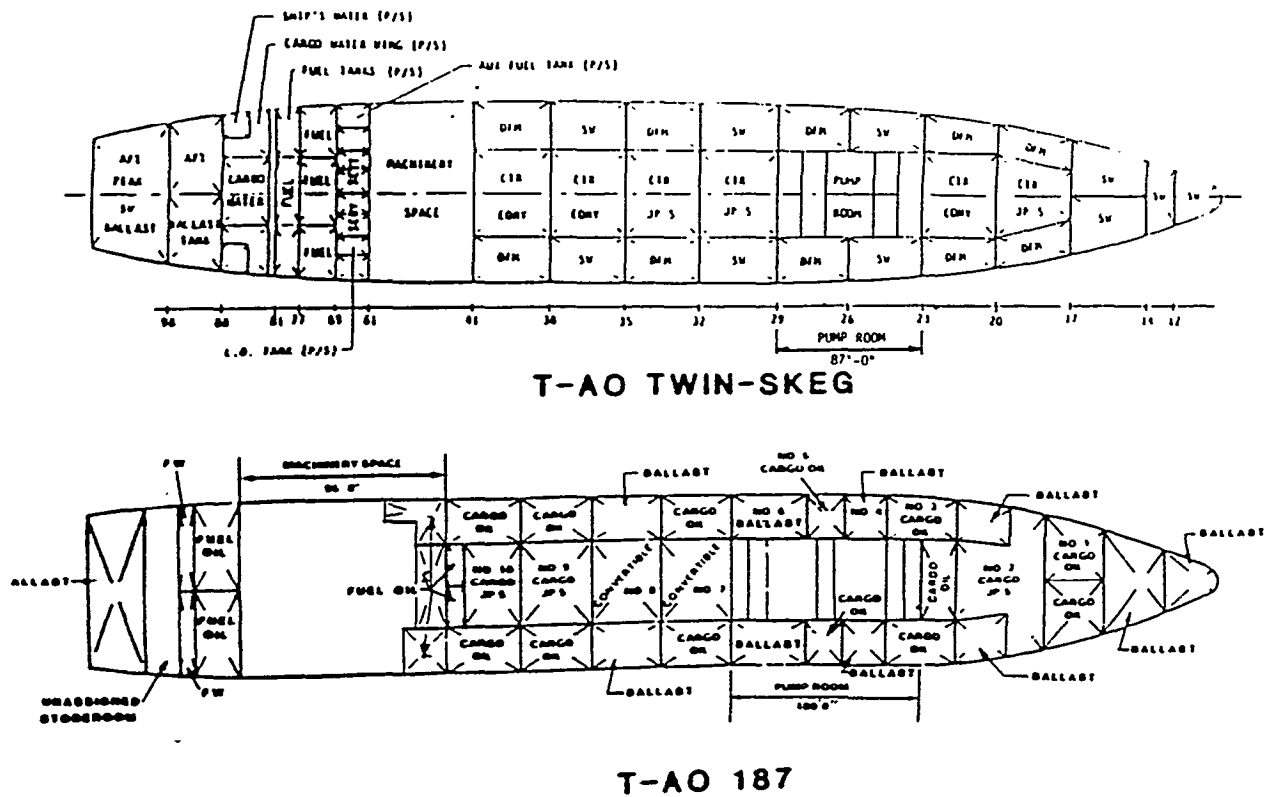


FIGURE 6 TANK ARRANGEMENTS

The forepeak tank has been divided horizontally into an upper and lower peak tank at the top of the bulb. This prevents the otherwise overly large single forepeak tank from being filled completely and possibly over-stressing the hull girder in the process. The smaller forepeak tanks cannot overstress the hull. This is common practice on ships with relatively large bulbs and attendant large forepeaks.

The tank arrangement shown in Figures 5 and 6 is the result of the iterative design process involving damaged stability and structural strength analyses.

Cargo Pump Room

The cargo pump room on the Twin-Skeg T-AO is 87 feet 0 inches long from frame 23 to frame 29, in the center tank area, between the two main longitudinal bulkheads which are 23 feet 3 inches off centerline. The cargo pump room is divided into two segregated motor rooms and surrounded by the pump room, Figures 7 and 8. Outboard of the cargo pump room are two wing tanks each, port and starboard. Compared to this, the T-AO 187 has a 100-foot long cargo pump room which is divided into three segregated motor rooms, three pump rooms and

two manifold rooms. Outboard of the cargo pump room are three wing tanks each, port and starboard.

Machinery

The propulsion machinery plant is located in one machinery space, frame 41 to frame 61, and consists of two medium speed, ten-cylinder vee-type diesel engines. Each engine is capable of providing 16,500 BHP at 400 RPM.

The propulsion plant is designed for unattended machinery space operation, with the ABS classification ACCU. The engine room extends vertically from the tank top up to the main deck. There are four general levels of equipment in the engine room, the tank top, the 14 foot, the 25 foot, and the 40 foot levels.

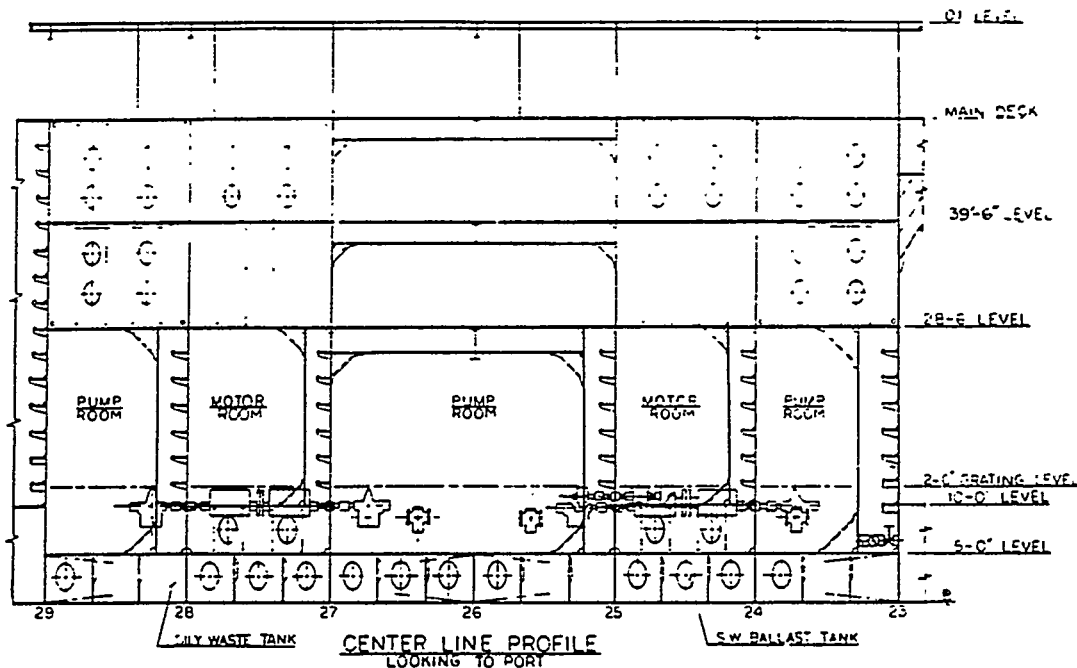
General Concept Evaluation

The Twin-Skeg T-AO structure had been designed according to the American Bureau of Shipping (ABS) Rules for Building and Classing Steel Vessels, 1987. The initial Twin-Skeg T-AO general arrangement and compartmentation had to be adapted to be similar to the configuration of the existing T-AO 187 Class Fleet Oiler so that the same mission

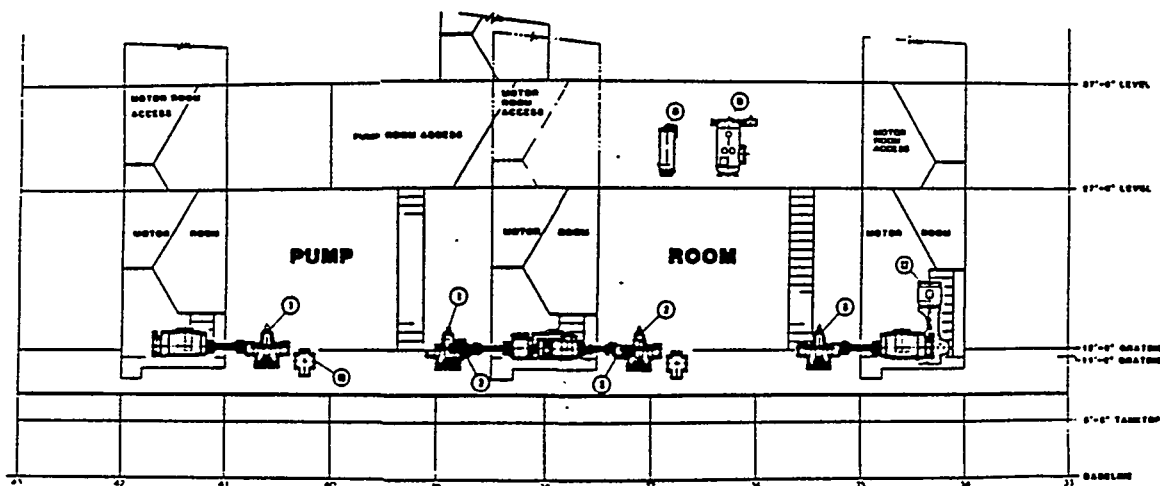
T-AO 187 from stations 15 to 18. However, the design configuration restricted the deck house location. Figure 9 clearly shows that the longitudinal weight distribution for the Twin-Skeg T-AO is significantly different from the T-AO 187. The effect, in terms of damaged stability for the longitudinal weight distribution increment, was found to be far more than the buoyancy increment from the twin-skeg. twin-skegs were also found to have some difficulties in counter flooding. The end products of this

adverse effect caused by the skegs with respect to damaged stability was rectified by designing a shorter machinery space for "the Twin-Skeg T-A9".

The tunnel created by the twin-skeg configuration was not conducive to the development of a functional machinery arrangement within the reduced space since the hull is much shallower in the area of the machinery room. At midlength of the machinery space, the Twin-Skeg T-AO tank top is 11 feet above baseline

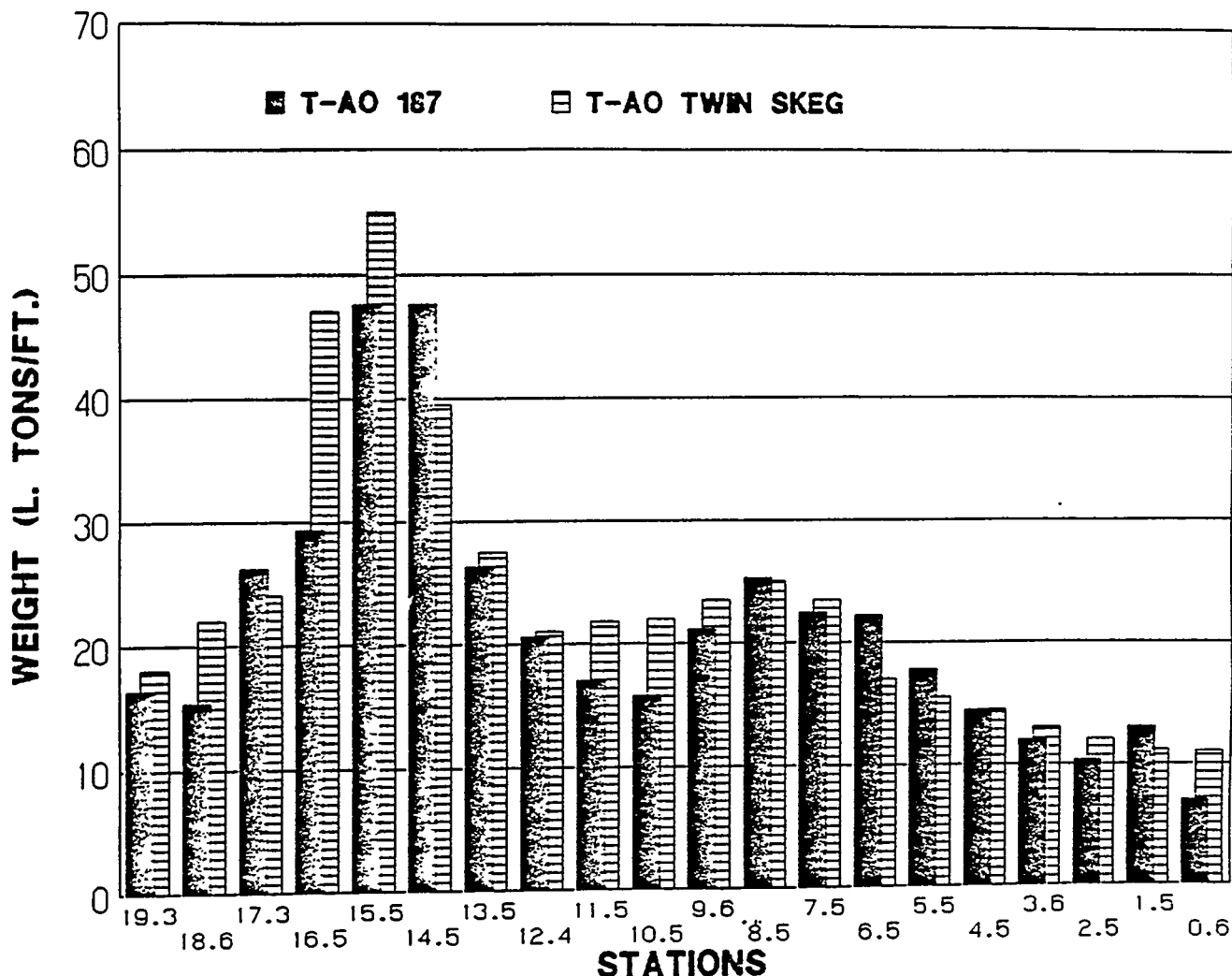


T-AO TWIN-SKEG



T-AO 187

FIGURE 8 PUMP ROOM (ELEVATION)



T-AO 187 VS T-AO TWIN SKEG

FIGURE 9 COMPARISON OF LONGITUDINAL WEIGHT DISTRIBUTION

between the skegs and 24 feet above baseline from the inboard side of the skegs to the ship side. In addition, the ship bottom between the skegs rises rapidly in the aft direction, dictating the 11 foot tank top height. In coinpazison, the T-AO 187 Class has a tank top 6 feet high. In effect, the T-AO 187 machinery space has one more useable level.

The final length of the Twin-Skeg T-AO machinery space was reduced to 60 feet to obtain satisfactory results for damaged stability. These machinery arrangement sketches were developed with the primary emphasis on fitting equipment into the space and only secondary emphasis on proper adjacency and access for maintenance. While the equipment was made to fit into the space available, it is not considered a satisfactory machinery arrangement by NAVSEA standards. If this were a completely new design, there would be greater flexibility to balance the conflicting require-

ments that drove the Twin-Skeg T-AO configuration. Therefore, an adequate machinery arrangement in a larger compartment could probably be developed, but this would require an additional analysis.

TWIN-SKEG T-AO PRODUCIBILITY EVALUATION

Producibility is systematic planned production, coordinating, and directing of all manufacturing activities and influences to ensure having goods designed and made in the most efficient procedure and configuration, on time, of adequate quality, and at the lowest practical cost.

As mentioned earlier, current U.S. Navy practice, any design for producibility must consider the procurement methods and rules that have to be followed by law. This in general means that the technical configuration and data in a bid package must permit all prospective builders to be able to bid on the

procurement in a fair and even competition. This procedure may not always permit optimum producibility, which would require the ship to be designed to be built by a single shipyard. Maximum optimization of producibility is only possible by designing around a given production system/equipment, to the consequential exclusion or handicapping of others with slightly different production systems and equipment. For this reason, the T-AO 187 midship section drawing was made a Contract Guidance Drawing in lieu of the usual Contract Drawing. This allows prospective shipbuilders to optimize the ship structure to suit their particular production methodology and to adjust such details as longitudinal and web frame spacing for their individual panel lane characteristics. It also permits the trade-off of fewer, heavier piece parts versus additional weld passes, considering that fillet weld size is driven by the thickness of components to be joined.

The next consideration of producibility is the number of "ships to be built to a single design. The efforts expended on producibility will vary to an extent, depending upon the number of ships to be built.

The Twin-Skeg T-AO is a simplified, integrated and design-to-build hull with a structure designed for producibility, with specific details of construction. The web frame spacing is 14 feet 6 inches versus 10 feet 0 inches on the T-AO 187. This reduces the number of web frames in each compartment between subdivision bulkheads from three to two, but individual components and plating tend to be heavier since the distance between unsupported plating is larger. In 1986, NAVSEA performed a design study for the AO 177 Jumboization program which indicated savings of 44 LT (2.9 percent) in Group 1, and 4.1 percent of Group 1 labor, by changing from 9 feet to 12 feet web frame spacing in the plug, using standard NAVSEA structural design practice. There is also a smaller number of transverse bulkheads, longitudinal stiffeners and frames and floors. Table 2 provides a comparison of the number of piece parts required for certain components on the Twin-Skeg T-AO versus the T-AO 187.

The deliberate absence of longitudinal stiffeners in the bilge area reduces the number of piece parts but requires the bilge plate thickness to be 1-1/4 inch, with

appropriate transition strakes 11/16 inch thick, inboard and above the bilge plate to the normal 5/8 inch bottom and side shell thickness. The absence of longitudinal in the bilge area also requires two bilge brackets between each set of web frames, or six bilge brackets per side per compartment of 43 feet 6 inches. These bilge brackets are half-moon shaped with a flange along their top edge and a flat bar panel stiffener at mid bracket. The ends of this bracket are fitted against the longitudinal stiffeners at the top of and inboard of the bilge plate. These bilge brackets are depicted on Figure 4. The work content of these brackets will partially offset the gain from the deletion of the longitudinal stiffeners in the bilge area (as will the heavier bilge plating).

develop a construction (erection sequence) plan ahead of the actual design work is a prudent approach for the selected shipyard when planning a detail ship design. However, considering the Navy procurement system, to apply this construction plan, it must be designed to suit all prospective builders equally. This requires access to a current data base on shipyard facilities, including such information as maximum crane lift capacity, panel lane characteristics, and module or raft transport capabilities.

The original Twin-Skeg T-AO structural concepts contained a variety of construction details which, while certainly most suitable for producibility, exceed the amount of detail usually depicted on NAVSEA Contract and Contract Guidance drawings for T-ships.

The erection sequence plan for the Twin-Skeg T-AOI indicating unit break location, was also provided. The unit breaks indicated were based on ideally sized modules rather than considering the existing crane capacities of a prospective range of

TABLE 2

PRODUCIBILITY SAVINGS

ITEM	T-AO 187	TWIN SKEG	DIFFERENCE
DOUBLE CURVATURE PLATE	34%	10% EST	--
WEB FRAMES - NO.	30	18	-40%
WING TANK STRUTS - NO.	60	0	-100%
LONGITUDINALS - NO.	68	56	-18%
FRAMES & FLOORS - NO.	140	105	-25%
TRANSVERSE BULKHEADS - NO.	24	21	-12%
BILGE LONGITUDINALS - NO.	8	0	-100%
BILGE BRACKETS - NO.	0	36	+100%

shipbuilders. The crane capacity of the eleven U.S. shipyards capable of building Twin-Skeg T-AO size ships ranges from a low of four 40-LT capacity cranes to a high of one 1,200-LT crane over a building way, allowing a range of modules for erection from 80/160 to a maximum of 1,200 LT.

Because of the attendant problem with the various size module requirements, it was decided not to indicate any unit breaks. But assumed unit break locations were considered in the development of the structural configurations. Uninterrupted sequence of erection was achieved" by assuring that no equipment is located across unit breaks which would prevent the pre-outfitting of modules in question.

Floors and bulkhead plating are installed up to a uniform height of 10 foot above baseline on the bottom shell. All these vertical plates mounted on the bottom shell are "capped" with face bars presenting a level flat surface lower module on which to land the upper hull modules with relative ease.

Where knuckles occur in the shell or deck plating, they are located within a few inches of a deck or longitudinal bulkhead respectively. This location allows ease of construction; for example, it permits the slight lengthening of the end cut-away of stiffeners or webs to free the knuckle rather than perform another radius cut-away over the knuckle joint. The Twin-Skeg T-AO has fewer double curvature plates because of its simplified hull form. Table 2 gives a comparison. Single curvature plates are easier to construct and assemble since less fitting time is required.

The use of standardized parts of structure for Navy T-ship designs would require the prospective shipyards to agree on the use of the same standard structural details and parts. The Twin-Skeg T-AO is designed to maximize machine welding and to avoid, where practicable, structural configurations that would require manual welding and fit-up. This approach has advantages, but the details of how to accomplish this are shipyard specific. Navy designs must be developed to allow prospective bidders to pursue their most efficient methods of production.

To summarize the producibility of the design-to-build Twin-Skeg

T-AO in the Navy procurement system, the following comments apply:

1. The design-to-build Twin-Skeg T-AO has distinct advantages in simplicity of construction, and its prospective application to a new design T-Ship can result in substantial cost savings due to the simplified hull shape, and to the simplified structural arrangement. Specifically, the Twin-Skeg T-AO structural concept features fewer, but heavier, harder to form pieces; minimized bending of plates and double curvature plates; longer frame spacing, and components serving more than one purpose, such as floor and foundation.
2. The design-to-build emphasis must begin in the Feasibility Study phase, where the designer should consider, based first on the ship parameters, the range of the prospective builders capabilities, and general producibility, considering the combined production characteristics of all builders. The producibility features incorporated here will have to be considered every time design changes are contemplated.
3. The emphasis on the design-to-build concept must continue through Preliminary and Contract Design. All appropriate sections of the ship specifications should have proper requirements assuring maximum consideration of producibility in the Detail Design process, which is normally performed by the builder.

CONCLUSIONS

The results of these studies indicate certain areas of possible improvements, particularly in producibility and hydrodynamics. The Twin-Skeg T-AO concept presents no unsolvable technical problems, although damaged stability is marginal, and machinery space arrangements are unacceptably tight with the current design constraints. If the degree of commonality with the T-AO 187

were relaxed, giving the designer more flexibility, the damaged stability characteristics could be improved. The concept of the producible, design-to-build ship is certainly worth further investigation for possible application to future high-speed naval auxiliary designs because of the potential for acquisition and life cycle cost savings.

This evaluation indicates that the producibility of future auxiliary ship designs can be improved upon by adopting longer frame spacings and simplified structural schemes to reduce the number of piece parts, and by minimizing hull curvature, especially double curvature plates. The potential improvements, however, would not be realized if these concepts were applied to an existing shipbuilding program. These concepts should be considered for new auxiliary ship designs, where weight sensitivity can be traded off against producibility, and where the design and program start-up costs would be applied only once.

RECOMMENDATIONS

Guidelines for the application of producibility should be developed, possibly subdivided into three phases -

I Feasibility Studies

II Preliminary Design

III Contract Design

The following is an example of how producibility guidelines for T-ship design could read. Please note that this is only an example since the development of actual guidelines is well beyond the scope of this paper.

Phase I - Feasibility Studies

- o Number of ships planned.
- o Approximate ship characteristics.
 - Limiting drafts (air and water)
 - Limiting beam (PANMAX-St. Lawrence Seaway)
 - Limiting length
- o Approximate power required for ship speed (step function in prime mover availability may require larger engine room).

- o Lea.St curvature hull form compatible with speed requirement and seakeeping.
- o Establish nonexclusive list of possible builders and prepare general guidelines based on these builder's capabilities.

Module size and weight (maximum) for lift, turn and horizontal movement of modules.

- o Establish data base on builder's facilities (most data exists with MARAD).

Phase II - Preliminary Design

- o Do not use sheer.
- o Use straight camber only where required for weather deck drainage.
- o Establish common panel lane characteristics.
- o Make midship section drawings Contract Guidance and require shipyards to submit their midship section for approval.
- o Use flatbar stiffening wherever practical, if angles are used vary only the web depth and use same flange width throughout.
- o Use as few variations in bar stock size as practical.
- o Design configuration of structure with the fewest possible piece parts.
- o Select the optimum (largest) frame and longitudinal spacing possible within the compartmentation required for stability.
- o Leave production details, such as collaring of stiffeners penetrating bulkheads or other plated boundaries generally undefined to permit the individual builders maximum use of their own methodology.
- o Establish limiting plate thicknesses for availability and to avoid progressive weight gain (requirement for transition thickness plates to limit steps in plate thickness).
- o Establish common weld pass steps based on plate/stiffener thickness, which is driven by stiffener/web spacing distance (i.e., plate/stiffener thickness at which welding would

require going from one to two weld passes).

- o V-line boundaries should be established as early as practicable to allow the location of cable and pipe trunks within those boundaries prior to fixing the location of all spaces to be serviced by these cable or pipe trunks.
- o Establish minimum number of different deck height dimensions for all levels throughout the ship.
- o Minimize the number of different size and type closures, scuttles, and accesses through standardization. Standardize room/space sizes within arrangement constraints.
- o Align and locate all **Sanitary** spaces to simplify piping.
- o Generate parameters for combined module characteristics equally suitable to the range of candidate builders.
- o Document the selected parameters for the design project at hand and require their use as guidelines throughout the design process.

Phase III - Contract Design

For ease of reading we have arranged the recommended general producibility guidelines for this phase by the SWBS category in which they most likely fall.

042 - General Administrative Requirements

To minimize the number of deviations and waivers, the specification should be written in a performance requirement format wherever possible to permit the prospective builder a maximum latitude in the equipment selection and system configuration design.

- o Contract and Contract Guidance drawings should only depict the amount of details in construction that are required to assure satisfactory performance.

070 - General Requirements for Design and Construction

- o Applicable bridge and canal clearances required should be clearly stated.

- o Cofferdams and voids should only be used where absolutely necessary.
- o By using a proper overall design approach, it is usually possible to colocate spaces of similar contents where the adjacency would not require cofferdams.
- o Structural boundaries should serve more than one purpose whenever possible.

071 - Access

- o The equipment module design needs to incorporate the special access requirements on Navy T-ships. This requires tempering the producibility aspect of a system design by considering damage control repair access requirements.
- o Access openings should be designed so as not to be located on erection joints which would prohibit the preinstallation of access closures in all modules.

072 - Survivability

- o Survivability requirements which, among other things, require the separation of crew accommodations are contrary to producibility but, of course, necessary. A compromise will have to be made between separation of crew and alignment/adjacency of similar function spaces.

077 - System Safety

- o The application of producibility guidelines to ship systems normally has no impact on system safety; in fact, these producibility considerations enhance system safety as a byproduct (for example, cable trunks confine electrical fires and could be arranged for Halonon flooding).

100 - Hull Structure

- o All guidelines enumerated under Phases I and II apply also to Phase III but will not be listed again.
- o Minimize the number of piece parts.

- o Optimize frame and web spacing against weight and number of weld passes.
- o Depth of inner bottom must consider module size for lifting/handling
- o Length of modules to suit steel availability.
- o Consider pipe passages and piping system, flange or muff pipe joints at erection joints.
- o Consider duct and cable passages in trunks to have fewer penetrations.
- o Consider extent of transverse and/or longitudinal framing.
- o Assure that the rudder support structure is segregated from the aft peak tank, so that the aft peak tank test does not depend on the rudder being in place.
- o Align structure with equipment foundation requirements (one component - two functions).

200 - Propulsion Plant

- o Prepare a preliminary list of candidate equipment.
- o Establish functional groups for skid/module arrangement.
- o Consider and select maintenance philosophy (change-out or repair in place) before determining connections, pipe joints, bolted plates and flanges.
- o Use commercially available equipment without modification.
- o Limit Navy type equipment to within the "fenced areas."
- o Standard system modules should "be developed for the following:"
 - Fuel oil purifiers, pumps, and other components.
 - Lube oil purifiers, pumps, and other equipment.
 - Fire pumps.

- Air compressors, denitrators, receivers, and other equipment.

Distillers and fresh water treatment system.

The foregoing examples of system modules are for illustration and not all inclusive.

300 - Electric Plant

- o Diesel generator set modules
- o Switchboard modules
- o Consider adjacency of generator and switchboards (over/under, etc.)
- o Assure switchboard is in relatively clean room and not in the engine room proper.
- o Emergency generator set module.
- o Standardize electric motor/starter - pump, etc., skid modules to the maximum extent possible.
- o Develop standard battery/battery charger and service modules.
- o Develop standard M-G set skids & modules.

400 - Command and Surveillance

This group consists usually of "fenced" systems, and is composed of Government Furnished Equipment (GFE).

- o Develop standard T-ship Navy communications room arrangement with a goal of a pre-outfitted space module.

This would permit more flexibility in scheduling the work on GFE.

500 - Auxiliary Systems

- o Standardize pump skids and instrument boards.
- o Standardize on the fewest practicable HVAC modules.
- o Develop standard refrigeration modules.
- o Modularize auxiliary boiler and steam system.

- Standardize hydraulic systems (tank, pump, and controls).

600 - Outfit and Furnishings

- Deck houses should have flat sides and square corners.
- Develop arrangement with as many identical spaces as possible.
- Develop spaces with standard furniture arrangement within each rank group.
- Develop spaces to accept either whole or half panels of a commercially available marine sheathing.
- Align service (pipe, cable or duct) receiving spaces vertically.

700 - Armament

- Continue implementation of modular weapons system installations.

The foregoing, as stated previously, does not pretend to be all inclusive, but rather a guideline to possible areas of producibility application during the ship design

process as it applies to T-ships. We realize that any one of the items listed could be the subject of a separate paper on producibility. We hope that this paper might motivate some thought in the direction of finding procedures to develop more producible Navy ship designs in the future.

ACKNOWLEDGEMENTS

We wish to thank Virginia Monaghan, without whose help this paper would not have been possible.

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Producibility in Ship Design

Gilbert L. Kraine, Member, Enterprise Assistance Inc., Falls Church, VA, Sigurder Ingvason, Visitor, SI Shipping Konsult A.B., Gardesvagen, Sweden

ABSTRACT

Much attention has been given in recent years to the problem of reducing ship construction costs. This has primarily emphasized the improvement of production techniques, processes and management controls. There is a great deal that can be accomplished in reducing ship construction costs, however, by improving the producibility of the design of the ship. The design of a more producible ship requires concurrent product and process design. Various principles and techniques can be applied throughout the design process in order to reduce the construction manhours required by ensuring that the manufacturing attributes are considered. This paper identifies some of the key principles involved and describes the techniques for applying the principles. A practical approach to estimating the cost benefit of alternative designs by estimating the labor input differential between the designs is also presented. Finally, specific examples of the application of the producibility techniques to several recent ship designs are included.

INTRODUCTION

In recent years there has been a concerted effort by many in the marine industry to reduce the cost of shipbuilding in the U.S. Much of this effort has focused on concepts such as modular construction, preoutfitting, new production processes, improved management control systems and the application of computers. There is an area which has received only limited attention: the reduction of costs as a result of making a ship cheaper to build by making it easier to construct. All too often reducing the cost of a ship has automatically focused on the removal of capabilities such as size, displacement, speed, payload or other features. The application of producibility in design concentrates on reducing the cost of

building the ship without a reduction in capabilities.

Producibility in design is not a new concept. It is routinely applied in many industries. Unfortunately, in the shipbuilding industry, perhaps because of the very complexity of the task, we have tended to lose sight of the concept. Even when we talk about "producibility", we tend to use the term in a "go/no-go" sense. The question here becomes "Can the design be built?" not "Should it be built the way it is designed?"

There is an increasing awareness of the need to put the design engineer and the production engineer back together. It has been termed "concurrent product and process design" by some. In reference (1) the authors have termed it "design to build", but the goal is the same. It is not to make the design merely producible, but to make it producible at the lowest cost.

This team approach to ship construction originated in the U.S. shipbuilding programs of World War II when speed, not cost was the driving factor. Men like Henry Kaiser applied mass production techniques to the construction of a basic ship design such as the Liberty ships. Since then, the approach has been further developed and refined by major shipyards in various countries throughout the world. The goal was to reduce costs. That is the only way to compete in the international market. The techniques have been reintroduced to U.S. shipyards in recent years with the adoption of modular construction and preoutfitting in block. However, there is a step beyond which can be taken. That step is to reflect the production considerations back into the design and to adapt the design to use the lowest cost construction techniques.

In reference (2), Hiroshi Sasaki described the highly successful IHI approach and the technology the Japanese have transferred to some of our shipyards. He emphasized the leadership role which is required of design engineering and the need for design and production engineering to work together. He clearly states "Design engineers cannot contribute to cost reduction as long as they consider their job as simply producing drawings. They should be aiming at minimizing production man-hour requirements."

This paper describes specific approaches to the design engineering process which can be used to reduce the required production man hours through the consideration of the manufacturing attributes of ship construction.

Achieving cost reduction in ship construction through design producibility is not easy. Nor is it a one-time task. It is not a task with one big effort followed by a great savings. Rather it is a series of steps, some large, some small, which result in savings, some large, some small but the total of which makes a big difference in the final cost. It cannot be delegated to a computer, but computers can assist in the process. It requires that detailed knowledge of the production process be applied continuously throughout the design cycle.

When successfully applied, producibility in design can produce great rewards. How to incorporate producibility in a ship design and an approach to estimating the cost savings is the subject of this paper.

PRODUCIBILITY PRINCIPLES IN SHIPBUILDING

There are only two principal areas in which to reduce costs in applying producibility principles in ship design: the material costs and the labor costs. While savings in material costs are always possible through better selection, specification and purchasing, the total possible savings is limited. Engineers are traditionally concerned about the cost of the material that they specify. However, the labor cost is not as obvious and is therefore not given equal attention. Producibility in ship design must therefore primarily focus on reducing the manhours required to construct the ship.

The basic principle of the application of producibility principles to shipbuilding is to identify elements of the ship design which, if changed,

would allow the ship to be built for fewer manhours and/or less material cost without modifying the ship's operational or maintenance performance requirements.

The overall approach is therefore to: simplify the work processes, reduce the labor input, reduce the number of steps, reduce the number of pieces, reduce the number of different pieces, and increase repetition.

Certain of the principles enunciated below are of significance regardless of the type of construction a shipyard employs. Other principles however, are directed toward facilitating the use of modern modular construction techniques. This is the construction of a ship in units which are almost completely outfitted before erection and assembly. Included in the process is the fabrication of machinery in units comprised of machinery, piping, controls and foundations. These machinery units are normally constructed in the shop and installed in the hull at the appropriate time in the construction process.

The producibility principles are quite general and almost axiomatic. The application of the principles, however, when combined with a thorough understanding of the ship construction process and environment, can be extremely effective in reducing costs. For maximum effectiveness, producibility must be considered at every stage of the design -- from the very earliest stages. Ideally, the designer should be planning the construction of the ship as he places the first line on the paper or on the computer screen. Even during the earliest stages, unrecognized high-cost features may be locked into the design. Every decision made in the design cycle may limit the application of producibility cost-savings changes. As an example, the knuckle locations on the T-AGOS (SWATH "A") were not located near the bulkheads to minimize construction costs but were already fixed by hydrodynamic considerations at the start of a major producibility review.

The following is a description of the producibility principles which should be applied in the design of any ship to minimize construction costs. The application of these principles requires a team effort with the coordinated experience and knowledge of the ship designer, production engineer and production planner focused on the problem of reducing costs.

Limiting Capability

Remove everything from the design which is not required by the operational requirements. Features, equipment, capability and informal margins have a way of creeping into a ship design for a variety of reasons. To minimize costs, these aspects of the design must be found and removed. This is not a one-time activity but must be a continuing function to control costs. Adding capability always increases costs. Adding unneeded capability wastes resources.

Double Curvature

Avoid double curvature surfaces in hull plating. Many of the hull lines can be straight in one direction without loss of hydrodynamic performance or appearance. The curves in the other direction and the radius bends give shape to the hull. A double curvature plate will usually require heat treatment and increased work input to achieve the required shape. Figures 1 and 2 shows the contrast in sections for the bow of similar ships.

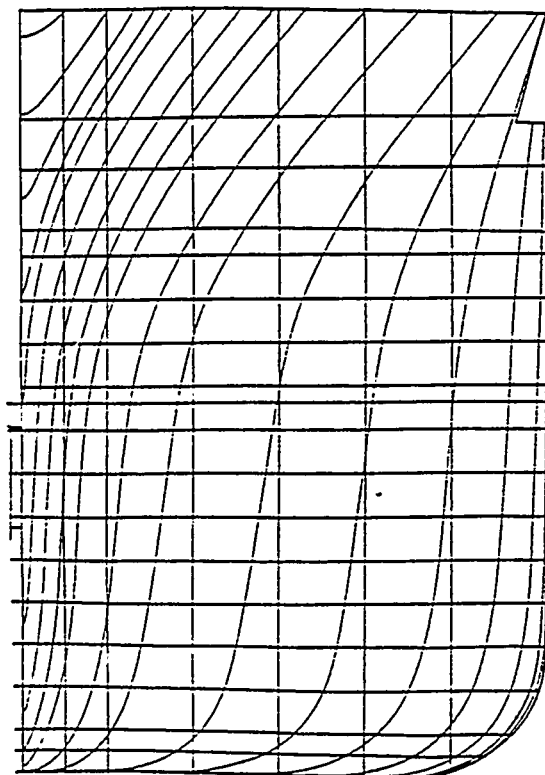


Figure 1. Hull Lines - Curved Sections

Hull Curvature

Do not carry the hull curvature into the structure inside of the hull plating surface. Use straight lines and flat surfaces wherever possible. Even though the hull lines are curved, there is no need to bring the exterior

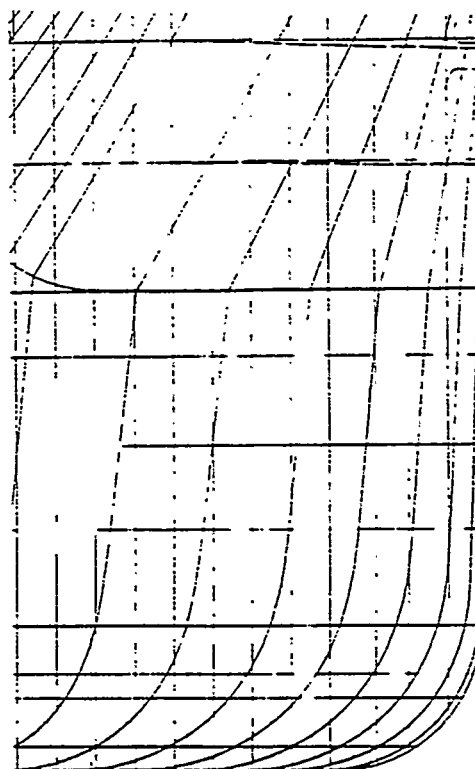


Figure 2. Hull Lines - Straight Sections

hull shape into the interior hull structure. The internal structure must support the hull plating but also serve as a transition between the curves of the hull exterior and the straight lines and flat surfaces of the interior. Figure 3 shows a hull structure which illustrates this concept. Figure 4 shows a hull structural design in which the internal structure follows the external curves.

Frame Spacing

Maximize frame spacing to both reduce the number of pieces and improve access to the work. Frame spacing can have a major impact on construction cost. For various reasons, 24-inch frame spacing has been common design practice for the bow and the stern in the U.S. However, a two-foot space is difficult to construct. The shipyard worker is forced to work in tight spaces where movement is restricted, accessibility is awkward and the working position is difficult to maintain. Using a larger frame spacing of 33 to 36 inches simplifies the construction problems and allows for the removal of up to one-third of the frames. The weight of the removed frames can be applied to increasing the scantlings of the remaining structure to maintain strength. This will not only reduce the construction man-hours due to the fewer pieces but may also reduce the structural weight. The

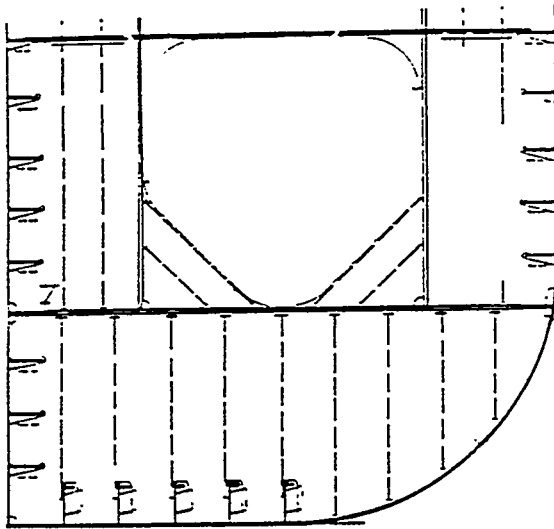


Figure 3. Hull Structure Straight Interior

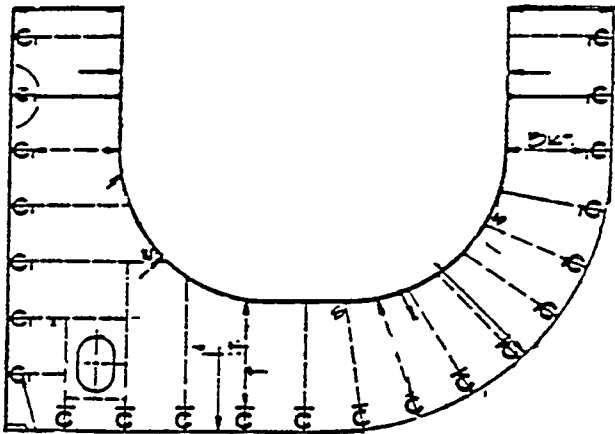


Figure 4. Hull Structure - Curved Interior

larger space will also improve the worker's productivity by easing the problem of gaining access to and working in the narrower spaces.

Reduce the total number of pieces which have to be manufactured, tracked, assembled and installed. Following the reasoning contained in the frame-spacing discussion, there are many areas in the hull where moderate increases in the size or thickness of some of the pieces can be traded for a decrease in the total number of pieces required. Decreasing the number of pieces represents a savings in man-hours required for the design, fabrication, material handling and tracking, welding and fitting of the pieces. Furthermore, the trade-off can usually be accomplished with little or no increase in structural weight and may even result in a weight reduction. As an example, Figure 5 shows a section of the cargo tank structure of the T-A0187 while Figure 6 shows the structure of a producibility enhanced

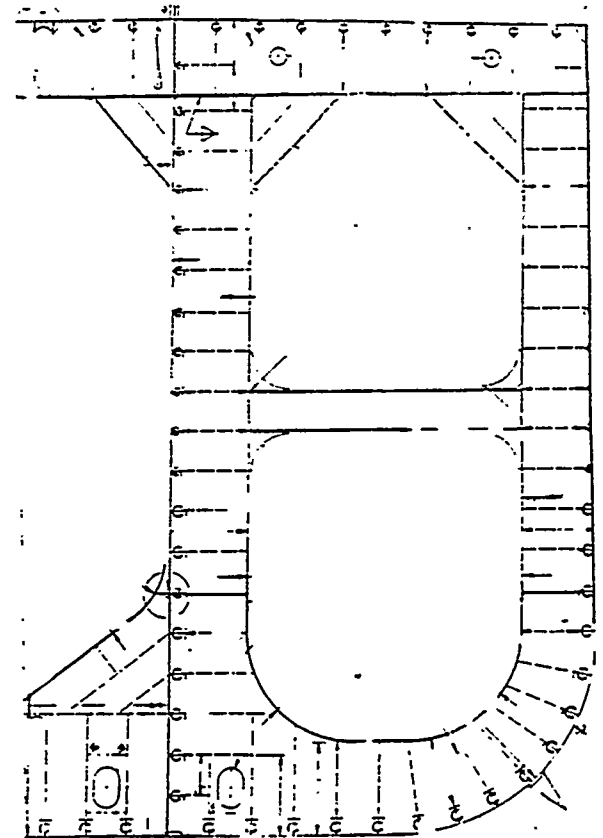


Figure 5. T-A0187 Cargo Tank Structure Design for Modular Construction

Design the ship to facilitate assembly and erection with structural units, machinery units and piping units. This is the key to modular (unit) construction. By building the ship in units, the work can be spread

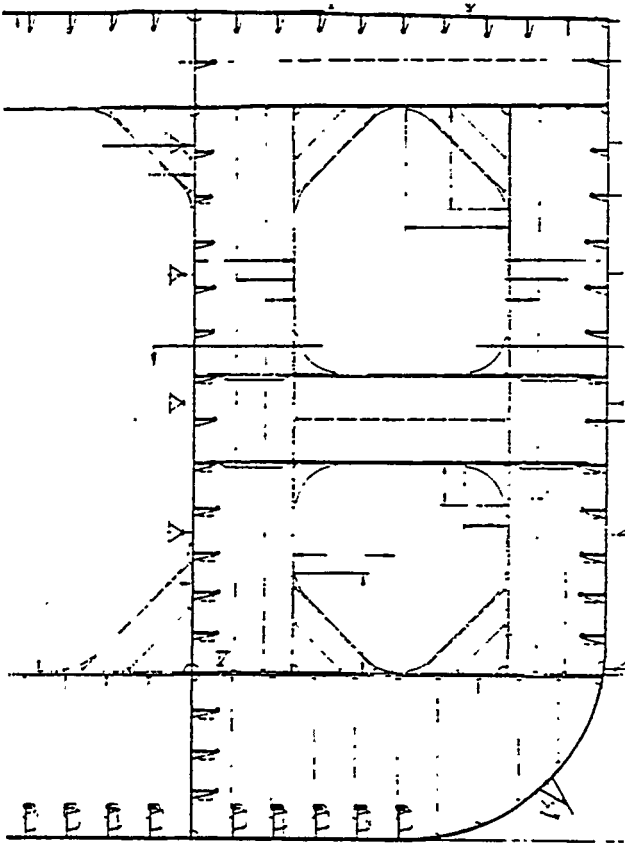


Figure 6. Producibility Enhanced Cargo Tank Structure

over the area of the shipyard. This improves access to the work and reduces interference in contrast to the older approach of assembling the ship, piece-by-piece on the building ways which concentrates all of the work in one small area. Further, with the ship to be constructed by units, the ship must be designed by units. The units should therefore be designed to simplify the construction and erection processes to attain the greatest cost savings from modular construction. Figure 7 shows the planned unit breakdown of a single screw tanker.

Unit Breaks

Establish the unit breaks EARLY in the design process and locate them for repetitive design and construction of the units. The location of the unit breaks (the lines identifying the units in unit construction) can be critical to cost reduction. For some ships, such as tankers and other bulk carriers, the structure is repetitive. By careful location of the unit breaks, the units to be fabricated can then be made nearly identical. All of the identical units can be built from one set of plans with a resultant savings in engineering manhours. This not only allows for assembly-line type construction with the cost benefits of line production, but also reduces the manhours required to design the ship.

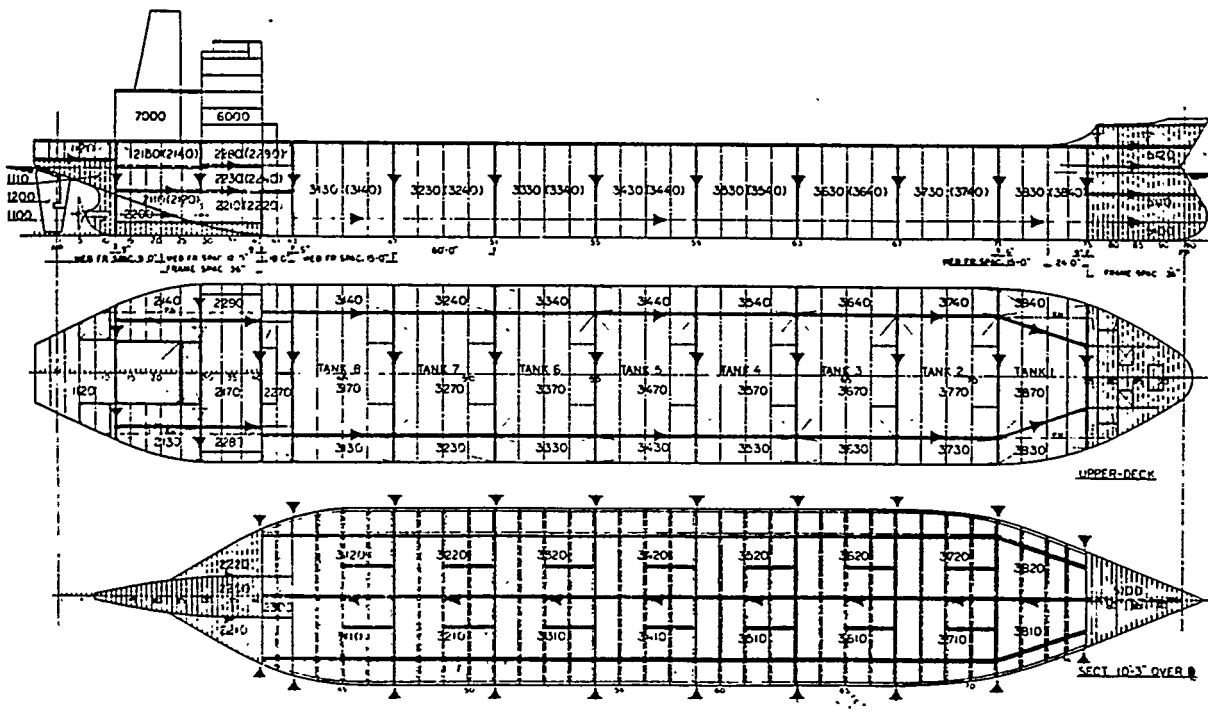


Figure 7. Unit Breakdown Plan

The location of unit breaks also affects the ease of erection. Joining two units is easier if the joint in one unit is stiff (near a joint) and the other flexible (distant from a joint). Joining two units also is easier if a unit is designed to be landed on a flat surface instead of joining two plates edge to edge. Figure 8 shows an erection sequence for a design employing these design features.

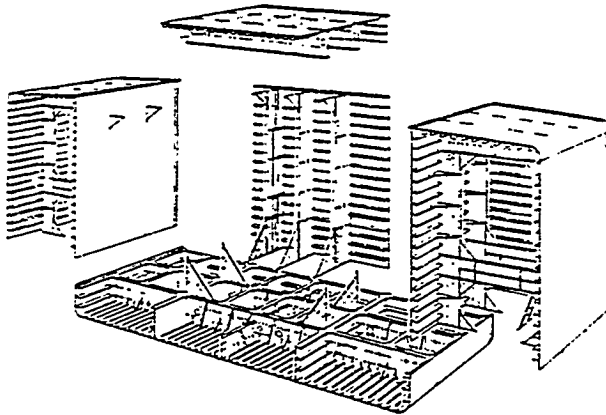


Figure 8. Cargo Tank Erection Sequence

The early location of unit breaks provides another benefit by permitting the designer to locate the various items of machinery and equipment in positions which facilitate unit outfitting. Any equipment which happens to be located across a break cannot be installed until after the units have been erected. Equipment which cannot be installed until after the unit is erected on the building ways is normally more costly to install. Arranging the machinery and equipment within a unit and avoiding the breaks is possible only if the unit break is known before the arrangement is designed.

Limit Unit Size

Avoid excessively large units. Unit sizes are frequently established by the maximum lifting capacity of the shipyard. However, as the unit increases in size, the problems of access, congestion and interference at the work site increase. A very large unit may present problems on the order of building a small ship. Making use of the maximum lifting capacity may not be the lowest cost construction approach.

Knuckles

Locate knuckles at unit breaks. Do not place knuckles either at or between bulkheads or decks but 9-12 inches from the bulkhead or decks where the breaks will be made. Knuckles are easier to fabricate if they occur at a unit break than if they occur midway in a unit. As unit breaks should be located 9 to 12 inches above a deck or away from a bulkhead, that is also the preferred location for a knuckle. A knuckle has little or no hydrodynamic effect if it is above the waterline. The proper location of a knuckle requires coordination between the lines, arrangements and structure at an early stage of a design.

Standardized Parts

Use standardized parts whenever possible. The use of standardized parts, such as brackets, can reduce the variety of pieces that the shipyard has to fabricate, keep track of and install. For example, the cost of using 100 identical pieces is obviously less than the cost of using 25 each of four different pieces. The cost differential may be difficult to evaluate, but it is real.

Machinery Arrangement

Arrange machinery to minimize piping runs and improve operation and maintenance. Machinery arrangements can contribute to decreased costs by reducing the amount of piping, electrical cable, exhaust pipes, etc. which must be installed. Arranging machinery symmetrically in a space can result in unnecessary additional costs as contrasted to careful grouping. Also, grouping pipe runs and treating them as units can transfer work from the machinery or other shipboard space to the shop, where greater productivity can be achieved.

Machinery Units

Plan machinery installations for shop assembly and testing. Assembling machinery on skids for installation aboard ship as a fully tested, complete unit permits the work to be accomplished in the more efficient shop as opposed to the shipboard space.

Welding

Design for use of automatic welders and other high-productivity tools. The welding processes to be used should be considered during the design. The use of straight sections and single-curvature plates improve welding productivity by facilitating the use of automatic welding machines

for the work. Similarly, care in design can permit the erection sequence to be planned for increased downhand or automatic welding. Finally, care in the design of welding details not only can decrease the man-hours required but can also improve the quality of the welds. Examples of improved producibility welding details are shown in Figure 9.

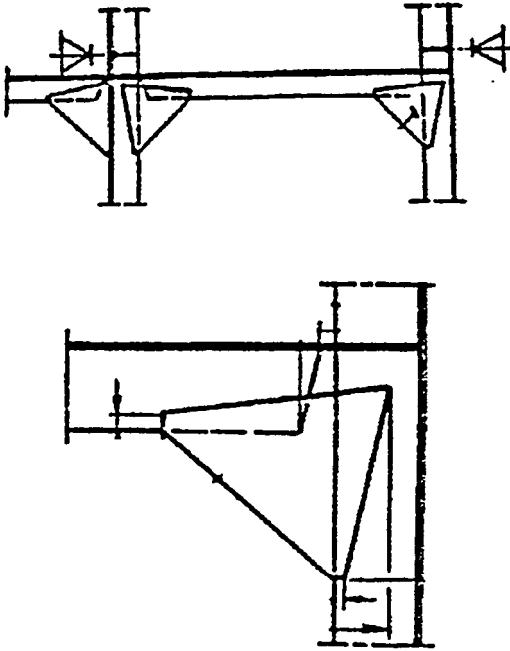


Figure 9. Welding Details

Weight vs Cost

Use limited increases in material weight, i.e., thickness, size, etc., as a trade-off when a decrease in manhours can be achieved. The increased material cost is more than compensated for by the reduced labor cost while the change in total light ship weight may not be significant. This has been validated by calculation and actual construction results. However, a small increase in light ship weight might well be acceptable to realize a significant reduction in construction manhours. Frequently limits on displacement, light ship or full load, are attempts to limit the cost of the ship. Trade offs between weight and cost therefore are possible.

DESIGNING FOR PRODUCIBILITY

In applying the producibility principles to a ship design, the design engineer and the production engineer must work concurrently and interactively. The earlier in the design process that the production engineer is brought into the effort, the more effective he can be. Every decision that is made in the design process before producibility considerations are introduced reduces the potential for cost reductions. The concurrent effort should begin as early as the feasibility/preliminary design stage.

It is obvious that incorporating producibility in the design requires extensive knowledge of the production processes used in the construction of a ship. The production processes are of course dependent to some extent upon the facilities and capabilities of a specific shipyard. This might appear to undermine the case for early involvement of the production engineer. The standard approach to ship design in the U.S. separates the early design from the building shipyard. While a commercial owner may well develop the contract package in consultation and negotiation with a shipyard, the U.S. Navy normally prepares a preliminary and contract design including a set of specifications before awarding the work to a specific shipyard. The Navy cannot deal with only one shipyard before contract award, but has invited shipyard participation during the design process. More than one yard will normally participate. The Navy's acquisition approach complicates the introduction of producibility into the process but does not prevent it.

The size, type and other characteristics of a ship normally dictate the group of shipyards with the capability to build the ship. While the capabilities of the shipyards vary to some extent, the number of similar capabilities is greater than the number of differences. There is a common set of capabilities which each shipyard in the group possesses and which can be used for the production engineering decisions that must be made.

With this approach, every shipyard in the group will find the resulting contract design a buildable design for their facility. The Navy/owner will have a contract for a ship which can be competitively bid on by a group of shipyards but which will also be designed for the lowest construction cost by those yards as a group. Further producibility refinements may be possible by the shipyard winning the

contract and should be considered after award. However, the most cost-effective, basic producibility decisions will have been made.

There are two basic questions which must be considered in designing for producibility. First, does the design meet the operational requirements? Second, is it the lowest cost? In comparing designs, cost therefore becomes a major driver. The cost of constructing alternative design features can be estimated and the decision can be reached in a rational, logical manner. Using this approach, the decision process will lead, **step by step**, to the lowest cost ship design.

ESTIMATING COSTS

General

Cost estimates are normally developed from different approaches -- the macro, cost-down, historical and the micro, cost-up, engineering analysis. In the macro approach, historical data is used to develop cost estimating factors. These factors are usually based upon weight, i.e., fabrication manhours per net steel ton. The factors reflect past practices and experience. The alternative approach is to break down the project into elements of work and build up a cost estimate in a detailed engineering analysis. This approach also uses cost factors but they are based upon work studies of elements of the operation, i.e., manhours per foot of weld.

The macro cost estimates are easier to apply and can provide earlier results than the alternative. Macro cost estimates can provide a gross estimate before the design is completed. However, from a producibility point of view, there are four major deficiencies to macro estimates. First, they are based upon historical cost returns. Shipyards are traditionally poor sources of cost information. The data is frequently skewed reflecting pressures on the first line managers and other factors. Second, by being based on historical data, macro estimates tend to continue past practices. Third, by being based upon weight, any change which increases weight will automatically increase the cost estimate regardless of the effect on cost. Cost reductions which result from weight increases tend to be ignored. This aspect of macro estimates leads to an over-emphasis upon weight as a means of cost control. Finally, macro estimates do not permit the cost comparison of the features or details of a design which is so necessary for selecting the

lowest cost design approach at each step. Clearly, macro estimates are not supportive of improving producibility in ship design.

The NAVSEA ship cost estimating model is of the macro, historical, cost history type. As such, it has an inherent dampening effect upon innovation.

The micro or engineering cost estimate is more difficult to develop but can be applied to specific features of a design as they are developed and the construction process selected. The results of an engineering analysis are inherently more accurate and flexible. Finally, because micro estimates are prepared in considerable detail, actual cost returns can be more readily compared to the cost estimates to pinpoint divergences, problems and needed corrections.

Comparative Cost Estimates

For producibility decisions, it is fortunately not necessary to develop a total-ship, detailed cost estimate, either macro or micro. Rather, a comparative cost estimate will suffice to demonstrate the potential cost impact of a proposed producibility change, i.e., this change will result in a reduction of x feet of weld. The comparative cost method applies a form of engineering analysis but limits the extent of the application to the differences in the alternative designs.

Inherent in the comparative cost estimate is the assumption that the construction plan has been developed. It is difficult if not impossible to divide the work into elements if the basic construction plan for the unit or feature has not been developed.

Example

The application of the comparative cost estimating techniques to the SWATH "A" project will be used as an example. During the course of a producibility review, a producibility enhanced design (PED) for the lower hulls was proposed. This design was compared to the lower hull design under consideration which was similar to the TAGS-19 design.

For the analysis, a construction plan was assumed for the NAVSEA baseline design similar to that being followed by McDermott Shipyards on the TAGS-19 project. For the lower hull, this includes laying the keel, erecting the bulkheads, installing the longitudinal frames and then wrapping the hull plating around the structure. Modular construction is not possible

and preoutfitting can be only minimally used. This is a rational construction approach for the complex structure of the TAGS-19 and the baseline NAVSEA design for the SWATH "A".

The producibility enhanced design was developed to permit the use of modular construction techniques and preoutfitting. The planned construction/erection sequence for a section of the lower hull is shown in Figure 10. The construction of the producibility enhanced design does not require capabilities or facilities beyond that customarily found in U.S. shipyards. The producibility enhanced SWATH "A" design could be constructed in different erection sequences but it is believed that any of these would require more construction manhours than the proposed erection sequence.

In developing the comparative cost estimate for the lower hulls between the NAVSEA baseline design and the PED, the following approach was used: An 18 foot section of the lower hulls, equal to one compartment length was selected. For both hulls, a detailed weight estimate was prepared. The manhours required to fabricate and erect each section was then analyzed in detail.

Welding. For an 18 foot section, the total length of welding required was measured and calculated. The basic welding technique to make the welds, i.e., downhand, overhead, and automatic, were also identified and lengths for each technique totaled, with downhand welding assigned a factor of 1, overhead welding assigned a conservative factor of

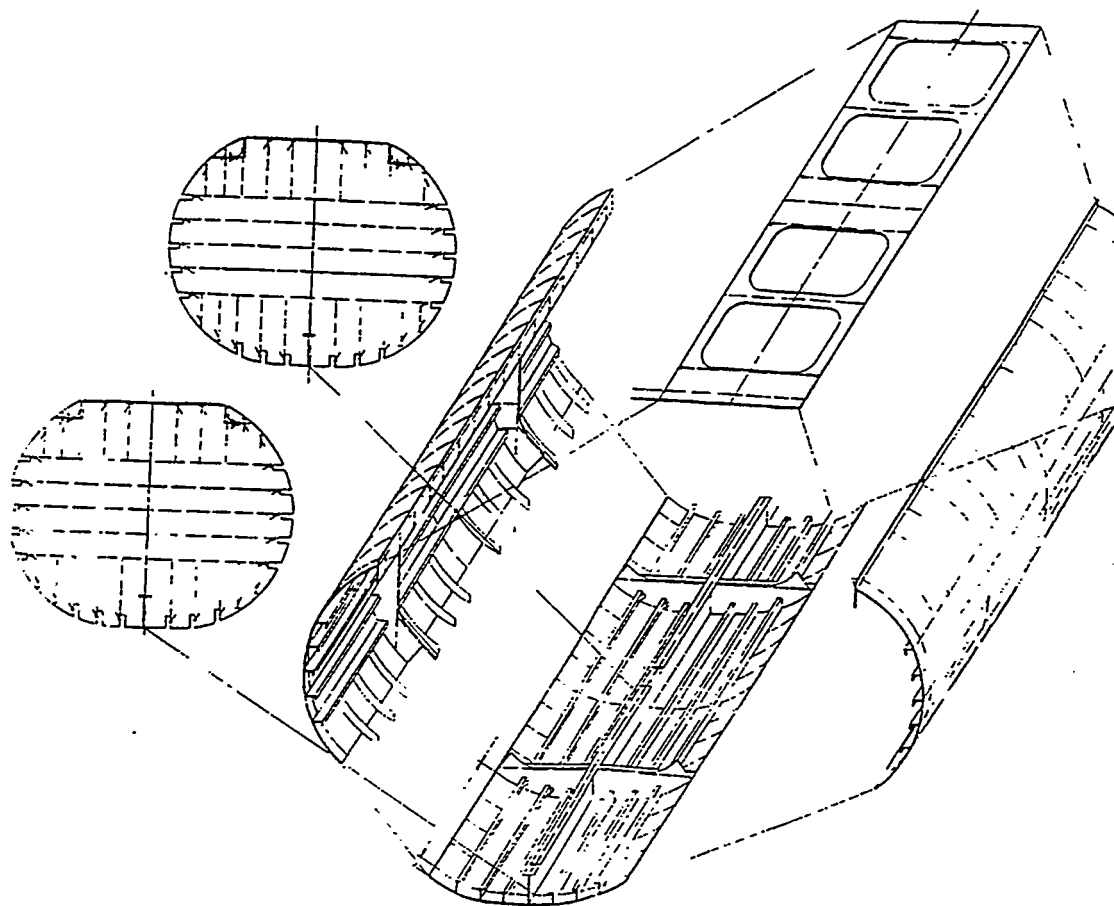


Figure 10. SWATH "A" PED-Lower Hull Construction Sequence

difficulty of 2, and automatic welding a factor of 0.2. The equivalent lengths of welding for both designs were then calculated and compared. It is estimated that the PED would require 35 percent of the welding effort of the baseline design.

Fitting. The number and type of individual pieces in an 18 foot section of the lower hull were identified for each design. The number of pieces, the variety of pieces and the difficulty of positioning the pieces were used to derive a factor of difficulty of fitting. With the PED assigned a factor-of 1.0, the baseline design was conservatively estimated to be 1.5 times as difficult. The product of the number of pieces times the factor of difficulty was compared for each design. It is estimated that the PED would require 28 percent of the fit-up effort of the baseline design.

Savinas. Since 40 percent of the structural construction effort is normally in welding and 60 percent in fit-up, the cost factor for each category was multiplied by the factors and summed. The resulting estimated average cost for the lower hull construction of the producibility enhanced design was 30 percent of the baseline design. The data and calculations are provided in detail in Table 1.

PRODUCIBILITY EXAMPLES

Some specific examples of the application of producibility concepts to three specific ship designs are provided in this section. While these examples represent potential cost savings, due to various circumstances, not all of them have been accepted or incorporated in the design. If the

COMPARATIVE COST ANALYSIS

NAVSEA SWATH "A" BASELINE VS PRODUCIBILITY ENHANCED DESIGN LOWER HULL : 18'-0" FOOT SECTION

	NAVSEA BASELINE	PRODUCIBILITY ENHANCED DESIGN
WELDING		
WELD LENGTH-TOTAL (FT)	2186	1386
OVERHEAD LENGTH (FT)	855	55
OH FACTOR OF DIFFICULTY	2	2
AUTOMATIC WELDING LENGTH (FT)	215	550
AUTO FACTOR OF DIFFICULTY	0.2	0.2
EQUIV LENGTH OH WELDING (FT)	1710	110
EQUIV LENGTH AUTO WELDING (FT)	43	110
REMAINING WELD LENGTH (FT)	1116	781
EQUIV WELD LENGTH-TOTAL (FT)	2869	1001
COST FACTOR(CF)- WELDING		34.9%
FIT UP		
PIECES- TOTAL NUMBER	334	139
DIFFERENT PIECES	20	14
FIT UP DIFFICULTY FACTOR	1.5	1
FIT UP -EQUIVALENT EFFORT	501	139
COST FACTOR(CF)- FIT UP		27.7%
	% OF EFFORT	COST FACTOR
WELDING % OF EFFORT x CF	40% x	34.9% = 14.0%
FIT-UP % OF EFFORT x CF	60% x	27.7% = 16.6%
COMPARATIVE COST - LOWER HULL		30.6%

Table 1. SWATH "A" - Comparative Cost Estimate

proposed producibility changes had been available earlier in the design cycle, more of them might have been included in the final designs.

T-AGOS (SWATH "A") LOWER HULL STRUCTURE

The structure of the lower hull of the design under consideration by NAVSEA was not compatible with modular construction techniques. The design required the lower hull to be constructed piece by piece. The construction sequence is: the keel is laid, bulkheads erected, longitudinal framing installed and the hull plating wrapped around the framing. Manual welding must be employed extensively and, much of that in inaccessible or awkward locations. Access for outfitting is restricted. The design limits the building yard from employing a more efficient unit construction and preoutfitting approach.

The initial NAVSEA structural design, shown in Figures 11 and 12, had the following features:

The lower hull was longitudinally framed with 36 T-profile longitudinal installed perpendicular to the curved hull plating, requiring difficult fit-up and welding procedures.

The 36 longitudinal represented a stiffener-to-plate ratio of over 51 percent, which is not considered to be optimum for strength and weight considerations.

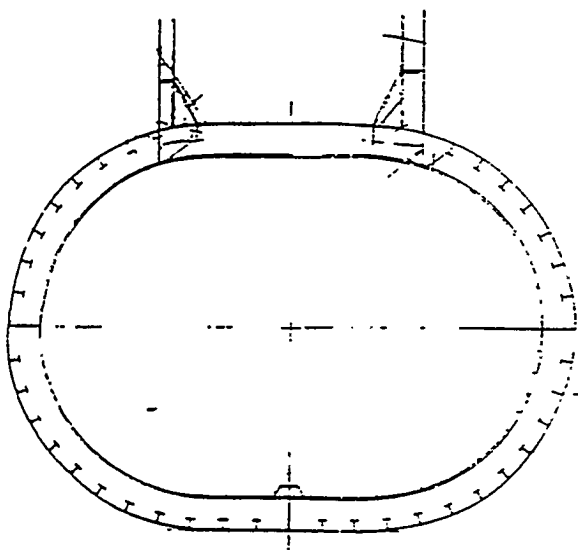


Figure 11. T-AGOS (SWATH "A") -Lower Hull Structure

TWO heavy girders were installed in each hull for pier loadings.

The bulkheads were designed with vertical webs, a horizontal stringer, and 13 vertical stiffeners.

The upper (internal) surface of the hull was curved, an unnecessarily costly detail. Hull strength can be provided equally well with straight structural members.

Each hull had 28 T profile web frames.

The lower hull structure of the PED, shown in Figures 12 and 13, was designed for unit construction and extensive preoutfitting. In lieu of requiring construction on the ways, each subunit in the producible hull structure is designed for fabrication in a horizontal "position on the ground and assembly into units on the flat. The bulkheads are erected on the bottom unit, and the side units are assembled around the bulkheads. The top unit, which closes the hull, is not to be installed until the outfitting is completed. The erection sequence is shown in Figure 10.

Some specific features of the producible lower hull design include:

The use of 16 L profiles per hull for the longitudinal framing, each of which is oriented either vertically or horizontally. The pier loading girders are deleted.

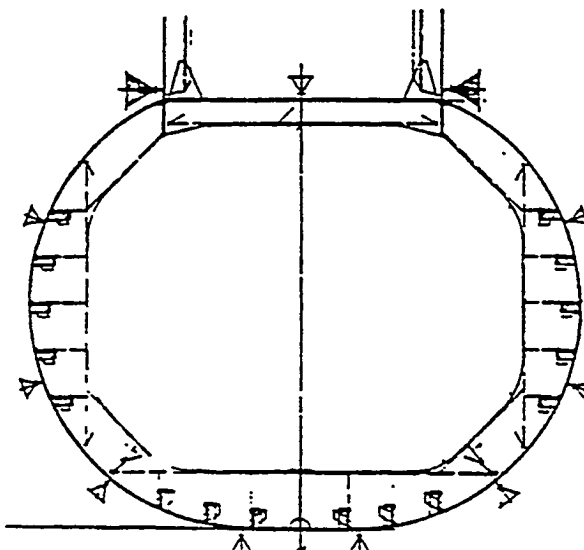


Figure 12. Lower Hull Structure Producibility Enhanced Design (PED)

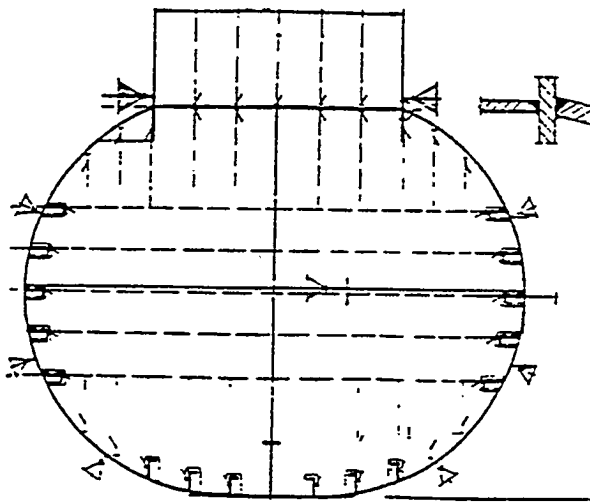


Figure 13. Lower Hull - Bulkhead - PED

The web frame spacing has been **increased from 6 to 9 feet and web frames reduced to 15** of built-up construction.

The bulkheads have a vertical web and five main horizontal stiffeners.

The upper (internal) surface of the lower hull is flat and part of the material inside the tanks has been removed.

The PED **lower** hull design is planned for construction of each hull unit in five sections (including the transverse bulkheads) and assembly in the fabrication shop. The top segment is to be installed after outfitting is complete.

The PED lower hull structure can be constructed by any U.S. shipyard with reasonable capabilities. Construction in 36 foot long units is planned, but 18 foot units may be substituted if necessary. There is no feature of the design which limits competition or would place any reasonably equipped shipyard at a disadvantage in competitive bidding.

The benefits of the producible lower hull design include:

Thirty-six "T" profiles and two horizontal girders have been removed per hull and replaced by 16 "L" profile longitudinals.

The installation and welding of the longitudinal has been simplified.

Thirteen web frames have been removed per hull.

In the bulkheads, 13 vertical stiffeners have been replaced by five horizontal stiffeners.

Finally to erect the haunch unit to the lower hull in the NAVSEA design, the upper unit must be landed on the curved upper surface of the lower hull. The lower edge of the haunch unit must then be aligned with the interior stiffeners -- which are not visible. In the PED sequence, the upper subunit of the lower hull contains the connection of the haunch to the lower hull. The lower edge of the haunch is welded to the upper edge of the penetrating section.

These changes resulted an estimated decrease in construction manhours of approximately 30 to 35 percent **for** the lower hulls.

AOE-6 Frame Spacing

The web frame spacing of the AOE-6 varies between 9, 10 and 11 feet in various sections of the ship. The changes in web frame spacing cause variations in the dimensions and design of the units from which the hull is constructed. This in turn prevents standardization of the design of similar units and thus reduces the production line "learning Curve" benefits from the repetitive construction of identical units.

The variations in frame spacing also impacts the length of shell and longitudinal bulkhead plating which must be procured. This increases the material costs including procurement, handling, tracking and storage.

The variations in web frame spacing will have a significant impact upon construction costs as opposed to the use of a constant web frame spacing.

A further disadvantage to the variation in web frame spacing is the unnecessary weight. The longitudinal throughout the ship are sized by the required longitudinal dimensions for the maximum spans. In the shorter span areas, the longitudinal will be oversized for the span. This represents an inefficient use of the weight resource of the design. Some of the structural lightweight weight is devoted to material which does not contribute to the strength of the ship.

Finally, the web frame spacing of 9 to 11 feet is excessively close for a

ship of the size of the AOE-6. A spacing of 13'9" (5 x 33") or 15'0" (5 x 36") would be more suitable for this design. A rearrangement of the web frames was recommended.

T-A0187 Machinery Arrangement

In the T-AO 187 design, the machinery arrangement did not locate the various items for minimum construction cost. The auxiliary machinery was not grouped together by function nor arranged to facilitate skid mounting of identical units.

Pipe, duct and electrical runs were not planned to minimize the material required, the installation cost nor the use of valuable machinery space volume. For example, the diesel generator location required the routing of the main electrical cables the length of the Engine Room. Further, the auxiliary boiler is located well aft while the uptakes are forward in the space over the main diesels. This requires the boiler exhaust to pass through, horizontally, a major part of the machinery space before turning up. Not only does the exhaust duct present a major obstacle for other necessary routings, but the horizontal run may well prove to be an operating and/or maintenance problem in the future.

The T-AO 187 Cargo Pump Room uses two motor rooms, three pump rooms and voids to separate the cargo from the motor rooms. This cargo pump room arrangement consumes excessive space, requires convoluted runs of large diameter piping and the installation of unnecessary structural material for bulkheads and voids. An alternate cargo pump room arrangement using a single motor room with a pump room at either end would be a major cost saver. The pump rooms would provide the required separation of the cargo from the motor rooms saving the structural material needed for the voids and one high cost motor room would be eliminated. Further major savings would have been possible from this change, if it had been made early in the design cycle and the resulting reduction in volumetric requirements were used to reduce the overall size of the ship.

CONCLUSION

Clearly, there are distinct benefits to be gained by bringing the concepts of producibility into the ship design process and as early in the process as possible. There are sizable savings in manpower possible by the concurrent process of design and production engineering. This is particularly true if the goal for the concurrent effort is not merely "Can it

be built?" but "Is it the lowest cost design?"

To gain the full benefits of producibility it must be started early in the design spiral and continued throughout the design and construction of the ship. It requires a continuing effort with many apparently small victories, but the final results can have an appreciable effect on cost.

Even after the ship is delivered, the design and production engineers with the assistance of the production personnel should continue with a detailed review of the actual results they achieved. Were they right in their producibility changes? Where did they make mistakes? Did they miss **aspects** of the design which could have been done better or cheaper? Without this follow-up effort, the learning process may stagnate and producibility become yet another tired, old watchword.

Finally, we must always keep in mind that we are trying to deliver the best ship at the lowest cost. When we succeed, we all benefit, even the taxpayer.

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Design for Steelwork Production During the Concept Design Phase

William Hills, Visitor and I.L. Buxton, Visitor, University of Newcastle Upon Tyne, Newcastle Upon Tyne, UK, Robert G. Maddison, Visitor, Kvaerner (UK) Ltd., South Shields, UK

ABSTRACT

Methods of improving the level of pre-contract design definition and the quality of information relating to steelwork are described. This information is combined with a comprehensive database of manufacturing process information to provide a system for estimating the work content of the main structural steelwork of ships such as ro-ro vessels. Procedures are described which facilitate consistent estimates to be made while minimizing data handling requirements and increasing the flexibility of the method at the concept design stage.

Applications are described which demonstrate the use of the system in investigations which examine the variation of factors which influence labour cost. The factors examined include the effect of changing midship block breakdown and length of productive day.

Suggestions are made as to how the system can be used to assess the importance of those factors which may improve overall yard production efficiency and assist in the planning function.

INTRODUCTION

Significant advances have been made in the application of advanced technologies to *SKIP* design and Calkins (1) provides an excellent overview of progress in this area. This rate of progress has not been accompanied by similar advances in the area of *SKIP* production in a way which facilitates rigorous analyses of alternative build proposals at the earliest stages in the development of a design. In today's highly competitive market, shipbuilders have to be capable of offering optimum designs, usually implying low construction cost, or at least being able to justify a design at above minimum cost in terms of some special design feature. In addition, the builder has to be confident of the costs estimated, so the methodology used to assess these costs has to be based on sound principles. It is recognised that the new technologies currently used to support ship design activities can be used to improve the builder's ability to assess the effects of different production scenarios on a design proposal. To be effective, a system should provide the capability of assessing different vessel arrangements, variation in hull shape and

alternative structural arrangements and build strategies.

Design tools which incorporate production considerations are not generally available, yet there is a clear need for methods which can provide improved levels of reliability and support at the pre-contract stage for those concerned with cost estimating and planning ship production. Developments in ship production methods combined with progress in the implementation of advanced information and resource control systems, e.g. Milne (2) and Vaughan (3), allow the retrieval and capture of production information which is adaptable for use in models which facilitate the estimation of work content and cost.

While it is appreciated that steelwork may not be the most important item when considering total ship construction cost, it is the area most under the control of the builder, where production monitoring systems development are most advanced and where reliable information of work content can be most readily determined. Steelwork lies on the critical path for delivery, so early definition is essential. For these reasons, we have chosen to develop a method of estimating the work content and costs of steelwork for use at the earliest stages in the development of a design.

SYSTEM OVERVIEW

It is necessary to be able to estimate the manhours taken to construct a vessel and parts of vessels at various stages of a contract, e.g.

- (i) Pre-contract
- (ii) Build strategy /orderbook planning
- (iii) Departmental/tactical planning
- (iv) Workstation loading/operations control.

These stages are often considered as distinct separate activities, usually because the data available increases both in quantity and quality as the contract is worked through. For example very few systems available today facilitate a breakdown of the structure and estimates of joint length to be made at the pre-contract stage. The advantages of making such information available as early as possible are obvious:

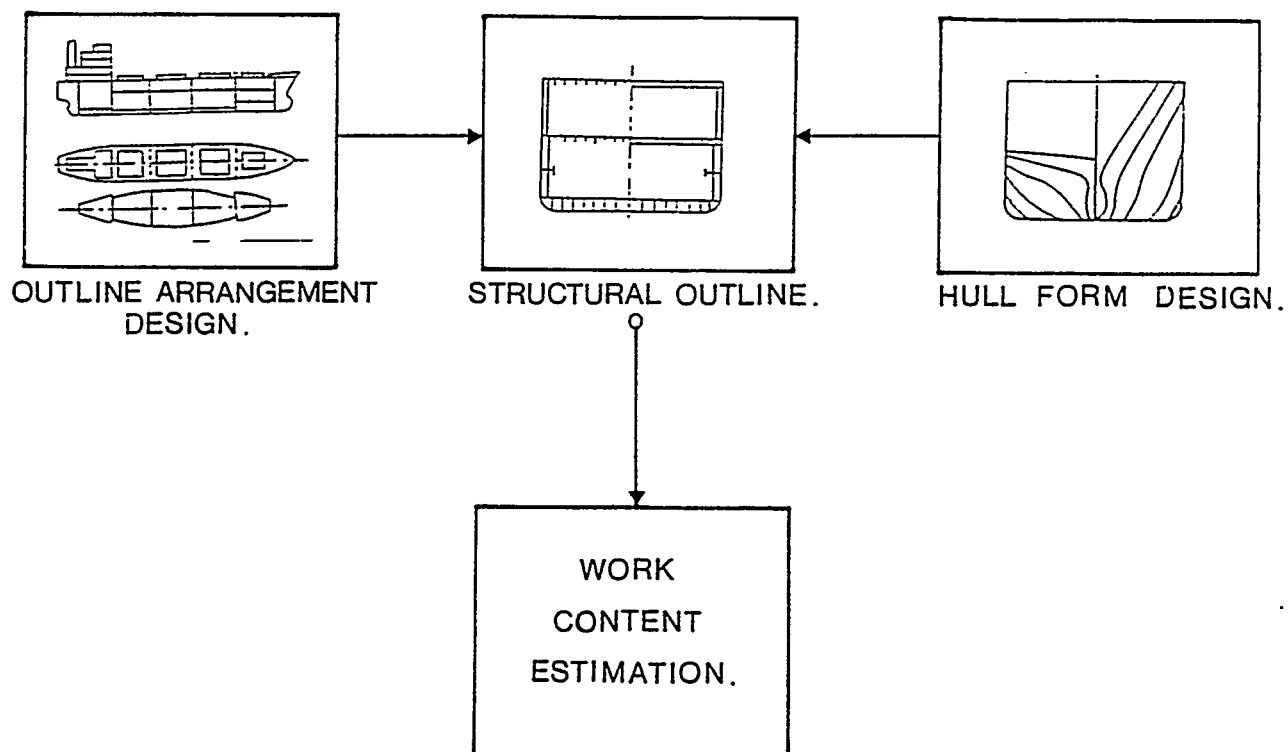


FIG (1). MAIN SYSTEM MODULES

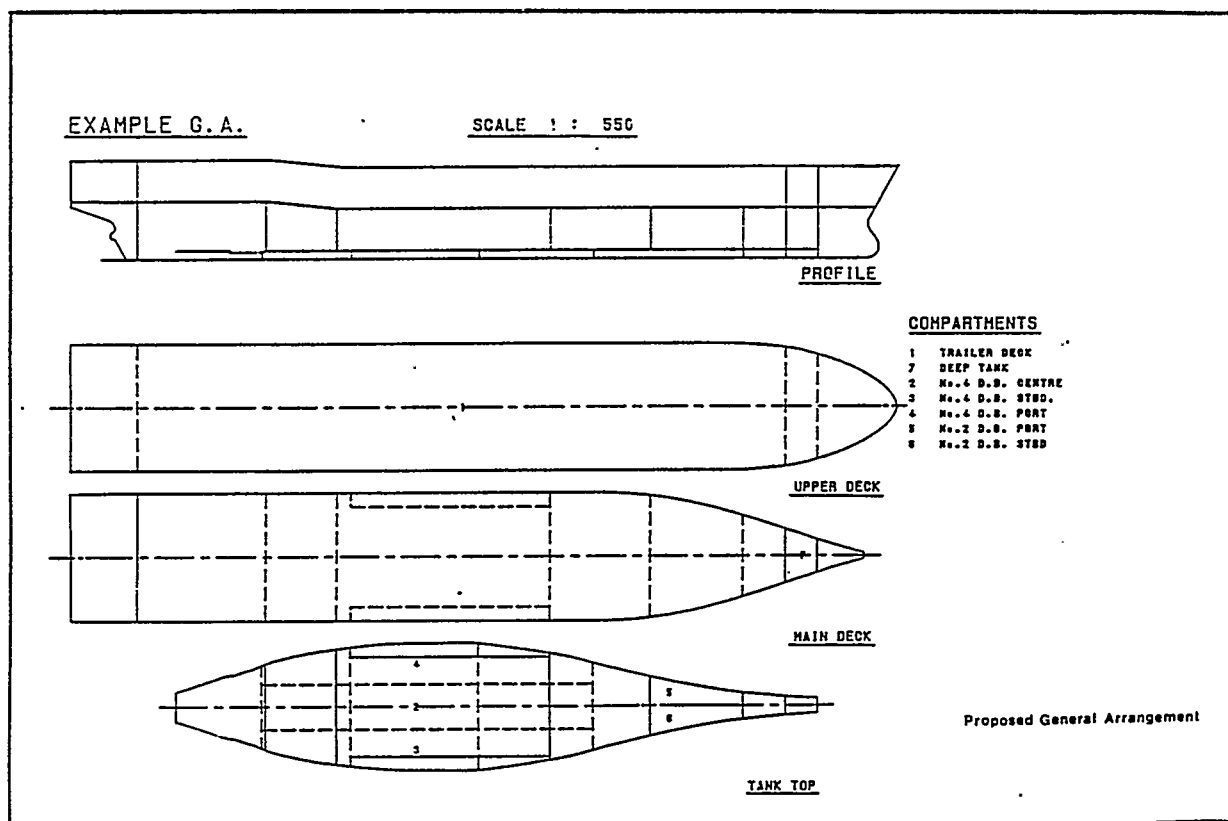


FIG (2). GENERAL LAYOUT OF Ro-Ro SHIP

- (i) The designer and production engineer can agree on a build strategy at the earliest stages in the development of the product.
- (ii) The implications for planning are significant. The system will be a valuable asset when considering the build strategy. Although the definition of the block breakdown and the related sub-assembly breakdown are associated with the wider aim of maintaining the product work breakdown defined in the shipbuilding strategy, we believe the facility to examine, pre-contract, alternative structural arrangements in this context will be of significant benefit to planners, production engineers and estimators.
- (iii) Estimates made of contract manhours at the pre-contract stage can be used to set preliminary man-hour budgets and manning levels at workstations. These can then be refined as new, more detailed, information on the ship is developed.

When considering the work content of steelwork, the preferred parameter is manhours per metre of joint length. In the past parametric methods were used which led to the evaluation of global measures of merit in which production costs were usually evaluated using weight as a basis. It has been recognised that methods based on costs evaluated through the estimation of joint length offer a more rational approach: Winkle (4), Bong (5), Brown (6). The difficulty has been in estimating early in the design process the various joint lengths consistently, rather than just relating to some simple parameter such as weight. However no attempt has been made to develop a system which extends these principles to the ship as a whole, including the ability to take into account alternative build strategies, differing vessel arrangements and hull shape.

These are features which require consideration at the concept stage, where the search for improvement requires a number of alternative designs to be generated and assessed rapidly and accurately. Fortunately research carried out by the authors has produced a design system which can generate useful information specifically developed for use at the concept or pre-contract stage. Fig.(1) shows the main modules of the system upon which the work content estimation process depends. The structure of the system enables comprehensive information regarding shape, layout, structure and scantlings to be provided directly to the cost estimating module.

Links with the Design Process

Hills and Buxton (7) have described a design system which incorporates features which utilize the attributes of artificial intelligence, graphics and database technology. It is sufficient for the purpose of this present paper to indicate the type of data available via such a system to the estimator or planner when assessing work content. This includes:

- (i) A hull form incorporating any special features
- (ii) An outline general arrangement and principal compartmentation information, e.g. Fig.(2).
- (iii) Main structural layout and scantlings at principal sections, Fig.(3).
- (iv) Steelmass estimate and distribution along the length.
- (v) Preliminary checks on: trim, stability, strength, power, motions etc.

The availability of this information at the concept or pre-contract stage at an appropriate level of definition and accuracy within about a day or so of making a

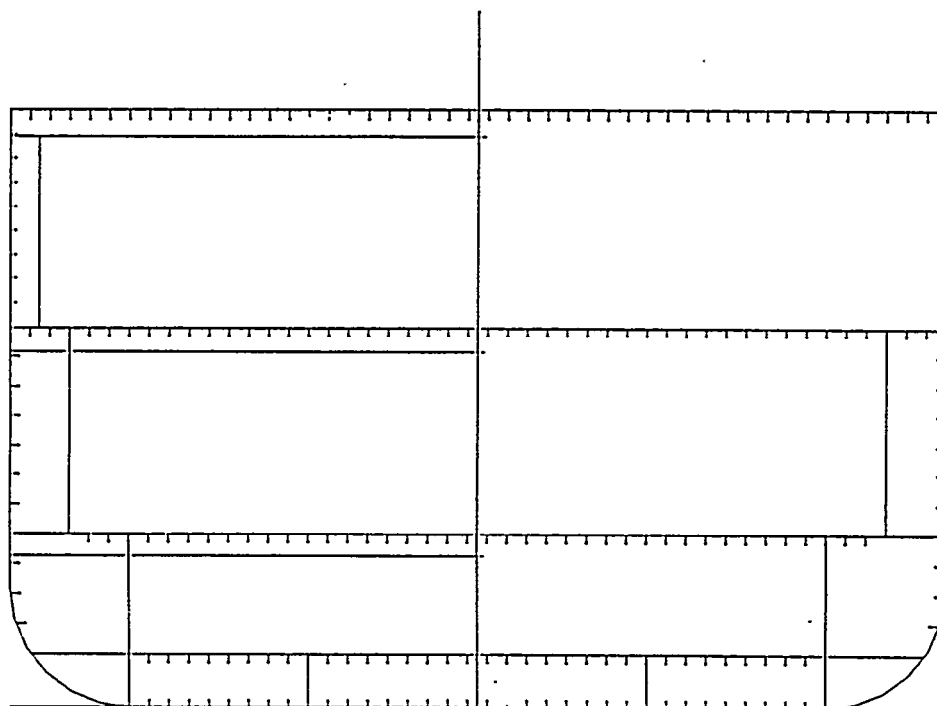


FIG (3). STRUCTURAL LAYOUT

sketch of the design is a significant advance which allows variations to be explored, so that a tender can be prepared with a higher level of confidence. It is possible to use the cost estimating module in a stand-alone mode. In this case the user would simply input information (which had been obtained from alternative sources) under (i) to (iii). A particularly useful application is to consider the midship section only. By doing so a series of sensitivity studies can be carried out in the minimum of time. This mode of application will be demonstrated later in this paper. The ability to estimate scantlings is a necessity if steelwork process analysis data is to be used effectively in the estimating process, since consistent measures of work content are the key.

Determination of Scantlings and Steelmass

The adopted approach requires a reasonably complete internal layout definition, showing decks, bulkheads, hull form and other structural details such as pillars or inner skin. From this information and the applied cargo loadings, the spans of each member are found and the scantlings determined. Most of the scantlings are determined according to the Steel Ship Construction Rules for General Cargo Ships defined by Lloyds Register of Shipping. Where the scantlings are generated consistently, and give an indication of a likely value, it must be emphasised that they are not necessarily final approved values.

The system as developed at present will cater for most types of cargo roll-on/roll-off vessels but not those parts of the ship with cellular container holds. It will also cater for ferries up to the uppermost continuous deck. In principle it will cater for other multi-deck ships not having large hatchways, where the layout and loading of decks can be converted into the equivalent 'ro-ro' input.

Since the scantlings of such ship types as ro-ro ships are significantly affected by the number, height and loading on each deck, special attention is paid to their structure. Vehicle loads are used to assess the basic deck structure, but deep beams and web frames are estimated from an abbreviated finite element calculation.

Due to the variability of possible internal layouts and range of user-defined hull sections, the extent of the results output can vary. A typical ro-ro layout is drawn in Fig.(3). Broadly speaking the following information is generated as output:

- (a) Approximate deck scantlings
approximate bottom scantlings
approximate side shell scantlings
- (b) steelmass rates, V. C. G., components and local dimensions of:-
 - (i) decks
 - ii) bottom
 - iii) side shell
- (c) graphical bar chart of hull section rates along the

length

- (d) mass rates and V.C.G. summary
- (e) main hull steelmass (structure) total and distribution
- (f) ship extremity mass estimates
- (g) transverse bulkhead masses
- (h) superstructures
- (i) graphical plot of cross-sections
- (j) alternative ship depths or clear deck heights on ro-ros.

A typical example of part of the output is shown in Fig.(4).

The availability of this data which gives number, spacing, length and scantlings of the main steelwork components, together with the graphics capability of modern engineering computer workstations, provides the ship designer and production engineer with a powerful product development aid. The place of the scantling and steelmass module within the cost estimating process is indicated in Fig.(5).

WORK CONTENT AND COST ESTIMATING

Some other industries are much more advanced than shipbuilding in not only establishing work content associated with different equipments and construction processes, but in publishing data (8). In the absence of published data for shipbuilding, it is necessary for each company to establish (e.g. by work study) a database of unit times for principal activities of the construction process, which are compatible with the technical description of the hull. In the case of hull structure, it is therefore necessary to be able to break the main portion of the hull into units from which work content can be generated for each of the three principal workstations:

- (1) Preparation (shotblasting, priming, marking, burning, rolling)
Number, areas and perimeter of plates and sections, flat or curved.
 - (2) Fabrication (construction of sub-assemblies and panels, and welding into units or blocks).
- For generic 2D and 3D units, and their panels, units and connections; joint length of plates, sections and associated thicknesses and number of parts.
- (3) Erection (transporting, lifting, fairing, tacking and welding at the berth).
Number, weight, 2D or 3D flat or curved, perimeter joint length, position and access, free-standingness.

Generic Units

The level of detail being considered results in large numbers of structural items being generated by the system. Clearly the problems of handling such large amounts of data are considerable, particularly when the necessity for rapid computer response times is paramount. Large numbers of alternative types and arrangements of units can be defined when considering a build strategy for a ship. At the concept stage these

	mass t	rate	vcg m	bth m	t mm	l m			
TANK TOP PLATE=	7.33	2.89	1.50	22.99	16.0	2.54			
	mass t	rate	vcg m	dw mm	tw mm	ff mm	tf mm	l m	No.
CENTRE GIRDER =	0.40	0.16	0.75	1500.	13.	0.	0.	2.54	1
SIDE GIRDER =	1.18	0.46	0.75	1500.	10.	0.	0.	2.54	4
FLOOR =	3.02	1.19	0.77	1500.	12.	0.	0.	22.99	1
FLOOR STIFFS =	0.42	0.16	0.75	163.	11.	0.	0.	1.00	30
BILGE BRKTS =	0.74	0.29	0.75	1500.	12.	0.	0.	1.81	6
BOTTM LONGL,S =	1.60	0.63	0.11	220.	9.0	bulb	flat	2.54	30
T.TOP LONGL,S =	2.72	1.07	1.36	280.	12.0	bulb	flat	2.54	30
BOTM/BLG SHL =	5.94	2.34	0.12	t=	13. mm				
BOTTOM TOTAL =	23.36	9.20	0.86						
Tank Top load=	6.50	t/m2	spacing=	550. mm					
SIDE SHELL PLT									

	mass t	rate	vcg m	t mm	bth m	l m
STRAKE	1.08	0.43	2.79	10.5	2.54	2.59
STRAKE	2.06	0.81	6.54	10.5	2.54	4.91
STRAKE	2.03	0.80	11.82	9.0	2.54	5.65
STRAKE	0.92	0.36	15.50	13.5	2.54	1.70

SIDE SHELL = 6.08 2.40 8.98

DECK DATA

MAIN DECK Load= 2.50 t/m2 spacing= 550.mm. shell frm spacing= 635.mm

	mass t	rate	vcg m	t mm	bth m	l m			
PLATE =	7.34	2.89	9.00	16.0	23.00	2.54			
	mass t	rate	vcg m	dw mm	tw mm	ff mm	tf mm	l m	No.
DECK BEAMS =	3.69	1.45	8.55	900.	13.	350.	25.	23.00	1
DECK LONGLS =	3.29	1.30	8.85	300.	11.0	bulb	flat	2.54	37
INNER HULL =	8.57	3.37	5.15	2500.	11.	2540.	12.	7.50	2
SIDE FRAMES =	2.67	1.05	5.25	400.	14.0	bulb	flat	7.50	6
DECK GIRDERS =	1.62	0.64	8.55	900.	10.	600.	30.	2.54	3

UPPER DECK Load= 1.50 t/m2 spacing= 600.mm. shell frm spacing= 635.mm

	mass t	rate	vcg m	t mm	bth m	l m			
PLATE =	7.34	2.89	16.35	16.0	23.00	2.54			
	mass t	rate	vcg m	dw mm	tw mm	ff mm	tf mm	l m	No.
DECK BEAMS =	3.20	1.26	15.98	750.	12.	350.	25.	23.00	1
DECK LONGLS =	2.93	1.16	16.20	300.	11.0	bulb	flat	2.54	33
DEEP FRAMES =	1.96	0.77	12.30	850.	12.	350.	25.	6.60	2
SIDE FRAMES =	1.19	0.47	12.68	240.	10.0	bulb	flat	7.35	6
DECK GIRDERS =	0.59	0.23	15.98	750.	10.	200.	12.	2.54	3

TRANSVERSELY FRAMED FLOOR SPACING 2.540 metres

SUMMARY OF HULL SECTION

Item	tonnes	tonne/metre	VCG m	clr ht.blw m	Hght a.b. m
DOUBLE BOTTOM DECKS	23.36	9.20	0.86		
MAIN DECK	15.94	6.27	8.82	6.56	9.00
UPPER DECK	14.07	5.54	16.22	6.56	16.35
SIDE	20.48	8.06	7.42		
TOTAL	73.84	29.07	7.33		

FIG (4). PART OUTPUT FROM SCANTLING AND MASS ESTIMATION MODULE

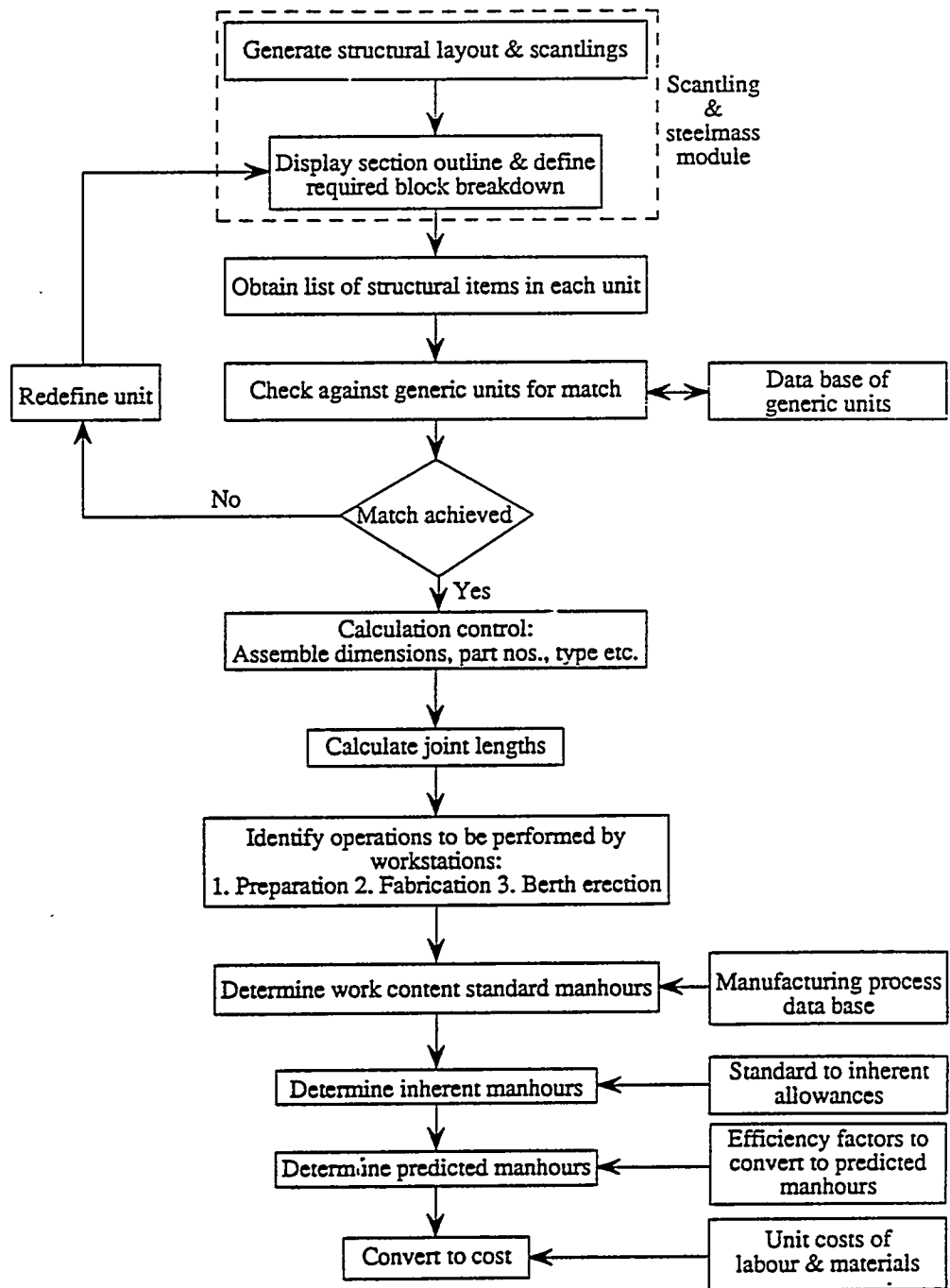


FIG (5). SCHEMATIC OF COST ESTIMATING PROCEDURE

problems can be overcome, without seriously reducing the accuracy and flexibility of the system, by introducing the concept of 'generic units'.

An examination of a range of ship types shows that the structural arrangement of a ship is composed of stiffened panels composed of flat or curved plates to which are welded frames, beams, longitudinals, girders etc. These in turn are joined to make units or blocks of which there are about two dozen basic or 'generic' types. Each generic unit is further sub-divided according to whether each panel is flat or curved, longitudinally or transversely framed etc. For a specific ship type it is usually possible to define a realistic structural arrangement using a sub-set of these generic units. Table (1) gives a list of those used to define Ro-Ro ship structures. Fig.(6) illustrates the arrangement and composition of typical generic units.

Table 1

MENU OF GENERIC UNITS (Ro-Ro Type)

- (1) Flat or Curved Panel with associated stiffeners
- (2) L-Unit Flat or Curved (e.g. deck plus side panel)
- (3) L-Unit **with Inner Hull.**
- (4) **C-Unit Flat** or Curved (e.g. deck plus two side
- (5) C-Unit with Inner Hull
- (6) F-Unit Flat or Curved (e.g. two decks plus side
- (7) F-Unit with Inner Hull
- (8) F-Unit with Lower Inner Hull
- (9) Double Bottom Unit - Full breadth, 5 girders
- (10) Double Bottom Unit - Full breadth, 3 girders
- (11) Double Bottom Unit - Flat with 3 girders
- (12) Double Bottom Unit - Flat with 1 girder
- (13) Double Bottom Bilge Unit - 1 side girder
- (14) Double Bottom Bilge Unit - 2 side girders

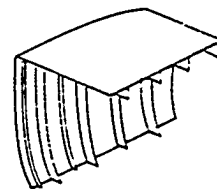
A generic unit can be considered as a 'macro' in computing terms, so has a limited number of defining parameters and possible construction processes. Program development has been facilitated by limiting the potentially infinite number of possible constructional arrangements to generic building blocks which are typical of practical shipbuilding.

Using his knowledge of the range and form of available generic units, the designer/planner is able to divide the hull into a number of blocks which represent a possible build strategy, Fig.(7). The dimensions of a unit are compared against the maximum dimensions that the facility can handle and against defined 'preferred dimensions'. For example the unit length is checked to ensure that it is a multiple of the deep frame spacing and that it is less than or equal to the maximum plate length which has been defined as a yard standard or as a preferred plate size. The availability of weight data also allows the total weight of a unit to be compared against the maximum lifting capacity. Once the user has defined a unit envelope, the system interrogates the structural database and assembles a list of items which exist within the envelope boundaries. The list

Fig.6 — EXAMPLES OF GENERIC UNITS.

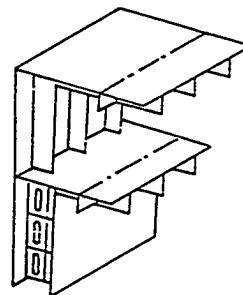
L - Unit.

Side Shell and Deck Panel.



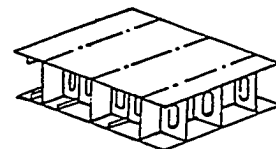
F - Unit.

with Lower Inner Hull.



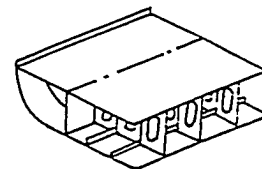
Double Bottom.

Centre Unit - Flat 3 Girders.



Double Bottom.

Bilge Unit - 1 Side Girder.

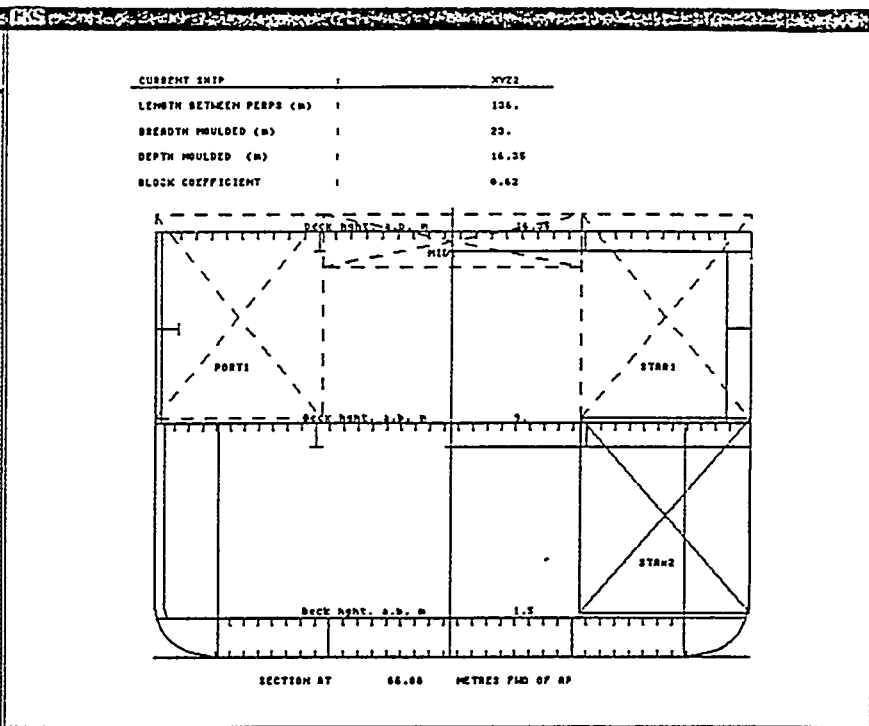
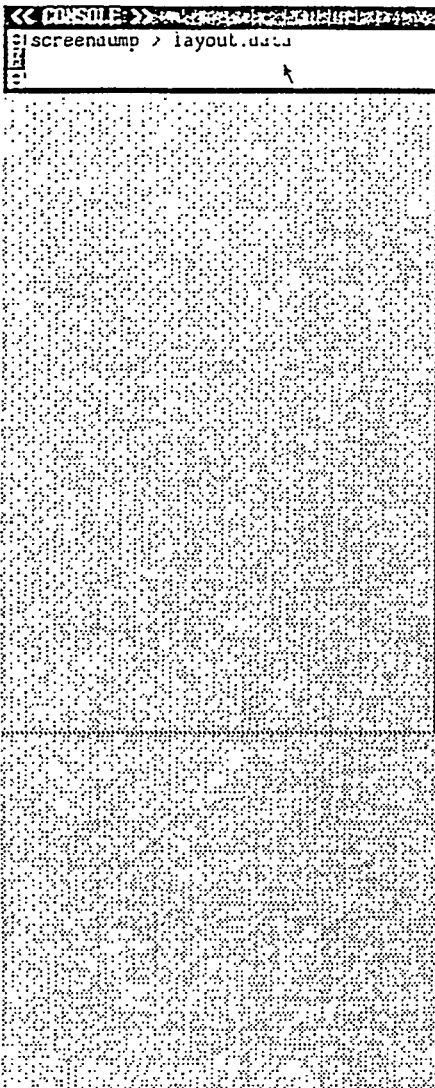


of items is checked against the list of structural items which are used in the definition of each generic unit. If a match is not found, a message appears on the screen and the user is invited to re-define the boundaries of the unit under consideration. When a unit has been successfully defined and matched, the output from the scantling and mass estimation program is accessed to pick out the geometry and scantlings associated with each panel, e.g. plating thickness, stiffener type, spacing and dimensions.

The procedure by which a match is made between the user defined unit and the data bank of generic units is as follows:

- (i) The structural data base is interrogated to identify the structural items which lie within the defined boundaries.
- (ii) The program creates a list of items for the Unit, each item being represented by a number.
- (iii) Using an indexed search technique, this list of numbers is checked against the stored sequences that predefine each generic unit.
- (iv) When a comparative list of items is found, the structural routine is invoked and the work content parameters are generated.

An example of a typical record for a generic unit is shown in Fig.(8). This is for a 'L' unit, e.g. deck and side shell. It can be seen that the match has been made on the list of items where



NOTE axis are:- NEGATIVE to PORT of CL
POSITIVE to STARBOARD of CL

INPUT THE LEFT HAND SIDE OF UNIT " STAR2 " looking fwd about CL m ? 5
INPUT THE RIGHT HAND SIDE OF UNIT " STAR2 " looking fwd about CL m ? 11.5
INPUT THE HEIGHT a.b. OF THE BOTTOM OF UNIT " STAR2 " m ? 1.7
INPUT THE HEIGHT a.b. OF THE TOP OF UNIT " STAR2 " m ? 9.2

INPUT CORRECT (Y/N) ? Y

RE-DEFINE THE CURRENT OR A PREVIOUS UNIT Y/N ? ☐

FIG (7). MIDSHIP SECTION SHOWING PARTIAL BLOCK BREAKDOWN

* GENERIC UNIT TYPE		SPECIFIC UNIT	
* L Units		Deck & side shell: curved, longl framed	
2		1	
* NO. FOUND	NO.GENERATED (PREPARATION)	NO. GENERATED (FABRICATION)	NO. GENERATED (BERTH ERECTION)
7	10	17	12
* SEQUENCE FOUND			
0 1 2 3 16 18 22			
* SEQUENCE GENERATED (PREPARATION)			
0 1 2 3 7 8 16 18 22 38			
* SEQUENCE GENERATED (FABRICATION)			
0 1 2 3 4 5 6 7 8 16 18 22 27 35 36 37 38			
* SEQUENCE GENERATED (BERTH ERECTION)			
9 10 11 12 13 14 28 29 30 31 33 91			

FIG (8). STRUCTURAL ITEMS IDENTIFIED BY WORKSTATION FOR GENERIC UNITS

- 0 = Deck Plate
- 1 = Deck Beams
- 2 = Deck Longitudinals
- 3 = Deck Girders
- 16 = Side Shell Plate Curved
- 18 = Deep Web Frames Curved
- 22 = Side Longitudinals Curved

However the record also shows an extended list for each workstation, i.e. complete construction 'sequence generated'. These additional items cater for processes implicit in the assembly operations but not explicitly defined by the structural routine. For example in the fabrication of the 'L' unit, these are:-

- 4 = Beam/Longitudinal Interconnections
- 5 = Beam/Girder Flange Interconnections
- 6 = Beam/Girder Butt Interconnections
- 7 = Beam/Girder Gussets
- 8 = Beam Tripping Brackets
- 27 = Deep Frame/Side Longitudinal Interconnections
- 35 = Deck/Side Shell Interconnections
- 36 = Deep Frame/Beam Interconnections
- 37 = Beam/Side Shell Interconnections
- 38 = Deep Frame/Beam Bracket Interconnections

While these items are not calculated 'structure' and may not have weight, they do have the other attributes of structural items such as: joint length, thickness and number and they therefore have a work content associated with them.

When a defined unit has been accepted and the appropriate workstation identified, the program calculates the work content parameters for each item in the list. Each item in a panel is then associated with a pre-determined manufacturing process module, which is part of a comprehensive process analysis database, which identifies the steelworking processes necessary to prepare and fabricate it, in terms of workstation, equipment needed, joint type and sequence of construction. The work content database (which can be modified by the designer) is then accessed to pick out the standard time for each process invoked.

The work content database

The original work content data base was developed after extensive work study operations in British Shipbuilders Govan Shipyard at Glasgow. In essence the database consists of the standard times necessary to carry out an operation. The 'standard time' is the time in which a task should be completed by a worker at normal performance as defined in British Standards and described later. The range of operations contained in the current data are given in Table (2). A typical record for an operation is shown in Fig.(9).

The items are identified via the models of the assembly/fabrication process in which the sequence of the work process has been modelled for each generic unit and thus, implicitly, for the defined unit. This model of the assembly/fabrication process together with the

information on joint length, thickness, number of piece parts etc. allows the work content to be determined. The joint length is the physical connection length, irrespective of the number of weld passes needed to complete it.

Table 2 - WORK CONTENT DATABASE

- 1 Manual butt weld downhand restricted
- 2 Manual butt weld downhand unrestricted
- 3 Manual butt weld downhand and overhead restricted
- 4 Manual butt weld vertical restricted
- 5 Manual butt weld vertical unrestricted
- 7 Manual butt weld overhead restricted
- 10 Manual butt weld horizontal restricted
- 11 Manual butt weld horizontal unrestricted
- 13 Manual fillet weld downhand restricted
- 14 Manual fillet weld downhand unrestricted
- 15 Manual fillet weld vertical restricted
- 16 Manual fillet weld vertical unrestricted
- 17 Manual fillet weld horizontal restricted
- 18 Manual fillet weld horizontal unrestricted
- 19 Automatic butt weld seam constant
- 20 Automatic butt weld welding constant
- 21 Automatic fillet welding
- 22 Automatic butt weld seam constant
- 23 Automatic butt welding constant (one side)
- 25 Fair and tack T-Section restricted (positioned manually)
- 26 Fair and tack T-Section unrestricted (positioned manually)
- 27 Fair and tack T-Section restricted (positioned by crane)
- 28 Fair and tack T-Section unrestricted (positioned by crane)
- 29 Fair and tack longl or frame (OBP - straight) unrestricted
- 30 Fair and tack longl or frame (OBP - CURVED) unrestricted
- 31 Fair and tack flat plate butts
- 32 Fair and tack curved plate butts
- 50 Berth erection type 1 unit
- 51 Berth erection type 2 unit
- 52 Berth erection type 3 unit

Once a generic unit has been identified and the manufacturing information generated at each of the three main workstations, the work content estimation algorithms are invoked. For each structural item within a unit, e.g. deck girder, a manufacturing process code is applied. For example, at fabrication of deck girders, processes include from Table 2:

- 28 Fair and Tack T-section unrestricted, positioned by crane
- 21 Automatic fillet welding.

In turn these operations are associated with the length and thickness of each particular girder. By looking up in the appropriate work content database record similar to Fig.(9), the basic and hence the standard minutes can be calculated.

MANUAL BUTT WELD DOWNHAND UNRESTRICTED CONSTANTS (MBWDUC)

ARRAY POINTER	SIZE		
2	20		
Std. Global Job Constant	Basic Global Job Constant	(in minutes)	
16.5	12.29		
Std. Lifting & Turning Constant	Basic Lifting & Turning Constant	(in minutes)	
12.12	9.18		
Std. Section Constant	Basic Section Constant	(in minutes)	
0.0	0.0		
RATE: Std Min/mtr	BASIC Min/mtr	PLATE THICKNESS ('T' mm)	
		lower < T <=	upper

53.96	11.34	0.0	8.0
63.73	24.41	8.0	10.0
67.70	27.29	10.0	11.0
76.62	33.79	11.0	13.0
77.64	34.51	13.0	14.0
86.39	40.89	14.3	16.0
96.69	48.35	16.0	18.0
107.03	55.88	18.0	19.0
119.42	64.93	19.0	20.0

'K' PREPARATION ABOVE			
'M' PREPARATION BELOW			

74.17	53.08	20.0	22.
83.02	59.35	22.0	23
94.88	67.26	5	2
106.11	75.72		
117.16			
130.80			
144.03			

FIG (9). RECORD FROM WORK CONTENT DATA BASE FOR ONE PROCESS

Such calculations are made using a 'standard algorithm' which allows for the appropriate coefficients to be automatically selected according to the structural item, processes and thickness. Thus standard minutes for deck girder fabrication are calculated in the form of:

Global Job Constant Process 28 + Global Job Constant Process 21
+ Section Constant for Process 28 x Number of Sections [2 for web plus flange]
+ (Minutes per Metre Process 28 + Minutes per Metre Process 21) x Piece Part Assembly Joint Length [Flange welded to web].

A similar calculation is made for welding the fabricated girder to the deck plating using Panel Fabrication Joint Length. Each element is adjusted if necessary for actual manning if different from standard manning levels and then converted to manhours. It can also be multiplied by a process efficiency factor if the actual process in the shipyard differs from the standard assumed.

Comparable algorithms are used at Preparation and at Berth Erection workstations using the appropriate processes and work content parameters.

ESTIMATING OVERALL STEELWORK MAN-HOURS

The basis of the standard manhour estimate is the structural definition generated by the scantling and steelmass program and the unit breakdown as input by the user. At the preliminary design stage, it is not possible to specify every item of structure in complete detail, for example, cut-outs in floors, so that it is necessary to make allowances for such elements which are inherent in any as-built structure. Thus standard man-hours are converted to inherent manhours according to type of generic unit and the relevant workstation.

The inherent manhours reflect the work content built-in by the structural designer and the proposed build strategy. In an ideal world, inherent manhours would be the same as actual manhours, but there are many reasons why actual hours will be significantly higher. Elements such as rework percentage, effective use of the working day or material control efficiency all add to the manhours recorded for actual ships. Thus factors which are specific to a particular shipyard and its management need to be added to obtain predicted manhours as a realistic estimate of Actual manhours.

Standard Time

Standard times have been derived from work study data, so represent the average time that a qualified worker should take, using the specified method and proper motivation. Normal relaxation and contingency allowances are included to account for 'legitimate' extra time to add the basic process time. The user may build into the database additional factors to allow for process efficiencies different from the standard. For example a particular process may use a more efficient method than incorporated in the database (e.g. laser cutting of thin plate), while the actual manning level of this process may require a different number of operators to that assumed.

Inherent Time

At each of the workstations, it is necessary to make allowances for additional operations that are not explicitly included in the hull definition. At the preparation stage, for example, burning lengths calculated for bare plates need to be increased for (undefined) cut-out lengths. At fabrication, minor brackets and stiffeners need to be allowed for on top of the main structural elements. If any outfit structure such as seatings are being added at this stage, the factor can be adjusted, although it is probably better to keep such items separated from main structure in the estimate.

At berth erection, the basic process of say butt welding of adjacent panels uses the standard database for type of weld and thickness. Allowances need to be made for the location of the unit on the berth and access thereto, whether it is a 2D or 3D unit, as well as the overall weight in terms of extra time to transport and lift. Thus for berth erection, a typical form of Standard to Inherent calculation for a particular generic unit is:

Inherent manhours = Standard manhours (1 + access factor)

- + Berth erection joint length x 2D/3D factor
- + Unit weight x weight factor

The database containing default values may be adjusted by the user.

Inherent time reflects on a consistent basis differences in work content arising from the way the structure has been designed and the proposed breakdown of units. Thus it can be used to compare the 'efficiency' of alternative strategies.

Predicted Time

Predicted time has to incorporate all those efficiencies which are not inherent in the technical specification, but reflect the success (or otherwise) of a particular shipyard's management in controlling all the ways in which jobs take extra time. Anyone who has worked in a shipyard will recognise that the number of hours booked to a job will be higher than the somewhat idealised inherent hours due to:-

poor plant layout resulting in additional time to transfer men and components between workstations
inadequate craneage resulting in extra time to lift and move units

environmental conditions, e.g. bad weather in terms of wind, rain or temperature delaying activities.
An open facility in a bad weather region will lose more time than a covered facility, but less so in a good weather region.

rework, due to poor accuracy control or distortion, e.g. cutting and trimming units

poor time-keeping. Late starting and early finishing is not unknown in shipyards

official and unofficial breaks for meals, refreshments etc, reducing the effective working day

material control efficiency, reflecting the ability to ensure that labour is not held up waiting for materials

labour control efficiency, to ensure that work, especially on the critical path, is not held up for lack of labour, either of any type, or of a specific type, e.g. due to trade demarcation

excess manning levels. A yard may allocate more men to an activity than is strictly necessary, perhaps as a result of trade union pressure, or 'using' surplus manpower.

shipyard loading. It is not always possible to match the workload to the available labour, particularly as order books run out, when the tempo of work may also slow down.

In the program, these factors are incorporated in a number of factors:-

Generic Unit or Workstation

- (i) Plant layout factor
- (ii) Environmental factor
- (iii) Rework factor
- (iv) Labour application factor
- (v) Waiting factor

Global Shipyard Factors

- (vi) Effective working day factor
 - (vii) Manning level factor
 - (viii) Shipyard loading factor
-
- (i) Covers deviation from ideal flow-line layout
 - (ii) Varies between workstations; obviously shipyard location specific
 - (iii) Rework includes a factor to allow for cutting and edge correction particularly at berth erection. It depends on the ability of the yard, together with its accuracy control procedures, to produce structural components within acceptable tolerances. There is a separate allowance of manhours per square metre to allow for distortion correction which is a function of panel area and generic unit.
 - (iv) Labour application factor depends on the effectiveness of management and supervision in ensuring that the correct labour is available at the correct time and working properly.

- (v) Waiting factor allows for delays where labour is waiting for materials, services, information or due to equipment breakdown.

The remaining three factors can be expected to apply across the entire shipyard at any given time. They are essentially self-explanatory, and applied as global factors to the total manhours.

The importance of the above eight factors should not be underestimated, since they are cumulative. For example, if one postulates the following values for each factor (averaged across units):

- (i) 1.05 (ii) 1.10 (iii) 1.30 (iv) 1.15 (v) 1.20 (vi) 1.25 (vii) 1.15 (viii) 1.00

this gives an overall factor of 2.98. Thus three times as many hours have to be paid for as are technically required. Furthermore, elapsed build time is likely to be longer (though not proportionately) and direct overheads will be increased.

In practice, the elements are estimated on the basis of techniques such as activity sampling and rework measurement, plus professional judgement. In particular areas, overall Inherent to Actual factors as low as 1.5 and as high as 6 have been found. It is also desirable to check the overall factors from completed units in a specific shipyard so that individual factors can be tuned on a heuristic basis to give consistent results. The factors do of course highlight areas where the most managerial attention should be paid. Broadly speaking, poor performance shipyards will get a better return from controlling the above factors than installing new equipment, where the latter mainly affects Standard Time rather than Actual Time.

APPLICATIONS AND DISCUSSION

To illustrate the use and capabilities of the system a basis ship is selected. The vessel is a 7500 tonne dead-weight, two-deck ro-ro ship, with an inner hull in the lower hold. The principal dimensions are:

Length B.P.	136.0m
Breadth moulded	23.0m
Depth moulded to upper deck	16.4m
Depth moulded to main deck	9.0m
Design draught	6.9m
Block coefficient	0.622
Scantlings	See Fig.4 for estimated data

The main benefit of the new system is that it enables the designer to investigate the effects of possible changes in structural configuration, production facility capabilities and workstation parameters. To illustrate this capability, examples are given in which the following are examined: changes in the number of units used to construct the midship region and the effects of variation in length of productive day.

Effect of Change in Unit Configuration

One of the most important decisions to be made when developing a design concept is to determine the unit or block breakdown which is compatible with the available production facilities and is capable of being produced efficiently at minimum cost. One stage in the investigation might be a comparison of alternative unit breakdowns on a basis of minimum cost of labour plus material, while satisfying the maximum lifting capacity at each workstation. To illustrate this approach, three alternative unit configurations were generated, consisting of 3, 6 and 9 units respectively, which are shown in Fig.(10). The joint lengths, work content and labour cost estimates, are generated. A typical output for a 'C' unit at the fabrication workstations is shown in Fig.(11) and a summary of the figures for all three unit configurations at the fabrication and berth erection workstations is given in Fig.(12). This data can be examined to identify areas of high work content, e.g. beam/girder gusset plates.

The total costs of labour plus material for each configuration, presented by workstation, is given in Fig. (13). The total cost for the 3, 6, and 9 unit configurations are £150,685 £155,471 and £156,746, respectively indicating that over the midship region the 3-unit configuration minimises cost. Then providing the shipyard's handling facilities are adequate, a 3-unit arrangement is to be preferred and can save 4% of the cost of a 9-unit configuration. A similar study by Bong (5) for bulk carriers using Korean data gave a similar result showing that a reduction in the number of units from 8 to 4 reduced costs by 5%.

Effects of Changing the Length of productive Day

One of the most obvious factors which influences productivity levels is the length of the period during which work is carried out. The benefits to be gained can be readily assessed by means of a sensitivity study in which the appropriate value is systematically varied. The original data used in these examples is shown in Table 3. To demonstrate the effect of varying the length of productive day the original figure of 5 hours was changed by + 1 hour. The effects are shown in the tables in Fig.(13). It can be seen that a one-hour increase in the productive day produces a saving of approximately £13,000, whereas a decrease of one-hour adds about £20,000 or 25%.

These changes refer only to different build strategies. An even more valuable application is to look at:

CURRENT SHIP	1	MY22
LENGTH BETWEEN PERPS (M)	1	126.
BREADTH MOULDED (M)	1	23.
DEPTH MOULDED (M)	1	16.35
BLOCK COEFFICIENT	1	0.82

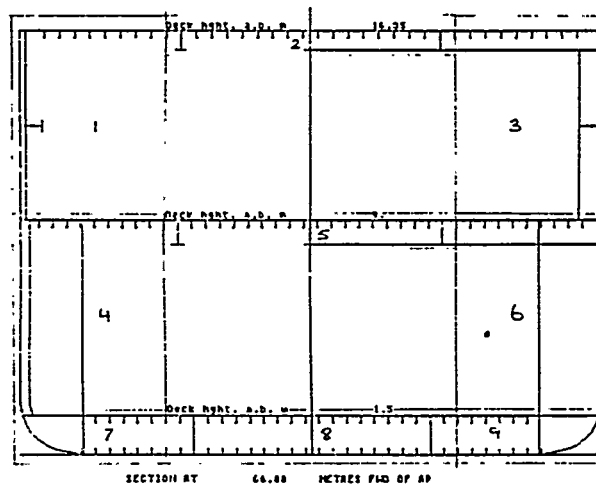
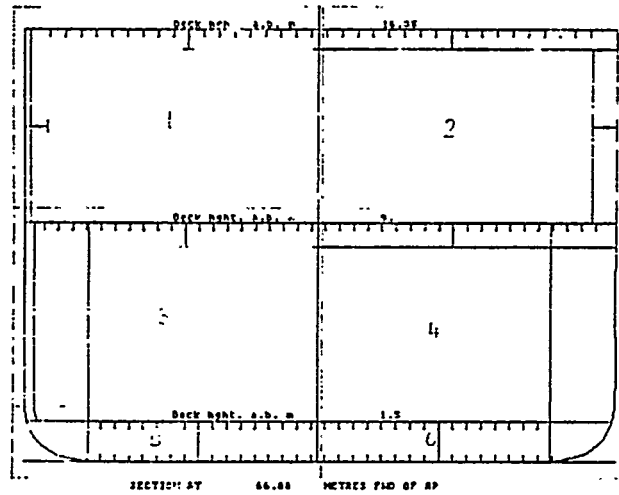
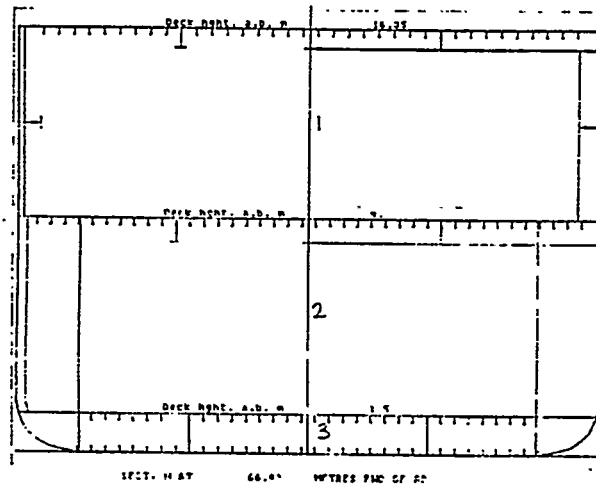


FIG (19). ALTERNATIVE UNIT CONFIGURATIONS

Unit No : 1											
Unit Type											
C-UNIT (Deck + 2 Sides)											
Items (By Panel)											
Work Content and Material Cost Parameters											
	PPAJL	PFJL	UFJL	BEJL	No.	THKS	NETT	GROSS	GD		
	(m)	(m)	(m)	(m)	Parts	(mm)	WT. (T)	WT. (T)			
Data For Deck No. 2 and Below											
DECK PLATE	71.12	0.00	0.00	23.00	8	16.0	29.35	30.52	NA		
DECK BEAMS	4.40	184.00	0.00	0.00	8	12.0	12.82	13.33	NA		
DECK LONGITUDINALS	0.00	345.44	0.00	10.20	34	11.0	11.74	12.21	NA		
DECK GIRDERS	0.00	60.96	0.00	2.85	3	10.0	2.37	2.46	NA		
BM/LONG'L INTER	0.00	0.00	20.40	0.00	136	11.0	0.00	0.00	NA		
BM/GRDR INTER (F)	0.00	0.00	22.20	0.00	12	10.0	0.00	0.00	NA		
BM/GRDR INTER (B)	0.00	0.00	4.80	0.00	12	12.0	0.00	0.00	NA		
BM/GRDR GUSSETS	0.00	0.00	33.60	0.00	48	25.0	0.58	0.60	NA		
BM/TRIP BRACKETS	0.00	24.00	0.00	0.00	32	12.0	0.17	0.18	NA		
S.SHELL PL (FLAT)	20.32	0.00	0.00	17.41	3	9.5	5.50	5.72	NA		
D.FRAMES (SRT)	26.40	26.40	0.00	3.10	4	12.0	3.93	4.08	NA		
S.FRAMES (SRT)	0.00	88.20	0.00	1.44	12	10.0	2.24	2.33	NA		
DECK/S.SHELL INTER	0.00	0.00	10.16	0.00	1	16.0	0.00	0.00	NA		
DP.F/BEAM INTER	0.00	0.00	4.80	0.00	4	25.0	0.00	0.00	NA		
BEAM/S.SHELL INTER	0.00	0.00	4.40	0.00	4	12.0	0.00	0.00	NA		
DP.F/BEAM BRACKETS	0.00	0.00	13.60	0.00	4	25.0	1.13	1.18	NA		
S.SHELL PL (FLAT)	20.32	0.00	0.00	17.41	3	9.5	5.50	5.72	NA		
D.FRAMES (SRT)	26.40	26.40	0.00	3.10	4	12.0	3.93	4.08	NA		
S.FRAMES (SRT)	0.00	88.20	0.00	1.44	12	10.0	2.24	2.33	NA		
DECK/S.SHELL INTER	0.00	0.00	10.16	0.00	1	16.0	0.00	0.00	NA		
DP.F/BEAM INTER	0.00	0.00	4.80	0.00	4	25.0	0.00	0.00	NA		
BEAM/S.SHELL INTER	0.00	0.00	4.40	0.00	4	12.0	0.00	0.00	NA		
DP.F/BEAM BRACKETS	0.00	0.00	13.60	0.00	4	25.0	1.13	1.18	NA		
Totals	168.96	843.60	146.92	79.96			82.62	85.93			

PPAJL = Piece Parts Assembly Joint Length
PFJL = Panel Fabrication Joint Length
UFJL = Unit Fabrication Joint Length
BEJL = Berth Erection Joint Length

FIG (11a). TABLE OF JOINT LENGTHS FOR 'C' UNIT

UNIT LABOUR COST BREAKDOWN

SHIP	Structural	STANDARD	INHERENT	ACTUAL	FAB	W.CONT/	W.CONT/
UNIT	Items	W.CONT	W.CONT	W.CONT	LABOUR	METRE	TONNE
No.	(Within Unit)	(MHRS)	(MHRS)	(MHRS)	COST (\$)	(MHRS/m)	(MHRS/T)
FABRICATION							
1	DECK PLATE	40.94	46.27	151.81	835.0	2.13	5.17
1	DECK BEAMS	234.70	265.21	870.21	4786.2	4.62	67.88
1	DECK LONGITUDINALS	65.40	73.91	242.50	1333.8	0.70	20.66
1	DECK GIRDERS	30.31	34.25	112.39	618.1	1.84	47.44
1	BM/LONG'L INTER	26.50	29.94	98.25	540.4	4.82	0.00
1	BM/GRDR INTER (F)	28.81	32.56	106.82	587.5	4.81	0.00
1	BM/GRDR INTER (B)	4.99	5.64	18.51	101.8	3.86	0.00
1	BM/GRDR GUSSETS	41.68	47.10	154.56	850.1	4.60	267.88
1	BM/TRIP BRACKETS	1.53	1.73	5.67	31.2	0.24	33.44
1	S.SHELL PL (FLAT)	12.24	13.84	45.40	249.7	2.23	8.26
1	D.FRAMES (SRT)	17.01	19.22	63.06	346.8	1.19	16.06
1	S.FRAMES (SRT)	18.00	20.33	66.72	367.0	0.76	29.74
1	DECK/S.SHELL INTER	13.92	15.73	51.62	283.9	5.08	0.00
1	DP.F/BEAM INTER	8.26	9.34	30.64	168.5	6.38	0.00
1	BEAM/S.SHELL INTER	4.74	5.36	17.59	96.7	4.00	0.00
1	DP.F/BEAM BRACKETS	7.55	8.53	27.99	154.0	2.06	24.68
1	S.SHELL PL (FLAT)	12.24	13.84	45.40	249.7	2.23	8.26
1	D.FRAMES (SRT)	17.01	19.22	63.06	346.8	1.19	16.06
1	S.FRAMES (SRT)	18.00	20.33	66.72	367.0	0.76	29.74
1	DECK/S.SHELL INTER	13.92	15.73	51.62	283.9	5.08	0.00
1	DP.F/BEAM INTER	8.26	9.34	30.64	168.5	6.38	0.00
1	BEAM/S.SHELL INTER	4.74	5.36	17.59	96.7	4.00	0.00
1	DP.F/BEAM BRACKETS	7.55	8.53	27.99	154.0	2.06	24.68
SUMMARY TOTAL		638.3	721.3	2366.8	13017.3	2.04	28.65

FIG (11b). TABLES OF WORK CONTENT AND LABOUR COSTS FOR 'C' UNIT. AT FABRICATION WORKSTATIONS

3 - UNIT LABOUR COST BREAKDOWN

SHIP UNIT No.	GENERIC UNIT TYPE	STANDARD W. CONT (MHRS)	INHERENT W. CONT (MHRS)	ACTUAL W. CONT (MHRS)	FAB LABOUR COST (\$)	W. CONT/ METRE (MHRS/m)	W. CONT/ TONNE (MHRS/T)
FABRICATION							
11C-UNIT (Deck + 2 Sides)		638.321	721.30	2366.781	13017.31	2.04	28.65
21C-UNIT (Deck + 2 Sides 2		960.171	1142.60	3749.161	20620.41	2.04	33.84
31DBL BOTTOM TOTAL UNIT		1091.911	1299.27	4263.561	23449.61	2.73	46.39
GRAND TOTAL		2690.4	3163.5	10379.5	57087.21	2.27	36.38

SHIP UNIT No.	GENERIC UNIT TYPE	STANDARD W. CONT (MHRS)	INHERENT W. CONT (MHRS)	ACTUAL W. CONT (MHRS)	FAB LABOUR COST (\$)	W. CONT/ METRE (MHRS/m)	W. CONT/ TONNE (MHRS/T)
BERTH ERECTION							
11C-UNIT (Deck + 2 Sides)		39.101	89.83	345.281	1899.01	6.64	0.00
21C-UNIT (Deck + 2 Sides 2		42.541	182.54	701.631	3859.01	4.65	0.00
31DBL BOTTOM TOTAL UNIT		97.721	220.12	846.101	4653.51	5.26	0.00
GRAND TOTAL		267.6	771.1	2967.8	16322.91	5.24	0.00

6 - UNIT LABOUR COST BREAKDOWN

SHIP UNIT No.	GENERIC UNIT TYPE	STANDARD W. CONT (MHRS)	INHERENT W. CONT (MHRS)	ACTUAL W. CONT (MHRS)	FAB LABOUR COST (\$)	W. CONT/ METRE (MHRS/m)	W. CONT/ TONNE (MHRS/T)
FABRICATION							
11L-UNIT (Deck + Side)		333.521	350.19	1149.081	6319.91	1.94	27.49
21L-UNIT (Deck + Side)		301.181	316.24	1037.661	5707.21	1.88	25.42
31L-UNIT (Deck + Side + IH		501.051	531.11	1742.721	9584.91	1.85	30.67
41L-UNIT (Deck + Side + IH		455.351	482.67	1583.751	8710.61	1.79	29.34
51DB BILGE 2 S.GRDRS+CG		623.901	698.77	2282.821	12610.51	2.74	54.94
61DB BILGE (2 S.GRDRS)		461.561	516.95	1696.231	9329.31	2.42	43.26
GRAND TOTAL		2676.6	2895.9	9502.3	52262.51	2.11	34.64

SHIP UNIT No.	GENERIC UNIT TYPE	STANDARD W. CONT (MHRS)	INHERENT W. CONT (MHRS)	ACTUAL W. CONT (MHRS)	FAB LABOUR COST (\$)	W. CONT/ METRE (MHRS/m)	W. CONT/ TONNE (MHRS/T)
BERTH ERECTION							
11L-UNIT (Deck + Side)		45.631	105.81	406.711	2236.91	5.85	0.00
21L-UNIT (Deck + Side)		73.771	101.28	389.301	2141.21	5.86	0.00
31L-UNIT (Deck + Side + IH		49.041	150.49	578.451	3181.51	4.79	0.00
41L-UNIT (Deck + Side + IH		46.551	144.38	554.971	3052.31	4.76	0.00
51DB BILGE 2 S.GRDRS+CG		79.471	160.46	616.781	3392.31	5.21	0.00
61DB BILGE (2 S.GRDRS)		67.621	138.21	531.261	2921.91	4.99	0.00
GRAND TOTAL		529.2	1316.0	5058.3	27820.61	5.21	-

9 - UNIT LABOUR COST BREAKDOWN

SHIP UNIT No.	GENERIC UNIT TYPE	STANDARD W. CONT (MHRS)	INHERENT W. CONT (MHRS)	ACTUAL W. CONT (MHRS)	FAB LABOUR COST (\$)	W. CONT/ METRE (MHRS/m)	W. CONT/ TONNE (MHRS/T)
FABRICATION							
11L-UNIT (Deck + Side)		211.311	221.88	728.041	4004.21	1.89	26.35
21Panel Unit		217.201	230.23	755.431	4154.91	2.07	27.52
31L-UNIT (Deck + Side)		211.311	221.88	728.041	4004.21	1.89	26.39
41L-UNIT (Deck + Side + IH		308.731	327.25	1073.801	5905.91	1.65	29.71
51Panel Unit		337.281	357.52	1173.111	6452.11	2.26	30.31
61L-UNIT (Deck + Side + IH		308.731	327.25	1073.801	5905.91	1.65	29.75
71DB BILGE (1 S.GRDR)		277.301	335.53	1100.961	6055.31	3.44	58.02
81DB BTH FLAT 2 S.GRDRS		528.871	666.38	2186.571	12026.11	2.50	50.25
91DB BILGE (1 S.GRDR)		277.301	335.53	1100.961	6055.31	3.44	58.02
GRAND TOTAL		2678.0	3023.5	9920.7	54563.91	2.22	36.16

SHIP UNIT No.	GENERIC UNIT TYPE	STANDARD W. CONT (MHRS)	INHERENT W. CONT (MHRS)	ACTUAL W. CONT (MHRS)	FAB LABOUR COST (\$)	W. CONT/ METRE (MHRS/m)	W. CONT/ TONNE (MHRS/T)
BERTH ERECTION							
11L-UNIT (Deck + Side)		35.321	79.35	304.991	1677.41	6.03	0.00
21Panel Unit		40.941	78.99	303.611	1669.81	4.76	0.00
31L-UNIT (Deck + Side)		35.321	79.35	304.991	1677.41	6.03	0.00
41L-UNIT (Deck + Side + IH		34.631	114.95	441.861	2430.21	4.60	0.00
51Panel Unit		48.021	93.19	358.191	1970.01	4.72	0.00
61L-UNIT (Deck + Side + IH		34.251	114.06	438.401	2411.21	4.59	0.00
71DB BILGE (1 S.GRDR)		45.351	90.13	346.431	1905.41	5.16	0.00
81DB BTH FLAT 2 S.GRDRS		79.481	176.44	678.181	3730.01	5.33	0.00
91DB BILGE (1 S.GRDR)		45.351	90.13	346.431	1905.41	5.16	0.00
GRAND TOTAL		550.3	1317.6	5064.7	27855.81	5.13	0.00

FIG (12). WORK CONTENT ESTIMATES

Global labour costs table for 3 UNITS.

Standard work content = 2958.0 Man Hours
Inherent work content = 3935.4 Man Hours
Nett weight = 285.3 tonnes

	PAID day nours	PROD day hours	BUILD effcy %	YARD loading %	MAN level %	ACTUAL man hours	LABOUR rate pds/hr	LABOUR cost pound	GROSS mhr/t
ORIGINAL	7.5	5.0	29.5	80.0	100.0	13347.3	5.50	73410.	46.8
CASE 1	7.5	6.0	35.4	80.0	100.0	11122.7	5.50	61175.	39.0
CASE 2	7.5	4.0	23.6	80.0	100.0	16684.1	5.50	91763.	58.5

	SCRAP % of nett	GROSS wght tonne	MATRL pds/t rate	MATRL cost pound	LABOUR & MAT pound	GROSS pds/t Tot L&M
ORIGINAL	4.2	297.2	260.	77275.	150685.	507.00
CASE 1	4.2	297.2	260.	77275.	138450.	465.83
CASE 2	4.2	297.2	260.	77275.	169038.	568.74

Global labour costs table for 6 UNITS

Standard work content = 3205.8 Man Hours
Inherent work content = 4211.9 Man Hours
Nett weight = 285.3 tonnes

	PAID day hours	PROD day hours	BUILD effcy %	YARD loading %	MAN level %	ACTUAL man hours	LABOUR rate pds/hr	LABOUR cost pound	GROSS mhr/t
ORIGINAL	7.5	5.0	28.9	80.0	100.0	14560.6	5.50	80083.	51.0
CASE 1	7.5	6.0	34.7	80.0	100.0	12133.8	5.50	66736.	42.5
CASE 2	7.5	4.0	23.1	80.0	100.0	18200.7	5.50	100104.	63.8

	SCRAP % of nett	GROSS wght tonne	MATRL pds/t rate	MATRL cost pound	LABOUR & MAT pound	GROSS pds/t Tot L&M
ORIGINAL	4.2	297.2	260.	77275.	155471.	544.94
CASE 1	4.2	297.2	260.	77275.	142124.	498.16
CASE 2	4.2	297.2	260.	77275.	175492.	615.11

Global labour costs table for 9 UNITS

Standard work content = 3228.7 Man Hours
Inherent work content = 4342.2 Man Hours
Nett weight = 285.3 tonnes

	PAID day hours	PROD day hours	BUILD effcy %	YARD loading %	MAN level %	ACTUAL man hours	LABOUR rate pds/hr	LABOUR cost pound	GROSS mhr/t
ORIGINAL	7.5	5.0	29.0	80.0	100.0	14989.5	5.50	82442.	52.5
CASE 1	7.5	6.0	34.8	80.0	100.0	12491.2	5.50	68702.	43.8
CASE 2	7.5	4.0	23.2	80.0	100.0	18736.8	5.50	103053.	65.7

	SCRAP % of nett	GROSS wght tonne	MATRL pds/t rate	MATRL cost pound	LABOUR & MAT pound	GROSS pds/t Tot L&M
ORIGINAL	4.2	297.2	260.	77275.	156746.	549.41
CASE 1	4.2	297.2	260.	77275.	143005.	501.24
CASE 2	4.2	297.2	260.	77275.	177356.	621.65

FIG (13). COSTS OF ALTERNATIVE BREAKDOWNS

TABLE (3) . BASIS DATA USED IN SENSITIVITY ANALYSIS

Total cost variants menu

1. Change labour rate (pounds/hour)	original value -	5.50
2. Change scrap (Percentage of Gross)	original value -	4.00
3. Change material cost (cost per tonne)	original value -	260.00
4. Change length of paid working day (hrs.)	original value -	7.50
5. Change length of productive day (hrs.)	original value -	5.00
6. Change general build efficiency (%)	original value -	30.48
7. Change yard loading (%)	original value -	80.00
8. Change Global Manning Level (%)	original value -	100.00

(i) alternative structural designs

(ii) alternative vessel arrangement

Under (i) the system can be used to examine for example different stiffener spacings, or single versus double hulls at upper decks. The latter arrangement would enhance ro-ro survivability in the event of a collision. Under (ii), alternative depths to each deck and double bottom can be examined. For example, beam-to-beam depth can be reduced by using shallower heavier beams retaining the same clear deck height for vehicles. The scantling and mass estimation program estimates the changes in steelmass and centre of gravity, while the cost estimating program compares the costs. The designer and builder now have potentially much more creative tools available.

FUTURE ENHANCEMENTS

The principles and methodology on which this work is based can be extended not only to other ship types but to other areas of ship production, in particular applications in the outfitting area. Some outfit manufacturing process data does exist and systems are in place which will facilitate further information to be collected thus enabling the processes to be realistically modelled. This in turn will allow more comprehensive analyses to be carried out. For example the addition of outfit to the system will allow a more representative model of modern shipbuilding processes to be used when considering build strategy, resource utilization and modular construction.

Extending the system to a wider range of ship types including warships is being considered. This would necessitate a different database to be constructed to account for the different standards associated with the building of naval vessels.

In the computing field the applications of transputers could bring about significant benefits. A parallel processing environment which permits multi-tasking has obvious advantages at the concept stage where a number of alternative proposals could be examined simultaneously.

Some recent work by the authors [g] has demonstrated the Artificial Intelligence can be used effectively at the concept design stage. Some of the techniques described in Ref.(9) could be used to enhance the cost estimating process, e.g. some form of automatic data feedback from the production departments for ships recently built could be used, via an expert system, to update the database and thus continually improve the system performance and reliability.

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The responsibility for statements of facts and opinions expressed in this paper rest solely with the authors.

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No. 5

A Zone Outfitting Project At Puget Sound Naval Shipyard

Albert J. Caputo, Visitor, Gary M. Walters, Visitor, and Thomas S. Luis, Visitor, Puget Sound Naval Shipyard, Bremerton, WA

(Paper Not Available)



Strategizing and Executing the Implementation and Utilization of Zone Technology at Philadelphia Naval Shipyard

LCDR Larry D. Burrill, USN, Visitor, LCDR Barry S. Munro, CF, Visitor, LCDR Mark S. O'Hare, USN, Member, Philadelphia Naval Shipyard, Philadelphia, PA, Korea, Japan, Vietnam, etc.

Industries Co., Ltd. (IHI), Tokyo, Japan

ABSTRACT

The fundamental philosophies of Group Technology or Zone Logic Technology are accepted practices in Japanese Shipyards. The ideologies, originally conceived in the U.S. ironically, were considerably refined by the Japanese Shipbuilding and Repair Industry and since 1978, have been reimported to the U.S. The traditional system-by-system approach to work has been replaced by a zone oriented product work breakdown structure, Zone Logic Technology. This grouping of jobs if executed properly, has the potential to significantly enhance efficiency and productivity.

Numerous documented articles published by the National Shipbuilding Research Program (NSRP) and the Society of Naval Architects and Marine Engineers (SNAME) have explained in detail how the U.S. time-honored shipbuilding methods (post WWII) are slowly being replaced by the more efficient and analytical procedures of Zone Logic Technology. These concepts dictate that work be planned and executed under a priority scheme:

- 1) Divide work into geographical zones carefully considering the nature of the problems that are involved,
- 2) Develop a zone oriented product and interim product work breakdown structure,
- 3) Properly sequence the work to be accomplished by stage and area,
- 4) Plan final systems tests as necessary.

To date, the application of Zone Logic Technology in new ship construction is commonplace. On the other hand, its use in the ship repair, overhaul and conversion environment has been relatively small in scope and isolated in application in both private and public shipyards.

However, the application at the Philadelphia Naval Shipyard (PNSY) has greatly overshadowed all other U.S. shipyards' efforts combined. PNSY started its implementation of Zone Logic Technology in the late fall of 1986, targeting the Service Life Extension Program (SLEP) for the USS KITTY HAWK (CV-63) for its initial application.

This paper will discuss the strategy in the development and implementation of Zone Logic Technology at PNSY. Frank disclosure of the valuable lessons learned and current status will also be presented. Equally as important is what the future has in store for Zone Logic Technology at PNSY, which will also be described.

This paper provides a candid presentation of the experiences in the implementation of Zone Logic Technology in a demanding repair environment.

INTRODUCTION

PNSY is nearly half way through the 37 month USS KITTY HAWK SLEP. After approximately 30 years of operational service, a SLEP is expected to add 15 years to a carrier's life, Ref.1. It is this project that enticed Senior Shipyard Management to consider Zone Logic Technology (ZLT).

The implementation strategy developed as a result of Shipyard Management taking bold innovative steps to accomplish the Hull Expansion Project planning for the USS Kitty Hawk. Though this project was eventually canceled, the planning effort was so intricately woven into the overall SLEP project that it gave rise to alternate implementations of ZLT at PNSY. In scope, the Zone Logic Technology application on USS KITTY

HAWK encompasses approximately one-third (over 400,000 mandays) of the total production effort, three years of work, and involves over half of the ship's compartments.

A game plan was devised after having had visited several shipyards worldwide (Japan, US, Canada and Europe) to investigate any prospective productivity enhancements that would help PNSY meet the immediate short term requirement of the Hull Expansion Project.

The ultimate goal was to improve our overall productivity to meet the Navy's operational fleet repair and conversion requirements. As a consequence, PNSY entered into a contract with Ishikawajima-Harima Heavy Industries (IHI) co., Ltd., Japan, in January of 1987 to assist the shipyard in implementing Zone Logic Technology. Just twelve months prior to the start of the SLEP project with the planning processes well underway, the decision was made to implement ZLT.

In view of this, the implementation procedure necessitated the use of several products from the traditional planning processes (such

as Job Order Progress Cards), and then adapt these products to ZLT. The system orientated outputs were reduced and re-assembled into Product Work Packages in the form of Unit Work Instructions (UWI). UWI's marked the departure from the traditional systems approach to planning work. This new method took various types of work in discrete areas and treated it as a work package in direct support of products and interim products as discussed in Ref. 2. This is a very important aspect of ZLT and worthy of reemphasis here.

A UWI is the compilation of all production work by phase of a particular discipline/trade intended in a specific location/subzone. This package included all support services. Further, a UWI could be a grouping of work for a unit/system/area which are inherent or unique to that item. The UWI's were then provided to the Production Department. The Data Based Management System designed to support the technical publishing process used in the development of Unit work Instructions is discussed in Ref. 2. The flow chart, represented here in Fig. 1, outlines the process from source documentation to final product.

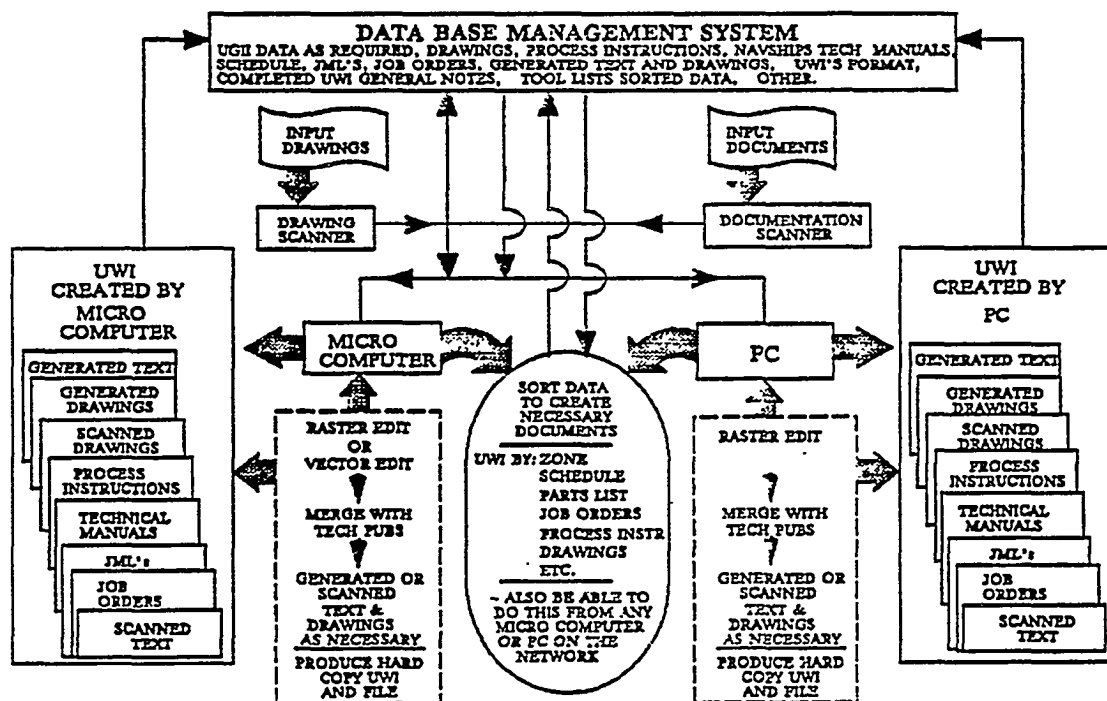


Fig. 1. ZLT System Process Requirements

The Production Department was re-organized to accomplish all zone work with a separate Zone Technology Production Group (see Fig. 2). This group drew its cadre from the existing Production Groups (i.e., structural, machinery, electrical, piping and service) to assemble nine Product Trades. These Product Trades were then organized into four Production Shops to perform the work.

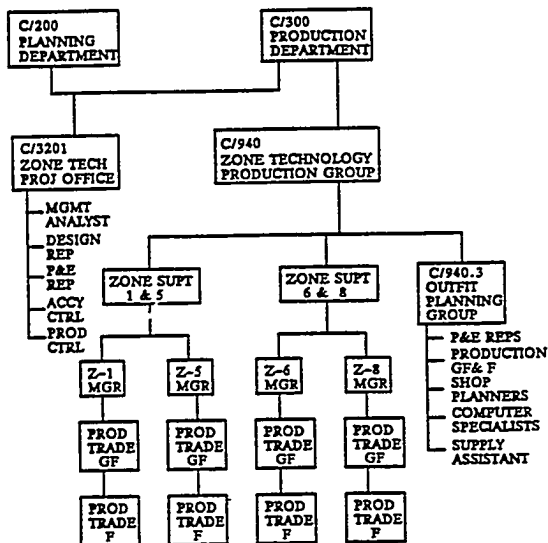


Fig. 2. ZONE LOGIC PROJECT TEAM

In a continuation of Ref. 2, this paper will consider two principal areas:

- 1) Detail the lessons learned during the USS KITTY HAWK SLEP, provide the current status, and outline the mid course corrections applied,
- 2) Describe the strategy intended for the continuation of ZLT applications at PNSY.

CURRENT STATUS OF ZONE LOGIC TECHNOLOGY IMPLEMENTATION

The broad scope of ZLT implementation at PNSY may best be broken down into three phases at this point:

- 1) Initial planning and the first year of execution in the USS KITTY HAWK SLEP, (Fall of 1986 - January 1989),
- 2) The planning phase for the USS CONSTELLATION SLEP and the final two years of execution of USS KITTY HAWK SLEP, (February 1989 - February 1991),
- 3) The execution of the USS CONSTELLATION SLEP in conjunction with other complex overhauls and other availabilities, (June 1990 - Future).

With the majority of planning complete, the USS KITTY HAWK was drydocked on November 25, 1987, though January 28, 1988, officially marked the start of her SLEP. Of the projected 1.2 million mandays to be completed during SLEP, the current physical progress is calculated to be 47%. Of the approximately 400,000 mandays to be accomplished by ZLT, over 230,000 have been completed (data date of 2 June 1989). Over the first 8 - 10 months of the project, a cost savings of approximately 1.8 million dollars was realized in the tank package alone. Although these preliminary results were encouraging, other developments within the shipyard in relation to ZLT were significantly impacting the overall potential for success. One alarming affect was the increasingly disharmonious working relationship developing between the Zone Technology Production Group and the Non-Zone Production Groups. The net result being a "Two Shipyard Syndrome". In conjunction with this was the growing appearance that anticipated productivity enhancements were not being realized. Consequently, in December 1988, the ZLT organization was changed to that reflected in Fig. 3. This action essentially dissolved the Zone Technology Group (Code 940) and reassigned the four shops (42, 44, 46 and 47) to the Structural Group Superintendent (Code 920).

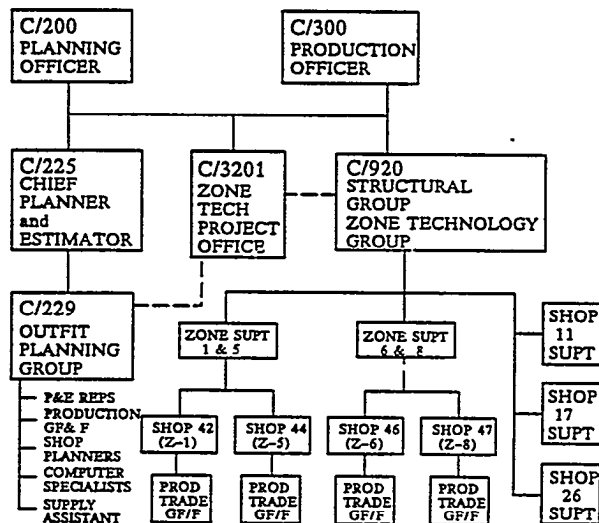


Fig. 3. CURRENT ZONE TECHNOLOGY ORGANIZATION

Further, the Outfit Planning Group (Code 940.3) was re-assigned as Code 229 to the Planning and Estimating Division, although remaining in the same location and performing the same function. The Zone Technology Project Office was not affected.

The Basis For Using A Group Approach
To Problem Solving (GAPS)

The existence of a problem between zone and non-zone oriented employees became particularly apparent late in 1988. The Shipyard Commander took the first step by dissolving the Code 940 group. Then, recognizing the need to clearly identify the hurdles preventing PNSY's ZLT efforts from succeeding as planned and define positive action to eliminate them, he directed that a GAPS team be assembled. The team consisted of select personnel associated with the planning and implementation of ZLT. The team was comprised of the following individuals:

<u>POSITION</u>	<u>CODE</u>
o Group Superintendent (Team Leader)	970
o Production Superintendent (Deputy Team Leader)	917
o Chief Planner and Estimator	225
o Assistant Repair Officer	331
o ZT Project Director	3201
o Zone Manager	944
o Zone Manager	942
o Supervisory Planner (Recorder)	970.03
o Head, Employee Division (Facilitator)	180

GAPS is a unique problem identification and resolving, and process improvement study.

For obvious reasons, it is initiated by managers. Though its approach is tailored to suit the intended purpose, it is also staged in way of problem/process discussion, brainstorming, cause and effect diagramming (fishboning), parieto diagramming, the gathering of information and/or data and the effective compilation of same for accurate analysis of the findings. Further, it addresses the implementation of positive corrective action and finally as a follow-up measure, the provision of a plan to monitor the improvements instituted. A GAPS team is expected to maintain the initiating authority attuned to their activities by way of regular project team meeting reports. The culminating activity of this GAPS team was a formal presentation of findings to the Shipyard Commander and members of his executive staff.

Over a period of four months the group met and conducted a series of interviews and surveys to investigate the implementation of ZLT. Initially, there were personal interviews conducted by the Team Leader and Deputy Team Leader. These were followed by other interviews with the entire GAPS Team with such personnel as ZLT Production Superintendents, Ship Superintendents, and representatives from Material Receipt and Inspection, Combat Systems, Hull, Mechanical and Electrical testing and the Supply Department.

<p>I UNIT WORK INSTRUCTION ISSUES</p> <p>1) DO YOU LIKE THE UNIT WORK INSTRUCTIONS? YES <input type="checkbox"/> NO <input type="checkbox"/></p> <p>A) IF YOU DISLIKED THE UNIT WORK INSTRUCTIONS, DID YOU EVER INDICATE SO ON THE FEEDBACK SHEET? YES <input type="checkbox"/> NO <input type="checkbox"/></p> <p>B) IF YOU DISLIKED THE UNIT WORK INSTRUCTIONS, TO WHOM DID YOU BRING YOUR OBJECTIONS? YES <input type="checkbox"/> NO <input type="checkbox"/></p> <p>CO WORKER <input type="checkbox"/></p> <p>FOREMAN <input type="checkbox"/></p> <p>GENERAL FOREMAN <input type="checkbox"/></p> <p>ZONE SUPT <input type="checkbox"/></p> <p>GROUP SUPT <input type="checkbox"/></p> <p>OUTFIT PLANNING <input type="checkbox"/></p> <p>C) WHAT DIDN'T YOU LIKE ABOUT THE UNIT? <input type="checkbox"/></p> <p>CLARITY OF DRAWING <input type="checkbox"/></p> <p>JOB DESCRIPTION <input type="checkbox"/></p> <p>JOB REFERENCES <input type="checkbox"/></p> <p>INSUFFICIENT ALLOCATED FUNDS <input type="checkbox"/></p> <p>THE FACT THAT IT WAS ONLY A PLACE OF <input type="checkbox"/></p> <p>THE TOTAL SYSTEM PICTURE <input type="checkbox"/></p> <p>HOW YOU CHARGE PRODUCT TRADE/ASSIST <input type="checkbox"/></p> <p>TRADE BAB MATERIAL LIST <input type="checkbox"/></p> <p>II MISCHARGING/COST SCHEDULE AND CONTROL (C/SCS)</p> <p>1) DO YOU KNOW WHO IS RESPONSIBLE TO CHARGE/TRACK ASSIST MANHOURS ON A UNIT? <input type="checkbox"/></p> <p>2) PLEASE PUT A CHECK NEXT TO WHO YOU BELIEVE IS RESPONSIBLE TO ENSURE ACCURATE CHARGES FOR THE ASSIST WORK ON THE UNIT. YES <input type="checkbox"/> NO <input type="checkbox"/> OTHER <input type="checkbox"/></p> <p>ZONE MANAGER <input type="checkbox"/></p> <p>PRODUCT TRADE FOREMAN <input type="checkbox"/></p> <p>PRODUCT TRADE GENERAL FOREMAN <input type="checkbox"/></p> <p>LEAD MECHANIC <input type="checkbox"/></p> <p>3) HOW MANY HOURS OF COST SCHEDULE AND CONTROL (C/SCS) TRAINING HAVE YOU HAD? <input type="checkbox"/></p>	<p>4) TO WHAT DEGREE DO YOU FEEL THAT MISCHARGING IS OCCURRING IN ZONE TECH WORK? <input type="checkbox"/></p> <p>NONE <input type="checkbox"/></p> <p>MINOR <input type="checkbox"/></p> <p>MAJOR <input type="checkbox"/></p> <p>OUT OF CONTROL <input type="checkbox"/></p> <p>5) IF YOU FEEL THAT MISCHARGING IS OCCURRING, WHAT DO YOU ATTRIBUTE THIS TO? <input type="checkbox"/></p> <p>CONFUSED AS TO WHAT JOB TO CHARGE <input type="checkbox"/></p> <p>DID NOT HAVE ANOTHER JOB/UNIT TO CHARGE TO OTHER (SPECIFY) <input type="checkbox"/></p> <p>III SCHEDULE ISSUES</p> <p>1) TO WHAT DO YOU ATTRIBUTE THE MAJOR REASON FOR NOT KEEPING ON SCHEDULE? PRIORITIZE FROM 1 TO 8 <input type="checkbox"/></p> <p>WORKSITE AVAILABILITY <input type="checkbox"/></p> <p>LACK OF MATERIAL <input type="checkbox"/></p> <p>LACK OF MANING <input type="checkbox"/></p> <p>POOR SCHEDULE <input type="checkbox"/></p> <p>POOR QUALITY UNIT <input type="checkbox"/></p> <p>QUALITY OF MECHANICS <input type="checkbox"/></p> <p>TECHNICAL ISSUES <input type="checkbox"/></p> <p>POOR SUPERVISOR DIRECTION <input type="checkbox"/></p> <p>OTHER (SPECIFY) <input type="checkbox"/></p> <p>IV MATERIAL ISSUES</p> <p>1) TO WHAT DEGREE DO YOU FEEL THAT LACK OF MATERIAL IS CAUSING A PRODUCTION HOLDUP? <input type="checkbox"/></p> <p>NONE <input type="checkbox"/></p> <p>MINOR <input type="checkbox"/></p> <p>MAJOR <input type="checkbox"/></p> <p>OUT OF CONTROL <input type="checkbox"/></p> <p>V GENERAL COMMENTS</p> <p>1) PLEASE PROVIDE ANY GENERAL COMMENTS, BOTH GOOD AND BAD, THAT AFFECT YOUR PRODUCTIVE EFFORTS UNDER ZONE TECH, FEEL FREE TO USE THE BACK OF THIS QUESTIONNAIRE <input type="checkbox"/></p>
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Fig. 4. GAPS TEAM QUESTIONNAIRE

1 CONTRIBUTION TO PROBLEM SITUATION

COMMUNICATIONS

Lack of senior management input
Lack of ongoing communications
Limited senior management support
Lack of outside support

METHODS

Too big a work package
Scheduling process-4 months
Full workload forecast not available
Too rigid implementation

MANPOWER

Wrong personnel assignments
Lack of prior practical experience
Undistributed mandays
Lack of training for first line supervisors

II IMPORTANT TO CORRECT AT THIS STAGE

COMMUNICATIONS

Lack of senior management input
Lack of ongoing communications
Limited senior management input
Lack of outside support
Failure to follow game plan

METHODS

Improper sequencing of work
Full workload forecast not available
Scheduling process-4 months
Lack of accurate monitoring system
Failure to follow game plan

MANPOWER

Wrong personnel assignments
Lack of training for first line supervisors
Undistributed mandays
Lack of prior practical experience

III POSSIBILITY TO CORRECT IN SHORT ORDER

COMMUNICATIONS

Lack of senior management input
Limited senior management input
Lack of outside support
Lack of ongoing communications
Failure to follow game plan

METHODS

Full workload forecast not available
Scheduling process-4 months
Errors in ways and means of charging
Too rigid implementation
Deviations from established work plan

MANPOWER

Wrong personnel assignments
Undistributed mandays
Lack of training for first line supervisors

THE MAJOR CONTRIBUTOR TO THE PROBLEM SITUATION
UNANIMOUS CONCLUSION DRAWN: FAILURE TO PROVIDE FOR SENIOR MANAGEMENT INPUT.

Fig. 5. GAPS TEAM FINDING

Formal surveys were also conducted by the GAPS Team. The survey questionnaire (Fig. 4), was distributed to all First and Second Line Supervisors in the ZLT Production Group. The table in Fig. 5 summarizes the findings of the GAPS Team with the single largest contributor being the "failure to provide for senior management input".

(1.4%) with poor graphics (column B) and 11 (1.2%) with poor quality drawings (column C). Production personnel found 30 (3.2%) with poor graphics (column D) and they considered the written work instructions of 44 (4.8%) too vague (column E).

Since the effort to produce the UWI's was such a large part of the ZLT implementation procedure, a great deal of attention was focused on their acceptance and quality. Shown graphically, the UWI product was very good. However, much effort has been expended to attend to the recognized deficiencies.

Lessons Learned

In addition, a survey was conducted by the Outfit Planning Group (OPG). Responses were retrieved via feedback sheets that accompanied each UWI. Of the UWI's issued and completed, a random sample of 924 which represented approximately 20% of those held on file at that time, were assessed for this study. The results are presented in Fig. 6. Column A shows the number assessed. The Planners who wrote the UWI's found 13

Prior to addressing the lessons learned, it is important to pause and review the more salient points to appreciate the gravity of the monumental task faced by PNSY. The decision to implement ZLT on the USS KITTY HAWK SLEP was made just twelve months prior to a 1.2 million manday availability. Of this, 400,000 MD's were allocated for ZLT. In addition to the tremendous administrative task posed by this decision, much of the traditional planning processes were complete or not economically feasible to alter. The majority of the shipalt drawings were complete as was much of the scoping of authorized work. Consequently, the fundamental concepts of ZLT could not be strictly adhered to. Rather, many compromises had to be negotiated several of which were not necessarily in the best interest of ZLT. The application of the concept on the USS KITTY HAWK proved to be a valuable learning environment.

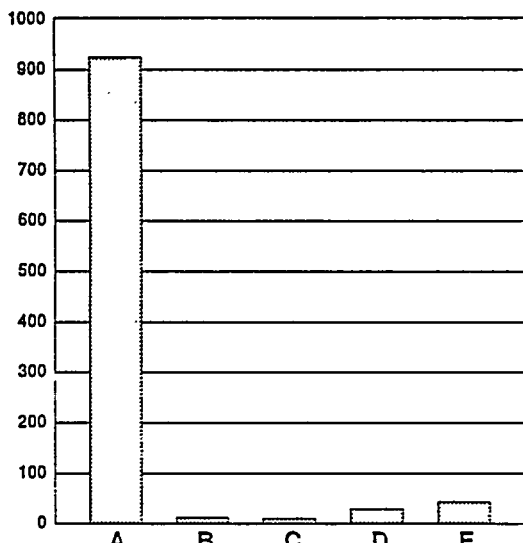


Fig. 6. COMPLETED UWI AUDIT

The following reflects a summary of the more important Lessons learned:

1) The Zone Technology Work Package was not initially networked into the overall ships scheduled network. As a result, Shipyard Management governing the availability had to refer to two sources of information to review the project's disposition. This meant administratively managing the project via two distinct parameters which was awkward at best, caused much confusion and was an additional burden. Ergo, it should be networked as soon as possible,

2) The ZLT work package was set up to work in four month windows. Only the work scheduled for that four month period was issued. Though this was not a popular decision and certainly not ideal, it was a necessary compromise. Four month schedules were used because there simply was not enough work available for issue to justify anything lengthier. In traditional fashion, the Planners and Estimators wrote job orders by phase and authorized work as the information was made available without requisite consideration given to all of the work to be accomplished in a zone/area. No guidance was provided them regarding the prioritization of this work. It should be appreciated that any one area could (and often did) have a number of Planners issuing work in it for a variety of different jobs which they progressed independently and in no delineated priority. As a consequence, the Outfit Planning Group found it extremely difficult if not altogether impossible to ascertain if absolutely all work in a particular zone, intermediate or subzone had been issued from P&E. There always existed an element of doubt. Ideally of course, all work would have been issued at the start of the availability. If that were the case, there would have been no doubt about adhering to the fundamental concepts of ZLT. But such was not the case and a schedule had to be provided to Production. Four month schedules (originally three month) were considered a reasonable compromise,

3) The unions representing the various trades and codes must be actively involved anti thoroughly supportive from the outset. This is important considering the novel Product Trade concept,

4) The cultural issues involving the people and personnel surrounding this effort were/are/will continue to be by far the most important concern of all. They must be dealt with from the outset to the maximum extent possible.

it should be obvious that the items noted above are not all unique to the implementation of ZLT.

FUTURE APPLICATIONS OF ZONE TECHNOLOGY

Despite the concerns previously discussed, senior PNSY Management remain committed to the continuation of ZLT. A reflection of this commitment is exhibited in the decision to undertake the entire USS CONSTELLATION SLEP via ZLT. Major efforts are currently underway to analyze and apply the lessons learned from the USS KITTY HAWK throughout the pre-planning phases of the USS CONSTELLATION. A meticulous review of the processes required *is ongoing* and will result in their thorough clarification. These processes are being utilized in the planning for the Docking Selected Restricted Availability (DSRAJ) of the USS SPRUANCE, DD 963, as well. It is the intent of Senior Management to test out these processes on the USS SPRUANCE as a precursor to the execution of USS CONSTELLATION SLEP. Although the manday package on the USS SPRUANCE is small, (approximately 11,000) exercising ZLT concepts on this project should prove invaluable in validating the entire PNSY process.

Integrated Strategies

The work of the Planning Department is thorough advanced planning in preparation for the customer, in this case Production. Chronologically then, this means that the zones and intermediate zones must be clearly defined and this information distributed as early in the planning process as possible. Secondly, it is necessary to accurately determine the scope of the work to be accomplished in each zone. Given this and the first cut (initial proposal) of the Production Schedule, the zones can be effectively prioritized. This first cut Production Schedule considers the area, work to be accomplished in it, identifies the most logical time frame (phase/sequence) to do it in (on a global sense) and how it is-proposed that this be done. This is an iterative process to be regularly reviewed and updated. Not to belabor the obvious but in a work environment of this magnitude, concurrent activity is expected.

This prioritization of zones and intermediate zones is then provided to the Supply, Design and Planning and Estimating Divisions for the sole purpose of positive and consistent guidance with respect to what aspects to pursue first. As an example, if

Supply had 10,000 Job Material Lists to process, the guidance would provide the approach to acquisition priorities driven by need dates to meet the Production Schedule. The same could be said of drawings from Design and of job orders from P&E. Herein marks one of the most significant departures from traditional shipyard management, that is "Integrated Planning for Production"!

In an attempt to address the issues identified above, a multi-tiered Zone Technology Steering Group was founded. The tiers are:

- 1) Senior Executive Zone Logic Technology Steering Group,
- 2) Zone Logic Technology Steering Committee,
- 3) Zone Logic Technology Steering Subcommittees.

The Senior Executive ZLT Steering Group, chaired by the Shipyard Commander, consists of the following individuals;

- Planning Officer
- Production Officer
- Chief Design Engineer
- All Production Group Superintendents
- Chief Planner and Estimator
- Chief Combat Systems Engineer
- Supply Officer
- Comptroller
- SLEP Project Officer
- Zone Technology Project Officer

This committee meets bi-weekly to discuss all aspects of ZLT implementation and planning. It is meant to monitor and discuss the overall progress in implementing ZLT, furnish a vehicle for important decisions when warranted, and provide guidance and direction to the other levels.

The ZLT Steering Committee is chaired by the Zone Technology Project Officer. It consists of division head level managers from various shops and codes across the shipyard management team. Its charter is to implement the second phase of ZLT. It assigns, oversees, and approves of the various subcommittees' activities involved in delineating the details of all aspects of ZLT implementation. This committee serves as the main conduit of information, administrative and strategic developments with respect to all issues involving ZLT.

ZLT Steering Subcommittees are chaired by designated steering committee members and consist of both members of the steering committee as

well as representatives from various trades and codes in the shipyard as required. There are currently three subcommittees:

- 1) integrated Strategy and Scheduling,
- 2) Material Support,
- 3) Training.

The flow chart (Fig. 7) reflects the completion of the first task of the Integrated Strategy and Scheduling (ISS) Subcommittee. Though initially generated for the CV SLEP Program, the availability strategy chart has been modified here significantly for the USS SPRUANCE. It shows the varied and complex interrelationships that exist in planning an availability. This may be considered as the simplified model of the SLEP version, which by virtue of sheer volume and complexity, would represent the most detailed of all availabilities.

The follow on task assigned to the ISS Subcommittee is to clearly define the implementation processes of a Master Schedule (center, Fig.7). The issue of a Master Schedule has been an integral part of the ship repair and conversion environment for some time. It is perhaps the singular most important aspect of an integrated repair/conversion strategy through the implementation of ZLT. As defined here, the Master Schedule draws the following schedules together in one data base.

- Drawing,
- Material Procurement Sequence,
- Test Development,
- Production,
- Tiger Team.

It should be emphasized that Master Schedule as used here is the culmination of many cycles in an iterative process beginning at the Proposed Planning and Production Strategy. (center, left Fig. 7).

The Material Subcommittee is responsible for delineating the Material Management System to support ZLT and specifically, the "kitting" effort planned for USS CONSTELLATION SLEP. Zone Technology has as one of its attributes, the fundamental requirement that a particular package of work be accomplished during a precise period of time, by a specific trade or product trade. Having this requirement, it is even more critical that an effective material management system be in place "and fully capable of supporting the work packages and schedule by providing all of the required material. The Material Subcommittee has reviewed the complete material support cycle from definition

This would support the development of detailed and accurate weekly schedules. The obvious consequence of this would be better schedule adherence, positive project management and equally as important, more desirable control of their work on behalf of the waterfront personnel.

Zone Technology In Design

Due to the time frame to implement ZLT on the USS KITTY HAWK, the Design Division Integrated Drawing Development effort was limited to two spaces; specifically, air conditioning machinery room number three and four and pump room number five.

The Design Team is fittingly called "Design for Production". Their mandate was to generate an integrated Design Work Package for each space, where practical, either by actual onboard shipchecks or by the use of Computer Aided Design (CAD) equipment. However, the actual method remains viable and is as outlined below:

- ° Shipcheck the compartments for systems that remain after shipalts are accomplished,
- ° Shipcheck for greater detail to support pre-fabrication accuracy,
- ° Develop composite drawings integrating new shipalt drawings with existing configurations,
- ° Perform interference checks,
- ° Review composite drawings for quality producibility for the purpose of pre-fabrication, pre-outfitting, providing detailed assemblies and conformance to standardizations.

CAD is a very dynamic method of accomplishing the same task. An example of a piping composite drawing for Pump Room number 5 as generated by CAD is shown in Fig. 8. This drawing is then supported by the requisite number of detailed drawings required for the actual system fabrication and assembly. On this particular work package alone, twenty Interference Control Memorandums were sent to various Design Codes highlighting interference problems. This number does not include the number of informal corrections initiated while working with the preliminary drawings. The benefits of CAD are:

- ° A detailed and accurate document to accomplish installation (easier/safer).
- ° Advanced production techniques eliminating interferences to a fine point of detail,
- ° provide consistent base line model supporting multiple Design Engineers to use and thus eliminating repetitive efforts,
- ° automated interference control eliminates guesswork and constant communication between Design Engineers,
- ° incorporates the most logical integrated installation configuration of all items within the space and supports ease of maintainability,
- ° accommodates computer interface with CAM for prefabrication and preoutfitting capabilities and accuracy of same,
- ° accurate computer model available for future availability advance planning efforts.

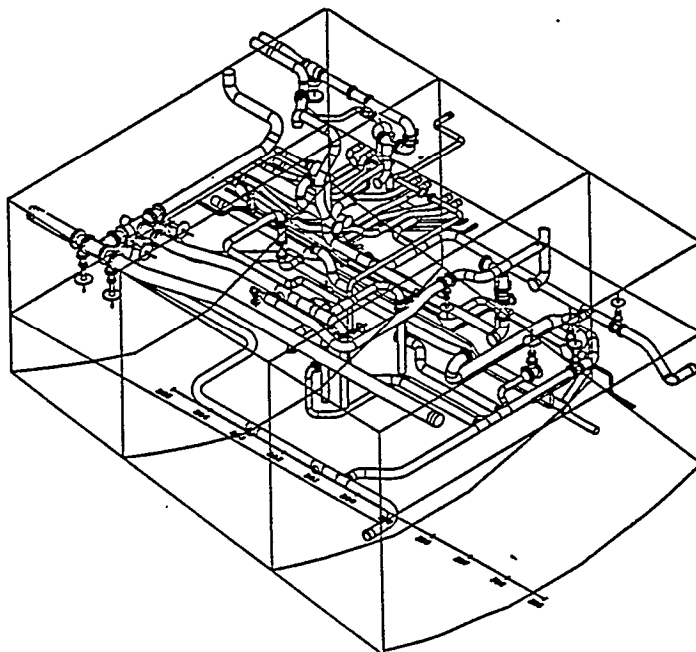


Fig. 8. PUMP ROOM PIRING COMPOSITE BY CAD

For the USS CONSTELLATION SLEP more than twenty-five complex compartments will have an Integrated Design Work Package. These may involve many of the extensive and complex ship alterations which include:

- ° Weapons Magazines,
- ° Catapult Accumulator Spaces,
- ° Rotary Retract Machinery Spaces,
- ° Combat Information Center,
- ° Two Air Conditioning Machinery Spaces,
- ° All three Arresting Gear Engine Spaces,
- ° NSSMS Control Space,
- ° Two Radar Rooms and associated Pump Rooms,
- ° All five Pump Rooms.

Additionally, all drawings for the USS CONSTELLATION SLEP are being developed by intermediate zone. As discussed in Ref. 2, the entire ship is broken down by area/zone whereby these zones reflect the products and interim products required to complete the availability. These zones are then further broken down into intermediate zones and then again to sub-zones. The generic zone breakdown for the USS CONSTELLATION in Fig. 9 shows the intended Zone Manager responsibilities of Production, Design and P&E. An example of intermediate zone in zone 9 would be both forward catapults and a sub-zone might be #1 catapult. In addition, a potential cohesive advantage of grouping work by product and zone/area exists.

C/230 C/240	C/300
C/970	ZONE 0: SERVICES DOCK WORK AND MISCELLANEOUS
C/920	ZONE 1: ALL TANK WORK, (CLEANING, PAINTING, STRUCTURAL PIPING, TESTING) TANK TOPS AND HULL STRUCTURAL
C/930 & 960	ZONE 2: ALL WORK ASSOCIATED WITH SHAFT ALLEYS INCLUDES MAIN MACHINERY SPACES EXCEPT FOR TANK TOP STRUCTURAL REPAIRS
C/960	ZONE 3: ALL WORK ASSOCIATED WITH AUXILIARY MACHINERY SPACES (EXCEPT TANK TOP REPAIRS)
C/950	ZONE 4: ALL MAGAZINE WORK EXCEPT TANK TOP REPAIRS
C/930	ZONE 5: ALL PUMP ROOM WORK, EMERGENCY GENERATION, AC SPACES, RUDDER WORK
C/920	ZONE 6: SPACES FROM 3rd DECK TO MAIN DECK
C/930	ZONE 7: HANGAR BAY
C/950	ZONE 8: MAIN DECK TO FLIGHT DECK PLUS ISLAND
C/930 & 960	ZONE 9: FLIGHT DECK

Fig. 9. GENERAL CV-64 ZONE BREAKDOWN

Zone Logic Technology In Planning

As a natural succession to the intermediate zone drawing development, the P&E Division is producing all initial job scoping information by intermediate zone or sub-zone as applicable. Owing to the sheer size of an aircraft carrier, some areas present unique problems. For example, consider one of four main machinery

spaces as an intermediate zone (Fig. 9, zone 2). The volume of concentrated effort to be accomplished within a main machinery space during a SLEP is absolutely immense, and since there are no geographic boundaries to speak of in the space, it is not at all practical to further divide it into subzones. After all, the work is very nearly in every case entirely contained within that geographic area. Another example but not as complex is the hull blasting and painting sequence. It is treated as an intermediate zone of itself and is not divided into subzones. On the other hand, consider the catapults (four in number) which do spread out amongst a wide variety of compartments and geographic locations. In this case, the subdivision into subzones is imperative to the success of the work packaging and execution.

This is a significant departure from what was done on the USS KITTY HAWK SLEP in the sense that Unit Work Instructions were developed from the traditionally written system job orders. Now that scoped work data is available by area, the information can be collated (via automated data processing) by phase and area to be packaged for Production. These packages in many cases will be supported by the integrated Design Work Packages as previously described. Because of not being able to collect detailed work area information on USS KITTY HAWK, the UWI had to be developed. It required an enormous duplication of efforts to the degree outlined in Ref. 2. Efforts are now underway that will enable the Outfit Planning Group to package work as before without having to actually duplicate the traditional job orders. This should result in significant cost saving improvements in the processes used for the USS KITTY HAWK.

Realize that it is the Production Schedule that drives the integrated efforts of the Planners, Schedulers, Material Suppliers and Outfit Planning Group. After receiving the detailed job order from the P&E codes and ascertaining the scheduled start date of the work, the Outfit Planning Group will be required to liaise with the Material Suppliers to determine if all of the required material is available and properly kitted. If so, they then prepare and issue the work package to Production.

The OPG may be considered as the final check point of all planning efforts. Though the case described above is ideal, there may be exceptions to it. For example, perhaps there may be an item or two of

the material that is not yet available; it may or may not have an expected delivery date and it may or may not be a problem that the Shipyard can control; there may be a plan or a shipalt drawing that is not yet available. In these cases, the OPG will assess the whole of the work package and make a conscientious decision with respect to whether it is or is not issued without this particular aspect of the package. The Production Schedule would be affected and administrative action would have to be initiated to deal with the problem. They may decide not to issue the package which would also have direct ramifications on the Production Schedule. Therefore, they must take positive steps to fill the void with practical alternatives.

The intent is to maximize the most efficient flow of work to accommodate the established Production Schedule. The corollary being, minimize incomplete work packaging. However, this piece of information (the OPG not able to prepare/issue a work package for whatever reason) is particularly important as it provides a valuable impact analysis. That is, the impact on the Production Schedule caused by unavailable material; the impact (or snowball effect) of any one division not adhering to established need dates provided in the zone and intermediate zone prioritization; the impact on the ships availability by significant growth in the authorized work package.

Only achievable work packages will be issued the likes of which will include:

- ° Cover sheet,
- ° Verification sheet,

- ° All Keyops that support the event work package,
- ° All technical references (plans, drawings, cesc procedure: ana standards, etc.) required to accomplish the work instructions, Job material list at the Keyop level,
- ° Work completion verification card,
- ° Customer feedback sheet.

Zone Technology In Production

The Work is then in the hands of Production. It is imperative that they execute the plans explicitly in strict adherence to the schedule. Common sense must still prevail and constructive feedback must be strongly encouraged if not altogether demanded to continually strive to improve upon the quality of the process.

The lessons learned from the USS KITTY HAWK SLEP precipitated the changes in the Production Department organization as detailed previously. As expected, the results of the surveys conducted through GAPS indicated the unanimous approval of the Product Trade concept. First Line Supervisors found this extremely beneficial in developing an efficient work flow. To enhance this process during future availabilities yet maintain parent shop identity, modifications will be made to the Production organization. That proposed for the USS CONSTELLATION SLEP is shown in Fig. 10. As indicated, there will be Zone Managers who will have production responsibilities for a zone and will report directly to their respective Group Superintendent. There will also be SLEP Superintendents who will report to Group Superintendents and will provide a direct interface between zones.

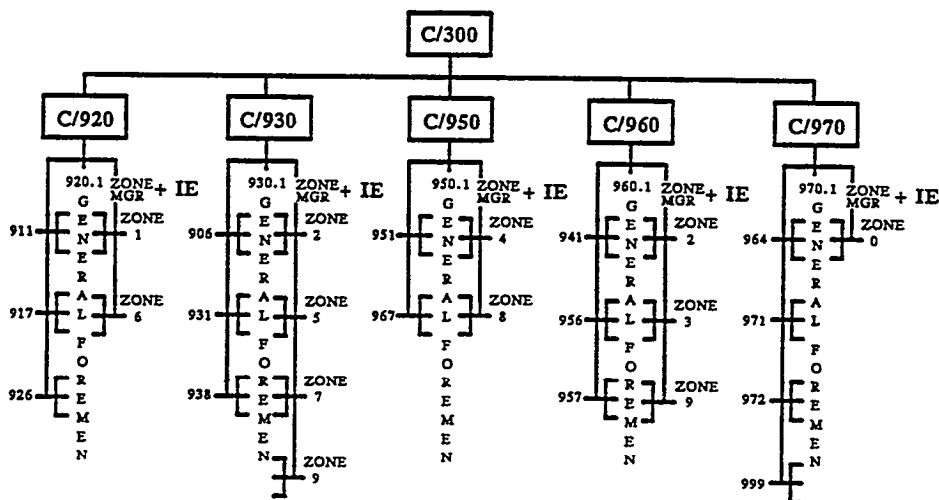


Fig. 10. PNSY PRODUCTION DEPARTMENT

By identifying work by area; producing drawings by area; preparing work packages by area; scheduling by area, and accomplishing work by area, the cohesive potential is again gainfully exploited to improve productivity, that is "Integrated Planning for Production".

Finally the involvement of Industrial Engineers in the daily Production Management team organization is planned to further foster the objectives of Zone Managers. The immediate benefit will be the detailed evaluation of all work processes. More importantly though, will be the direct interface (feedback) with other support codes such as Scheduling, Design, Testing, P&E and OPG.

Summary

The concepts of ZLT are being modestly applied to the USS KITTY HAWK SLEP with some administrative difficulties. In the past, these efforts were, in general, outside the traditional realm of shipyard organizational procedures. In subsequent availabilities and overhauls, ZLT will be applied much sooner in the planning process. The DSRA of the USS SPRUANCE is evidence of this and will prove to be the test case of all associated processes. The more important proposals are:

- ° Standardization of zone and intermediate zone principles applied to all classes of USN ships ultimately leading to standardization of zones and intermediate zones within each class of ship,
- ° Identify work by item in the work authorization document,
- ° Provide for electronic distribution of work instructions together with their supporting technical documentation (i.e. enhanced use of Automated Data Processing),
- ° Increased emphasis on the provision of and adherence to short term Detailed Production Schedules in direct support of the First Line Supervisors.

CONCLUSIONS

Much has been accomplished in the name of Zone Logic Technology at the Philadelphia Naval Shipyard. This paper has outlined the experiences and reactions to the problems encountered throughout this process. ZLT continues to be a part of the future at PNSY as the Senior Shipyard Executive Management are committed to its approach. They are convinced that ZLT is the vehicle to improve productivity. It has much to offer PNSY in the way of improving our quality and hence, our competitive edge. The motivation here is survival in an extremely competitive industrial environment by fundamentally changing the way we do business.

In general, the applications of ZLT are being infused into a greater part of the traditional shipyard organizations. As these organizations take on the new methods and procedures, it is essential that the fundamental precepts of Zone Logic Technology are maintained and used to guide the improvement efforts.

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The Evolution of Generating of Methods and Standards in U.S. Naval Shipyards

Alan J. Kaitz, Visitor,
Philadelphia Naval Shipyard, Philadelphia, PA

ABSTRACT

The Production Industrial Engineering Resource System (PIERS) is an automated system to improve industrial engineering. One of its components is Computer Aided Time Standards (CATS), a computer-assisted method to find, manipulate and store standard time data and existing standards to create new standards (1). CATS provides immediate, user-friendly access to the over 18,000 elements of standard time data and standards published by all shipyards. The system evolved from the DoD Computer Aided Time Standards program to collect, validate and publish standard time data in a single source for use by all DoD work measurement organizations. CATS uses menus, prompts, and instructions displayed on the screen to first direct the user to appropriate standard time data or standards and then to lead the user through the process of constructing a new standard. Because CATS performs the required mathematical computations, many hours of tedious manual labor have been replaced with a few keystrokes. One of the keys to CATS' flexibility and usefulness is its modular design. The system now includes many time-saving software packages, and additional packages can be made part of the system quickly and inexpensively. CATS has demonstrated a cost savings and positive return on investment of 3.5:1 (2). With strong management support, the use of computer systems similar to PIERS can significantly improve the bottom lines of other organizations.

INTRODUCTION

To understand what a revolutionary resource the PIERS system is, it is necessary to describe the work measurement system that predated PIERS and formed the original foundation for its data base.

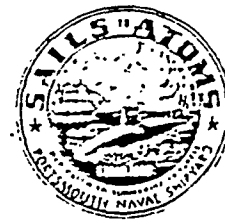
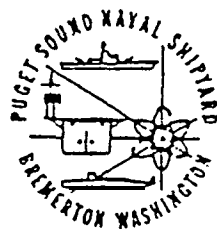
This system, the Defense work Measurement Standard Time Data Program (DWMSTDP), collects work measurement data into a single source, which is

published in nine volumes called "Standardization of Work Measurement" (DoD 5010.15.1-11) and in a DoD data base (3).

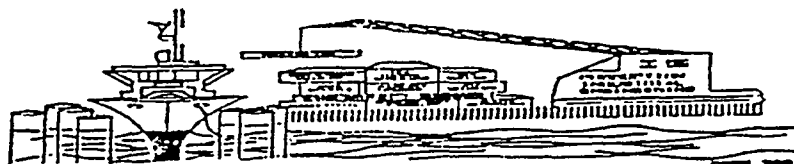
One of the most effective ways to improve the bottom line is to standardize work procedures -- to break them down into elements and make sure that each element is being used consistently in the same way in the same amount of time. The "Standardization of Work Measurement" contains descriptions and times for 18,000 of the elements that can be combined to form procedures.

These 18,000 entries were developed by Defense activities. DoD screens all entries and verifies that the methods described and the associated times are accurate before adding each of them to the DWHSTDP data base. The DUHSTDP systematically collects, verifies and disseminates standard time data. Since the nine volumes were published 12 years ago, all the military services and many DoD agencies and commercial organizations have used the data in their work measurement programs.

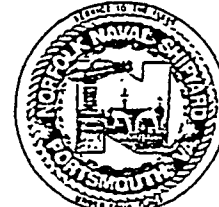
Within two years after the naval shipyards began using the systems they moved away from the DWMSTDP data base (3) and began creating a data base of standard data elements (4) more suitable to their specialized needs. Navy analysts who use this data to build standards follow a three-step procedure. First, they break down the work to be measured into elements. They establish the starting and stopping points of each element and verify exactly what work gets done during that element. Second, they search through standard data to find elements that match the elements they are measuring. Third, they add up the elements, apply frequencies, and tabulate times. An analyst can build an accurate standard without using time-consuming work measurement techniques because the stop watches have already been held -- they don't need to be held again. Only when some elements of the job cannot be matched with standard data elements is it necessary to use tradi-



THE NAVAL SHIPYARD PRODUCTION INDUSTRIAL ENGINEERING RESOURCE SYSTEM



PIERS



tional work measurement techniques.

Using standard work measurement data (4) can drastically cut the time needed to create an engineered method and standard. By using standard data, engineers and technicians avoid having to "reinvent the wheel" for each new document. Each time someone does a time study, his or her work can become standard data that someone else can use.

And, of courses the more data that becomes standardized, the less data that needs to be "assembled by hand." As the data base continues to grow, accurate standards can be created faster and faster.

To take full advantage of this ever-increasing data bases however, it was necessary to be able to access all the new standard data elements that were constantly being added to it. The more data there was to use, the more unwieldy the data base became to use. Storing, searching for, and retrieving data became increasingly costly and time-consuming. Often, because of poor record-keeping? standard data was available that the engineer or technician couldn't locate or wasn't aware existed. There is no advantage to having what You can't use. As a result, most of the standards created by naval shipyards were still being created the expensive way - slowly, from scratch, often with out the proper methods analysis.

HISTORY

Clearly, a more efficient and economical way to handle standard time

data was needed. If industrial engineers and technicians no longer had to manually search for, apply and maintain standard time data, they would have more time to devote to methods analysis and improvement and cost reduction. In the late 1970's, a DoD study concluded that using a computer system that would help generate time standards as well as store standard data elements was the best approach to this problem.

From 1980 through 1986, the Defense Productivity Programs Office (DPPO) developed and used a sophisticated program of computer technology known as CATS, or Computer Aided Time Standards. In 1987 CATS evolved into PIERS, the Production Industrial Engineering Resource System. This system is still evolving and expanding.

PIERS goes far beyond more efficient storage and retrieval of standard data. It can search for and retrieve standard data and then combine the elements it finds automatically to create a formatted method and standard. The program takes adverse *environmental* and working conditions and personal fatigue and delay into account. After creating the standard, the system can aid in analyzing the entire work process to spot tasks that can be redefined or *reorganized* to improve efficiency. This makes it much easier for engineers and technicians to create method improvements.

The best way to understand the full capabilities of the expanded PIERS system is to review the way it grew and

developed to meet expanding shipyard needs (2).

In 1981, the Defense Productivity Program Office introduced all the naval shipyards to CATS (4). The Philadelphia Naval Shipyard volunteered to be the prototype shipyard for the new system. In 1982, Philadelphia acquired its first personal computer.

In 1983, Philadelphia technicians converted an expensive mainframe system into a stand-alone CATS system, which dramatically reduced on-line time and expense (5). One Philadelphia technician developed a program for calculating personal, fatigue and delay allowances. The program was distributed to all U.S. naval shipyards. Philadelphia industrial engineering technicians created the first methods and standards using the CATS system. Their use of standard time data eliminated many time-consuming field studies. The volume of throughput increased so much that Philadelphia purchased a second personal computer.

Software advances marked 1983, but hardware improvements accounted for most of the changes in CATS in 1984. A change in personal computer manufacturers brought more memory, speed and storage capacity to the system. Although it had been clear that the CATS concept was sound, until this hardware change the system had been somewhat difficult and time-consuming to use. Philadelphia technicians assisted in the development of a new worksheet entry program to take fuller advantage of the new equipment. The other 1984 software change was an electronic mail service between the eight naval shipyards and other DoD activities. This system has had wide acceptance and use since it was first activated.

In 1985, it was clear that CATS was about to *outgrow* its hardware once again, and the decision was made to convert to an IBM-compatible system. The software method of analysis being used was changed from the traditional production-line, stopwatch approach to a more shipyard-compatible, job-shop approach. Several software resources were added as well: an electronic bulletin board to use to exchange technical data, a data base directory to speed information searches, an index of standard time data, and an industrial process instruction data base.

In 1986, the planned-for Zenith personal computers arrived and are currently used for the PIERS system at the eight naval shipyards. They are almost completely IBM-compatible and are three times more powerful than the systems they replaced. They have twice the storage capacity and eight times the speed. The Zeniths are also more user

friendly and have high-resolution color graphic capabilities and faster modems, which allow faster transfers of data.

During this year, the CATS software was upgraded to CATS-E-X-P (Expanded Productivity). User suggestions about CATS were the basis for the improved CATS-E-X-P, so developing and exchanging engineered time standards was finally fast, flexible and simple. The system's IBM compatibility allowed the shipyards to add desktop publishing, computer-aided design (CAD), and data base management to their software library.

Even though improvements to the system had been steady and significant, the shipyards recognized that the engineering documentation capabilities of CATS were no longer enough. The next step was a complete computerized engineering toolbox. So in 1987, CATS became PIERS. Some of the needs the shipyards hoped to address with this expanded system were ways to support industrial engineering studies, speed the production of industrial process instructions, improve work scheduling and control, and make the most efficient use of the shipyards' limited people resources.

An extensive search was conducted to find applicable software and turnkey systems to include in PIERS. Dozens of computer software packages and industrial engineering systems were evaluated, benchmarked and tested in actual shipyard trials. Because PIERS is a collection of computer programs, a program called Microsoft Windows was chosen to provide an operating environment to connect all the available PIERS applications. Microsoft Windows allows users to switch from one program to a second program quickly without having to formally exit the first program. Users can also access more than one program at the same time with Microsoft Windows. In addition, this program allows data to be transferred from one program to another. The other PIERS cornerstone is Microsoft Excel, which enables users to create state-of-the-art spreadsheets and graphs.

Last year, two hardware items and three software programs were the main forces behind PIERS progress. Philadelphia began working heavily with an optical character reader, or OCR, a machine that "reads" documents and adds them to the database directly without typing (6). Another hardware item, the Costimator, enables users to totally plan machining operations.

In 1988, the shipyards acquired a specialized expert computer system for welding, developed by the American Welding Institute. This software was provided to Philadelphia welding

engineers on a cooperative basis with Philadelphia industrial engineering technicians.

1988 also saw more widespread use of PC-based, computer-aided design, or CAD. In Philadelphia, this software program is used by industrial engineering technicians to illustrate industrial process instructions and engineered methods and standards and by waterfront engineering technicians to plot ship docking services. This speeds up drawing production and eliminates the need for redrawing if the ship revisits or if similar ships dock there in the future. A third important software system, Engineering Document/Drawing Information Exchange (EDDIE), was developed and brought on line. EDDIE was a big boost to the computer communication between shipyards. The yards can now send and receive any industrial-engineering-related document or drawing, even those done on different machines or using different software.

Shipyards recognize that, to make maximum use of PIERS, it must be a fully integrated system, not just a loosely knit collection of parts. In 1989, shipyards are working to make PIERS a truly automated, highly functional engineering tool. PIERS will evolve into an expert system known as the PIERS Advisor.

The Advisor will make PIERS even more user-friendly and more useful. It will provide a guide to using the system and will show users what is available. The Advisor will supply users with applied industrial engineering theory as well as helpful tips. It will show users how to work with PIERS to develop industrial engineering studies.

STANDARD DATA AND STANDARD DEVELOPMENT

While PIERS is a diverse collection of automated engineering applications, the most traditional application in the system is in standard data (7) and standard development. PIERS is an excellent tool for industrial engineers and technicians who want to improve the bottom line by standardizing procedures. By standardizing your procedures you can control costs, manpower requirements and scheduling more effectively. You can track your work and forecast your future requirements. This is only the beginning. Once you standardize, you can improve your methods easily--by changing your manufacturing procedures, your layout or your machinery area. Each of these changes can result in a change to the standard that usually means a positive change in the bottom line.

PIERS can establish baselines for method improvement studies, make labor

cost comparisons, compare investment alternatives, aid in conducting "what if" studies, and monitor auditing and performance. The system has sophisticated information retrieval capabilities. It will allow users to apply standards in a timely and uniform way.

PIERS contains a tailor-made tool for standardizing procedures called CATS E-X-P. This system can accommodate and integrate multiple data bases. It can easily handle standard data, standards, text (word processing), work orders, and method descriptions. It can make calculations to construct standards, do statistical analyses, and produce reports. CATS is a complete system to develop, maintain, share and apply standards. CATS E-X-P has demonstrated a cost savings and positive return-on-investment of 3.5:1 (2). In Philadelphia, for example, approximately 180 electronic/electrical standard data elements were produced by only one technician. Each of those standard elements has become a new piece of standard data. This technician is still developing new elements; 99 percent of one standard was created from standard data (8).

One of PIERS greatest strengths is how easy it is to use, even for workers who are not computer-literate. A good way to demonstrate this is to describe the creation of an engineered method and standard with PIERS.

Standard data begins as a single item. It is meant to be added to like a pyramid, in a hierarchy that starts with the simple and expands into the complex. Each step in the pyramid is completely traceable. Beginning with an analysis of a simple item and adding analyses of the more complex items that follow, each item can be traced forward and backward. The standard can be broken backward all the way down to finger motions if necessary.

A technician developing a standard on the computer terminal enters the work area or sub-directory. The technician calls up the Lotus 1-2-3 program used for data entry and begins to fill out the "template." The template will contain all the "boilerplate" information he would normally re-enter on each work sheet. (Shipyards use a separate work sheet for each standard element.) The template contains the analyst's name, the document number, the item or standard title, and the word search criteria that would appear on each worksheet. As the analyst moves along creating each new worksheet, keystrokes and time are saved by not reentering the same information over and over. With each work sheet the analyst fills out, there is ample space for the standard element description, a reference description

that supplies the backup information to support the work being done, and the manhours to complete the standard element.

This information comes from an area known as REFTAB or "reference table." This reference table contains the standard data developed by the shipyards and is easily accessed by one of the following methods. Code number: the analyst is given the opportunity to insert the code number if it's known. ^{KEY WORD} word: by giving a keyword like "inspect," the section of the table containing "inspect" items will appear on the screen. Section: each section has an alphabetic designator assigned; if the alpha is entered, that section of the table will appear.

Once the code number is selected, the code appears on the screen with a "stock" description. This description can be edited to better suit the item. The user requests frequency of occurrence for that actions and the manhour allowance is automatically provided directly off the reference table. The program recomputes total manhours each time another reference description is entered. When the analyst has completed the entry of all references for that particular element, an Allowance Factor that applies to that specific element is **entered and, once again, the program** computes the newly adjusted time. After all entry work for a standard is complete, the analyst can produce a manhour allowance table or readable product that can be reviewed and edited. As soon as the standard is ready for final correction, the analyst can go back into the worksheets and make necessary corrections. Once again, the manhour allowance table is run and the document is ready for signature. The document can now be entered into the mainframe for distribution to all shipyards.

The procedure just described produces a finished and signed standard. It may create more standard data, which will increase the reference tables. It will also automatically update the shipyard index, so other shipyards can use the information.

SOFTWARE AND HARDWARE

It's clear that using PIERS to build a standard significantly improves efficiency by allowing the user to automate time-consuming manual steps. The two keys to using PIERS are its database and its software. The example given above shows how just a few software applications can make a major product difference. But PIERS has more than just a few software and hardware tools. In addition to CATS E-X-P and the optical character reader, which have

already been discussed, PIERS currently has:

- word processing
- spreadsheet analysis
- statistical analysis
- structural analysis
- computer-aided design
- drafting and chart graphics
- projects scheduling
- electronic mail (9)

as well as several other software applications that are not self-explanatory.

One, Costimator (10), is a computer-generated method of estimating manufacturing costs and times. The user can change the data base as needed by simply inserting new information. Based on general information the user supplies, the program calculates speeds, feeds, volumetric material requirements, and basic machining information. Additions and revisions can easily be made to the data base.

Another software package is the Engineering Document Library (EDL). This is a computerized "card catalog" that helps users by automating their searches for drawings, documents and backup data in a local data base.

A similar "card catalog," Special Machine Tools (SMT), allow users to search for machine tools developed at other shipyards (11).

The Engineering Drawing/Document Information Exchange System (EDDIE) makes possible the electronic transfer of documents, drawings and spreadsheet files between computer systems or shipyards.

SUMMARY

The PIERS system, with its hardware and software, now stores a large collection of standard time data and related documentation. Studies show that naval shipyards are averaging at least a 50 percent reduction in the time needed to create a standard. This percentage will increase as the size of the data base increases.

The system is developing continuously as new hardware features and new software technologies become available. An artificial intelligence project now underway is expected to make the different components of PIERS even

more integrated, automatic and user-friendly.

PIERS provides the naval shipyards with several significant benefits:

- Systematic description of each work process
- Organization of work measurement data into a structured, readily accessible medium
- Analysis of the production process to implement methods improvements
- Reduction in manual effort required to develop and maintain mandated time standard coverage levels
- Significant cost savings due to more efficient use of production resources (labor, materials, plant equipment); improved production processes; and higher quality control.

The biggest potential Pitfalls that would face a system similar to PIERS are not with the system itself or its users but with management support for the system. The Navy is supporting PIERS in the naval shipyards. Any organization that contemplates installing a similar system must place a high priority on standards development and maintenance and on management support to succeed.

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Flexible Standards: An Essential Innovation in Shipyards

Louis D. Chirillo, Member,
L.D. Chirillo Associates, Bellevue, WA

ABSTRACT

Following a pattern established by Japan after World-War II, a number of other Asian countries are encouraging labor-intensive shipbuilding as means to develop their economies. For them, low-cost labor abounds. As a consequence, established shipbuilders elsewhere in the world market cannot be competitive for ordinary ships including multiple such ships of the same type. Their only alternative is to develop an organization that routinely ferrets out and solves new problems arising from custom-designed ships and different products other than ships, regardless of quantities, i.e., flexible-system production.

An indispensable feature of effective flexible-system production is a file of standards which can be adapted to changing requirements, including requirements for modernizing naval ships, while at the same time permitting reapplication of significant corporate experience. This paper addresses such flexible standards and their significance.

INTRODUCTION

Where the word "standard" is mentioned in the presence of traditional shipyard managers, they immediately fantasize about a material paradise. Regardless of manufacturing sources, all valves of the same type and nominal size would be geometrically identical, pumps for a specific service of a particular capacity would have the same foundation interfaces and the same nozzle locations, and so on. For the purpose of completing their dream, they envision standardized work methods to match a marketplace in which only their designs for runs of standard-series ships would be in demand. That's Tara. If it ever existed, it's gone with the wind.

Some traditionalists compound their self-celusion with the expressed intent to continue to build, convert, and overhaul just ships. This narrow focus, actually a rigid standardization of

corporate purpose, has caused shipyards to close or go into bankruptcy. Years ago one such firm turned away from an opportunity to focus on development of its construction process and to direct it wherever markets dictated. More recently, a manager in a private shipyard which has just Navy work, addressed the need to diversify by saying, "The door is always open." That inadequate response infers continued dependence on just the Navy and no intent to market elsewhere.

Despite profound changes in our economic world, by the 1973 Oil Shock and already by the growing influence of glasnost, traditionalists on both sides of the disintegrating iron curtain continue to associate security with stability. For free nations, security is inherent in flexibility, i.e., the abilities of industry managers to quickly shift from making plowshares to swords. For modern industrialists, security is also inherent in flexibility, i.e., regardless of what is being produced, constantly developing their manufacturing systems. No one has made this solution clearer and provided better pertinent definitions than Robert B. Reich in a paper appropriately titled "The Next American Frontier":

"Flexible-system production is rooted in discovering and solving new problems; high volume, standardized production basically involves routinizing the solutions to old problems. Flexible system production requires an organization designed for change and adaptability; high volume, standardized production requires an organization geared to **stability.**" [1]

Flexibility in this context does not mean the absence of standardization. But, the word "standard" in flexible system production is dynamic; it means more than the usual dictionary definition, "something established by authority, custom or general consent." In

modern industrial systems the word "standard" must be thought of, paradoxically, as something subject to continuous change. The word should be used as if it was set off in quotation marks because what is meant is a standard of the moment. As soon as something better is detected, a new or revised standard is adopted!

For most matters for which standards are useful, there is no time for achieving general agreement. A modern manufacturing system features unrelenting analyses which constantly identify even minute improvements. Authority, custom or general consent applies to acceptance of the system for constant improvement and not to the improvements per se. The latter are automatically incorporated in the forever changing standards.

FLEXIBLE MATERIAL STANDARDS

Traditionalists are right when they first think of material when standards are mentioned. But the need for material standardization transcends traditional concerns. Materials are tangible and thus comprise the soundest basis for production control. The most effective shipbuilders equate material volume to work volume. Using statistical methods they have, for work package after work package of the same problem category, identified some physical characteristic of material that varies directly with man-hours. Thus, as designers define and refine material requirements, a solid basis emerges for estimating required production man-hours. Moreover, the man-hours are expressed statistically, i.e., for each category of work, with a mean value and standard deviations so as to reflect real-world variation.

As long as the distribution of the variations approximates a normal curve, man-hour allocations and scheduling are based on the premise that jobs will probably go over or under in accordance with a prescribed variation pattern. But, the operational words in the foregoing paragraph are "same problem category", an aspect of group technology. Thus, if a drain pump of a specific type was included in an outfitting work package, it would not matter if a drain pump of a different type was substituted provided it had equivalent capacity and provided the problems inherent in associated work remain unchanged. The pumps' foundation interfaces as well as suction and discharge piping could differ significantly without changing the work classification.

Having appreciation of the foregoing, the most effective shipbuilders have over the years built computer files of so-called standards. In one case, the files are based on as many as four stan-

dard machinery arrangements which anticipate four different main-engine types. For each auxiliary-machine position in an arrangement two or three different vendors' catalog items are certified as shipyard standards. The items are functionally equivalent but physically different. Moreover, the auxiliary-machinery market is constantly monitored. When better buys are discovered, based on evaluations of the effects on required shipyard man-hours as well as on price, new vendor catalog items displace old ones in the files.

For the purpose of declaring vendors' equipments as shipyard standards, preference is given to those vendors who each produce machines of the same basic design for a range of capacities. Thus, each standard machinery arrangement for a particular main-engine type can expand or contract with engine horsepower. As any of two or more vendors' equipments can be employed for each auxiliary-machine position without impact on the normal performance of work, What could be more flexible and at the same time practical?

When during contract negotiations the customer agrees on the selection of one of the four main-engine engine types and usage of the flexible material standards, the shipyard simultaneously knows all auxiliary-machinery requirements as well as requirements for large valves, strainers, etc. which are treated the same way. Upon contract award or very soon thereafter, the definition is narrowed down to two, or some other reasonable number of vendors' products for each requirement.

Limiting prospective bidders to reasonable numbers makes it practical to maintain critically-needed material histories and material codes in a shipyards computer file. In some shipyards this includes design details, approval records, price and delivery histories vendors' prior agreements with procurement terms and conditions, and vendors' guarantee performances. Thus, in the moment of action sparked by contract signing, for each requirement only two steps remain for a procurement decision-issuing requests for bids which asks only for price and delivery, and evaluating a limited number of vendor responses. Three responses, perhaps one or two more for certain equipments, are judged to be optimum for balancing need for competition against a yard's capacity to maintain required material information in a computer file.

Instead of investigating, some managers quickly respond, "Neat! But, we can't use such standards. We're building warships; the government would not permit us to limit the list of bidders. One shipbuilder who so responded took a

second look, initiated a survey, and discovered that there were over a thousand material items in three different warships for which specifications were separately written and for which only one supplier responded with the same product. How many thousands more are there for which there are only two or three suppliers? Thus defacto standardization exists and few, if any, exploit it. The most significant problem for some of those items is not how to limit the bidders list. Instead, it is one of creating a second or third source, something the U.S. Navy's office of Competition Advocate General has been doing on a much larger scale.

The former Competition Advocate General, Rear Admiral Stuart F. Platt, U.S. Navy (Retired) recently offered pertinent advice:

"Getting up to date on computerized information systems is the greatest single barrier to continued gains in efficiency in the procurement process. The fact that we still rely to a large degree on a paper-based procurement system is ludicrous. Internal automation is the most attractive automation opportunity we have here. It will begin paying off almost immediately, in reduced overhead, faster and better decision making, and higher quality goods and services."

Elsewhere in the same article Admiral Platt advised:

"There are no fast fixes. Improvements will best be made from a disciplined inspection of the system's fundamentals. Common sense calls for a procurement process that is prompt, equitable, and administered with a firm hand that allows room for good judgement." [2]

Thus, U.S. shipyard managers including those in naval shipyards, should investigate how their material management systems support their operations. They would find that they have justification to change how government procurement regulations are being implemented. Traditional material managers should be pressed to identify and test the specific procurement regulations that are believed to inhibit productivity in the work place. If they are proven barriers to implementing flexible standards as thus far described, managers should be unrelenting in their pursuit of pertinent regulation changes. Nothing can facilitate promptness more than flexible material standards.

Good judgement dictates that equitability should not apply only to Suppliers. A vendor's sales practices, credibility and after-delivery services

usually impact more on a yard's productivity than the vendor's price. Thus, equitability should be interpreted as meaning benefit for all, i.e., designers, buyers, suppliers and production workers through manifest increases in productivity and quality. It is for this reason that Dr. W. Edwards Deming insists that U.S. industry must learn to deal with fewer suppliers for productivity reasons! It is for the same reason that in the most effective shipyard in Japan, the purchasing department reports to the production control manager. There, material, man-hour allocations and scheduling are inextricably linked. The linkage is the substance of corporate experience which becomes ineffective when too many suppliers are involved. The linkage is applied in a more profound way than can be surmised from just understanding flexible material standards.

FLEXIBLE STANDARD ARRANGEMENTS AND DETAILS

Eleven-years ago, Mr. Y. Ichinose presented a paper which disclosed how standards, including flexible standards, were organized and employed by Ishikawajima-Harima Heavy Industries Co., Ltd. (IHI) of Japan. This insightful paper advised:

"It is obvious that a comprehensive computerized design system, consistent from design through production, could not be effectively realized without standards or modules."

Conversely the paper also advised:

"Standards and modules show their greatest advantage when integrated with a comprehensive computer system."

Mr. Ichinose, then president of IHI Marine Technology, Inc., concluded:

"In the 80s it is hoped that the...demand for new ship construction will increase. Although the major demands may still concentrate on conventional ship designs, it is foreseeable that modern technology and sophistication in ship design may require more complexity in various ship's systems. This complexity can still be solved by refining the standards and modules to cope with the state of the art of the future era, so we remain convinced that shipbuilding can be changed to a mass-production industry without losing the ability to provide sufficient 'tailor made' features to satisfy the individual demands of ship owners." [3]

In the context of Mr. Ichinose's fore-

[1] Reich, Robert B., "The Next American Frontier," The Atlantic Monthly, March 1983.

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[5] The Society of Naval Architects of Japan recorded in its 1967 English-language annual report of shipbuilding developments that, "Statistical control 'epoch makingly' improved quality, laid the foundation of modern ship construction methods and made it possible to extensively develop automated and specialized welding." There is urgent need to repeat this statement until the last traditionalist succumbs.

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[7] The Commission on Merchant Marine and Defense, Third Report of the Commission on Merchant Marine and Defense: Armendices, U.S. Government Printing Office, September 30, 1988, p. 214.

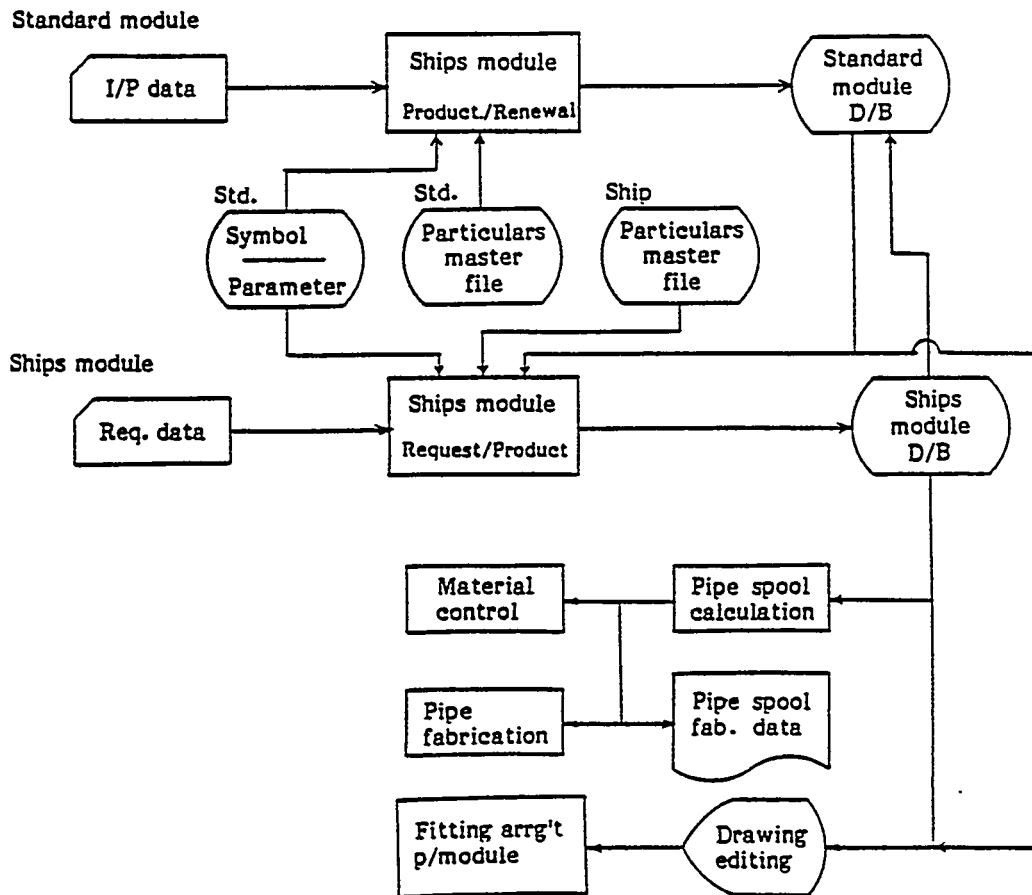


FIGURE 1: FRESCO-F Process Flow

Technical drawing of a mechanical assembly, likely a valve or pump component. The drawing includes a cross-section view on the left and a side view on the right. Dimensions are given in millimeters (mm) and inches (in). Key dimensions include 25, 50, 100, 278, 231, 20, 678, 889, and 716. The drawing is labeled with 'FD022C-', 'FD022E-', and 'FD022A-'.

FIGURE 2: Condensate Pump Unit

FIGURE 3: Purifier H.F.O. Heater Unit

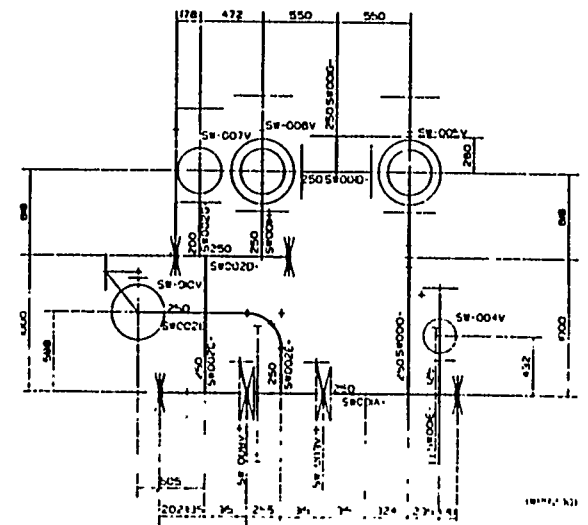
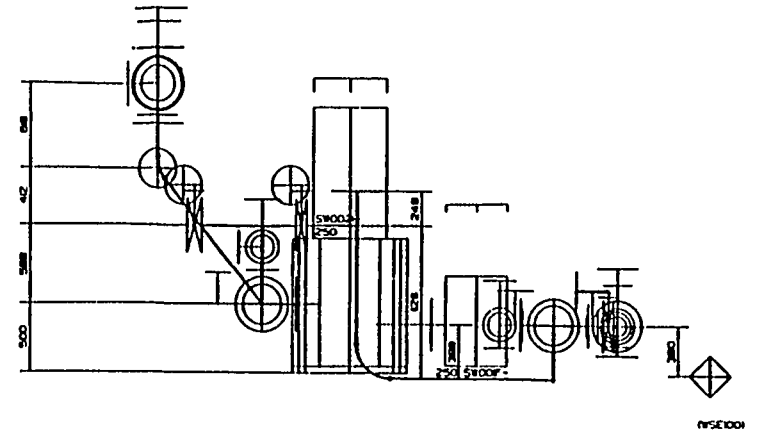
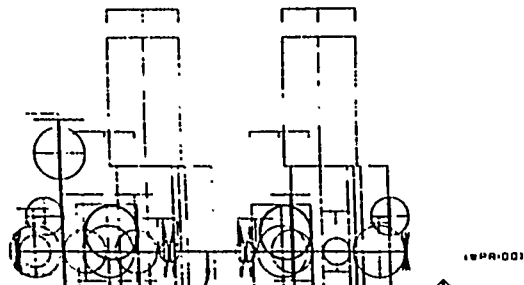


FIGURE 4: Fire and G.S. Pump Unit.

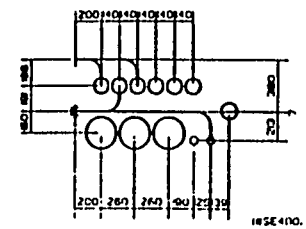
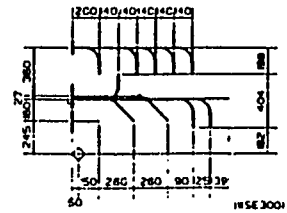
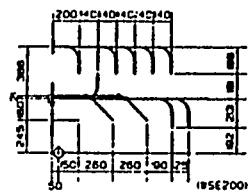


FIGURE 5: Lower E.R. Flat Unit (near D.G.)

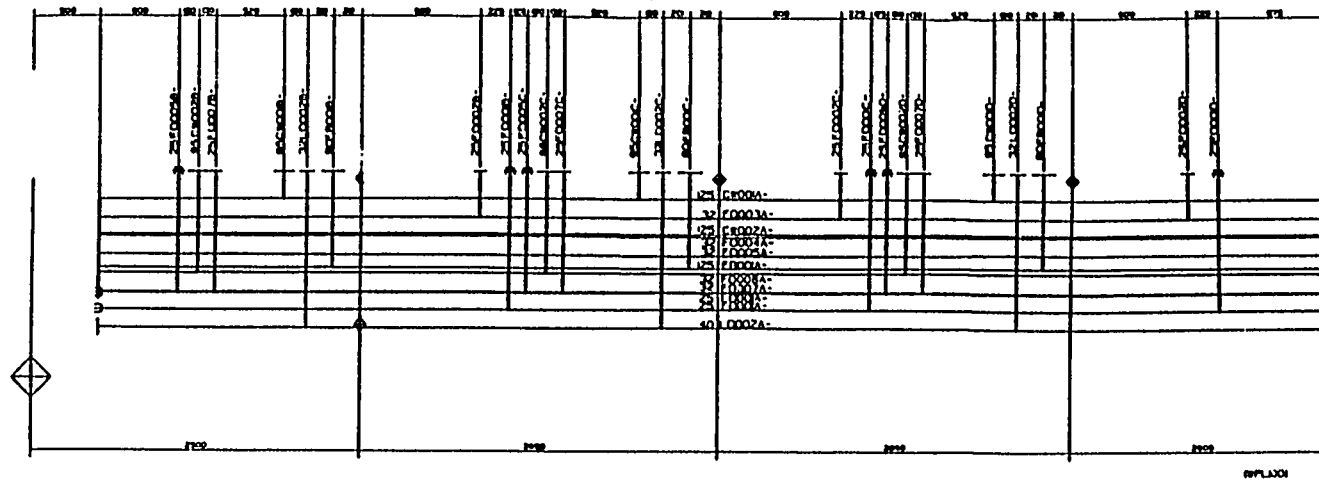


TABLE 1: Typical Performance Indicators (circa 1983-1984)

Hull Construction:

$$\text{Steel Yield Rate} = \frac{\text{Net Weight}}{\text{Invoice Weight}} \times 100 = > 93\%$$

Pipe Fitting:

Man-Hours/Ton	Fabrication	27.5 mh/t
" " "	Installation	40.0 mh/t
Man-Hours/Piece	Fabrication	1.6 mh/pc
" " "	Installation	2.3 mh/pc

$$\text{Pipe Piece Refab Rate} = \frac{\text{Refabrication Number}}{\text{Total Number Fabricated}} \times 100 = < 2\%$$

Electrical:

Man-Hours/Meter for Total Cable Length 0.18 mh/m

Painting:

Man-Hours/Square Meter	Zone 1	0.10 mh/m ²
" " " "	" 2	0.12 "
" " " "	" 3	0.10 "
" " " "	Total	0.11 "

Material Marshaling

$$\text{Pallet Completion} = \frac{\text{Lost Line Items}}{\text{Total Line Items}} \times 100 = < 1.8\%$$

TABLE 2: Principal Dimensions of Three FFG-7 Class Frigates

Differences from Design Principal
Dimensions (in inches)

	Shipyard X	Shipyard Y	Shipyard Z
Length overall	-13 ¹ / ₄	-6 ¹ / ₄	-7 ¹ / ₈
Length between perpendiculars	-3 ¹ / ₈	-3 ¹ / ₄	-1 ¹ / ₈
Beam (midship, main deck)	-1 ¹ / ₂	-2 ¹ / ₄	-1 ¹ / ₂
Beam (midship, design waterline)	-2 ⁷ / ₈	-4 ¹ / ₄	-1 ¹ / ₈
Depth (midship, main deck)	-1 ¹ / ₈	+2	-1 ¹ / ₈

Deviations Beyond Allowed
Tolerances (in inches)

	Shipyard X	Shipyard Y	Shipyard Z
Length overall	-8 ³ / ₄	-1 ³ / ₄	-2 ³ / ₈
Length between perpendiculars	accept.	accept.	accept.
Beam (midship, main deck)	-1 ¹ / ₂	-1 ³ / ₈	accept.
Beam (midship, design waterline)	-1 ⁷ / ₈	-3 ¹ / ₄	-1 ¹ / ₈
Depth (midship, main deck)	-1 ¹ / ₈	+1	-1 ¹ / ₈



IHI Zone Logic Application to Electrical Outfitting on Highly Sophisticated Ships

Shuji Sato, Visitor and Shizuo Suzuki, Visitor,
Ishikawajima-Harima Heavy Industries Co., Ltd. (IHI), Tokyo, Japan

ABSTRACT

Outfitting electrical cable in highly sophisticated ships, such as, research vessels, patrol boats, etc., has significant impact on every aspect of ship construction, modernization, overhaul and repair. In other words, cost, schedule adherence and quality for very sophisticated ships are fully dependent on the performance of electrical work. Ishikawajima-Harima Heavy Industries, Co., Ltd. (IHI) has been exploiting zone logic, also recognized as technology, for construction of virtually all ship types. But, the extensive cable footage in sophisticated ships requires special considerations and techniques. This paper presents practical design and production processes for zone outfitting electric cable.

Special focus is on:

- 1) functional end detail design,
- 2) conversion of system-oriented design data to zone-oriented work packages called pallets, and
- 3) work methods currently employed in IHI shipyards.

INTRODUCTION

significant advances are being made in North American shipyards to reduce cost and to assure schedule adherence by applying zone logic, for construction, and also for modernization, overhaul and repair of ships. Everyone so involved acknowledges that much more needs to be done. But, most do not yet understand how to include electric-cable work within the zone approach for integrated hull construction, outfitting and painting.

Traditionalists regard electric-cable work as incompatible with zone logic. They insist that most cables must be installed on board because, "cables extend over several ship compartments and/or zones." Where traditionalism has prevailed, cable work has taken a back seat while full-scale explications of zone logic are achieving unprecedented productivity increases for other types of work. Two different build strategies are underway at the same time. Unavoidably, cable installations then proceed rather haphazardly under

old-fashion control which relies on each supervisor's experience and intuition while other work proceeds in a much safer and productive manner. Moreover, system-oriented work does not yield the corporate experience needed for constant analysis and constant improvement in design details and work methods.

Also, continuing the system-by-system approach for installing electric cables while hull construction, other outfitting and painting are zone oriented, increases the probability of unsafe work situations, cable damage, and rework even for the other types of work. Any combination of these conditions could lead to a deterioration in quality and catastrophic confusion in attempting to implement a work schedule for a ship as a whole.

Obviously, the solution lies in integrating the installation of cables with other types of work. In this connection, design data which are originally generated in a system-oriented manner must be rearranged in accordance with zone-oriented classification criteria. Cables have to be grouped for both material and production control in accordance with problems inherent in their installation. Thus, group technology (GT) has an important role in the advanced techniques for installing cable.

The exploitation of GT for cable work is firmly established in IHI and is now regarded as indispensable, particularly for the most sophisticated ships. This advanced process has brought about a remarkable outcome for every aspect of electrical outfitting. An electric-cable length is regarded as a fitting every bit the equivalent of a single pipe piece. The approach has made it possible to adopt the "Cable Pre-cut Method" which is essential for making cable-installation work safer, more productive, and susceptible to production control commensurate with other outfitting work.

Cable grouping is performed in the Production Department as a major part of production planning and given to the Design Department for completion of the last stage of detail design. The data base and processing system for cables, called CLIP (Cable List Program) is an important tool that is applied from functional design through production.

such as: cable lengths, cable-tray widths, penetration-piece requirements and material lists. From the outset, CLIP was developed and applied for the construction of sophisticated ships.

OVERALL ENGINEERING PROCEDURE

1) Design

- a. Functional Design - Major work typically includes generation of wiring diagrams, equipment arrangement, basic design data, and construction of a data base in CLIP.
- b. Detail Design - This stage specifically defines cable lengths, cable routings, cable trays, penetration pieces, etc. as well as the CLIP data base.



- 2) Production Planning - This is the most important phase because it converts the system-oriented information that was generated, during functional design into zone-oriented information. The work includes definition of cable-installation sequences and methods. The output of this phase is processed by CLIP to automatically produce required information such as material lists and cable-cutting instructions. Other work such as preparation of the manning plan, cable-installation scheduling, and setting pallet-delivery dates, are also performed during this phase.

Design and production planning are further described in the next parts of this paper.

DESIGN

In addition to the role CLIP plays as a tool for grouping work, it has remarkable merit for reducing required detail-design man-hours.

The development of an electric-wiring arrangement (EWA) accounts for a significant part of a detail-design effort. Before CLIP was introduced, an EWA was the only drawing developed for cable-installation work and pertinent purchasing-data generation. The preparation of EWA then required a high degree of skill; each cable was superimposed to 1/25 scale on hull structural drawings. The process was extremely time consuming and required a huge manpower investment. As an EWA shows all cable routes, it thereby indicates cable lengths, cable-tray dimensions, penetration-piece sizes, and comprises the basis for placing purchase orders. EWAS are also used for installing cables at the production site. CLIP succeeded, not only in simplifying EWA formats, but also, in substantially reducing man-hours and the time required for their preparation.

The design phase consists of:

- 1) Prerequisites - The following are required before starting data input into CLIP:
 - a. Wiring Diagrams - These are prepared per circuit. Ten-digit circuit numbers, the names of terminal equipments, and the types of cable to be used are identified.
 - b. Equipment Arrangement - The positions of electrical equipments in the context of a general arrangement, machinery arrangement, cabin arrangement, etc., are shown.
 - c. Main Cable-Way Guidance Plan - This is needed to determine locations for main-cable trays. As a general rule cable ways are superimposed on an equipment arrangement. This plan presents the distances from nearest hull structure to each cable way and also gives the positions and numbers of cable index points. The latter are used to determine routes, calculate cable lengths, establish cable-tray sizes, etc.
- 2) Data Input - CLIP requires the following data input during the design phase:
 - a. Cable-Standard Master - The outside diameters and unit weights for all types of cables to be used are required. Note should be made that much of these data are common to many ships. Therefore, much is retained in the master file that is common to other ships. The work required to input data for a specific ship is usually negligible.
 - b. Circuit Data - The circuit numbers, the names of terminal equipments and the zones they are located in, are inputted. Since these data are conserved from previous ships' files, the actual volume to be inputted for a specific project is reduced substantially.
 - c. Cable Route Data - The index numbers alongside the route of each circuit runs, and the distance from the terminal equipment to the nearest index point on the route, are inputted. Margins at both ends of each cable to be precut are taken into consideration at this time.
 - d. Cable-Way Data - The distances between all index points on the main cable way guidance plan are inputted. These data in combination with cable-route data used to calculate cable lengths.
- 3) Preliminary CLIP output - CLIP preliminarily outputs the following information after processing the data inputted during the design phase.
 - a. cable route list - The circuit number, the type of cable, the names of the terminal equipments, the index points through which the circuit pass, and the cable cutting length are outputted for every circuit in the form of a list.
 - b. Cable point list - By each index point, the circuit numbers of all cables pass through are outputted in the form of a list. The sum of outer diameters of all cables, that determines the cable tray width, is also provided.
 - c. Cable quantity - The required cable length is summed up for each cable type and the purchase order is forwarded to the cable supplier.
 - d. Fitting information - Sizes and required quantities of penetration pieces, "Multi Cable Transit"s (MCTS) and glands are outputted, and thereby the fabrication details are developed. Another computer system which is capable of on-line processing being connected to CLIP determines the arrangement of MCT elements in a frame.

Aforementioned outputs are next processed in a production planning phase for determining the best sequences and methods and for converting system-oriented information into zone-oriented information.

PRODUCTION PLANNING

Production planning work consists of the following processes:

- 1) Zone Designation - Figure 2 shows typical zone designations. In this example the ship is divided into five zones: forward, midships less the engine room, aft, engine room and superstructure. Each cable is assigned to the zone or zones through which it runs. Thus a cable may be assigned to one or as many as five zones. Cables in common zones are grouped by problems inherent in their installation. Then, they are broken down to the pallet (work package) level. A pallet is the smallest unit for the sake of controlling material and is determined in accordance with two levels of grouping;
- 2) First-Level Grouping - The cables assigned to each zone are first grouped, in accordance with factors, such as, time to be installed, cable way to share, and locations of terminal equipments. This grouping is also used to determine the fundamental work procedure which will have a significant impact on the success of subsequent planning and installation work. Therefore, the grouping is performed by the same production engineer who will be in charge of work for electrical outfitting on block and on board.

First level classifications are:

- a. Lighting-Cable Group - This work is given top priority because the ship's lighting fixtures will be used for illumination during construction. Since 80% of the cables in this group will be installed on upside-down blocks before hull erection, the work to be completed on board consists mostly of uncoiling cable ends and pulling them across erection joints.

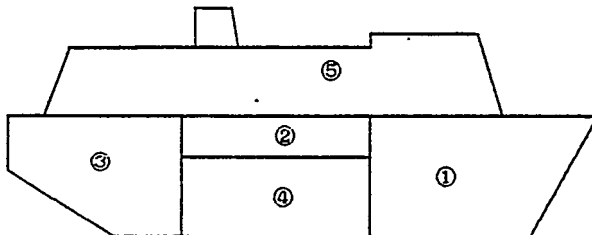


FIGURE 2 ZONE DESIGNATIONS

- b. Interzone-Cable Group - These cables run across several zones. They are further broken down according to the zones where terminal equipments are located.
- c. Intercompartment-Cable Group - These cables run through several compartments within one zone.
- d. Local-Cable Group - These cables run exclusively inside a single compartment.
- e. Coiled-Cable Group - These are cables that are to be pulled into position except for their ends. The ends are temporarily coiled at a bulkhead or at a block erection joint pending being able to pull them into position during a latter work stage.
- f. Other-Cable Group - These are cables that do not fit into the aforementioned groups. Usually they are cables that cannot be installed until after certain equipments are blue-sky landed or after certain blocks are erected, e.g., a main engine and the engine-room closing block.

After such formal classification of cables, the most appropriate cable installation procedure is developed and documented as shown in Figure 3. Immediately thereafter, the production engineer who performed first-level grouping interact with engineers for other work in order to avoid unintentionally having troubles by doing different kinds of work in the same zone during the same stage. As a consequence of the interaction, all groups usually have to make some adjustments in their proposed schedules. An electrical master schedule is formulated simultaneously.

- 3) Second-Level Grouping - At this level, there is a further break down in order to generate pallets (work packages). Detail scheduling, setting pallet delivery dates, and identifying pallet-interface problems are part of second-level grouping responsibilities.

Second-level grouping is carried out by the supervisors who will be in charge of the actual cable-installation work. They are supervised by the engineer in charge of first-level grouping.

- ① FWD Zone
- ② Midship Zone Less Engine Room
- ③ AFT Zone
- ④ Engine Room Zone
- ⑤ Superstructure Zone

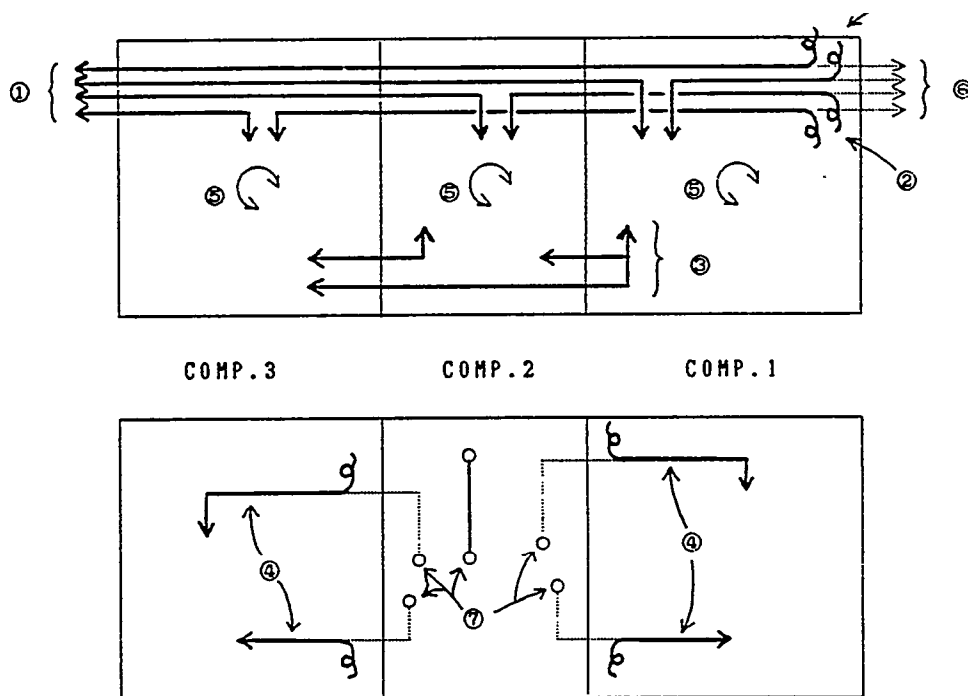
For each of the zones shown in Figure 2, an assistant foreman or a worker having sufficient experience and skill, would be in charge. As a matter of course, the foreman who coordinates electrical outfitting will give advice when need exists.

a. Second-Level Breakdown - Each first-level group is further broken down by taking into account such factors as terminal equipments, compartments in which equipments are located, cable trays shared, locations of penetration pieces, etc. As a consequence of this process the groups which are identified, each containing 30 to 40 cables, are regarded as pallets.

b. Implementation Schedule and Pallet-Delivery Dates - The electrical master schedule, formulated simultaneously with the cable installation procedure, is updated by making use of most recent planning information. Thereby, the

implementation schedule is formulated by breaking it down into activities which are the equivalents of pallets. Pallet-delivery dates are set based upon this latest activity.

c. Color Marking - Cables are positioned and strapped as soon as possible after they are pulled. Thus, despite extra length provided as a margin and correct precutting, a cable that is not pulled completely into its designed position could cause rework or even scrapping of the cable. The potential is greater when terminal points are located outside the working zone. In order to assist workers in pulling cables into their designed positions, the pre-cut cables are marked before they are pulled with colored vinyl tape at key points such as one which corresponds to a bulkhead penetration. Planning for such marking points is part of the second-level grouping activity.



- ① Engine Room Zone → APT Zone : Interzone Cable
- ② Engine Room Zone → FWD Zone : Coiled Cable
(Coiled at FWD BHD until FWD Zone is Ready)
- ③ Compartment 1 → 2,3 / 2 → 3 : Intercompartment Cable
- ④ Engine Room Zone → Superstructure Zone : Coiled Cable
via Closing Block
(Coiled at Erection Joint)
- ⑤ Local Cable within each Compartment : Local Cable
- ⑥ Uncoiling ② (To FWD Zone)
- ⑦ Uncoiling ④ (To Superstructure Zone)

- Engine Room Zone -
FIGURE 3 CABLE INSTALLATION PROCEDURE

- d. Interface Problems - At this level potential pallet-interface problems are identified in detail. They are organized as a check list to insure that they are addressed, solved and verified during the production phase. It goes without saying that this activity improves coordination efficiency and minimizes losses that would otherwise occur during construction.

The refined planning that results from second-level grouping is incorporated in CLIP.

- 4) Final CLIP Output - CLIP's refinement of preliminary planning yields the following:
 - a. Material List of Fittings (MLF) - Each MLF is a bill of material by pallet and represents a refinement achieved by some rearrangement of the CLIP-produced cable-route list during design phase. MLFs are used for production-control purposes, including by cable suppliers for precutting and assembling cable-lengths into pallets.
 - b. Cable-Point List - This is an updated version of the preliminary cable-point list.
 - c. Identification Stickers - These stickers are needed for the purpose of identifying precut cables during warehousing and installation. They are fried to both ends of each cable and identify circuit number, pallet number, names of terminal equipments, and color-marking specifications.

MLFs and identification stickers are delivered to cable suppliers. MLFs and the cable-point list are sent to production.

PRODUCTION METHODS

The following work methods which support zone-oriented cable installation are noteworthy:

- 1) Cable Precutting - Precutting virtually all cable is most important for implementing zone-oriented cable installation work. Each pallet consists of many types of cables that have common problems inherent in their installation. Systems to be served and cable types are not relevant. Therefore, bringing reels for many types of cable on board, as in traditional shipbuilding, is impractical and unsafe. They needlessly clutter working environments and, if not sufficiently secured, could be very dangerous on cambered decks or on decks that are inclined due to list, trim, etc.

All except very small-diameter cables, e.g., lighting-circuit cables, are precut. The supplier delivers precut cables pallet by pallet complete with identification stickers and color marking per MLF cutting and other instructions furnished by the shipyard.

- 2) Lighting Cable - In order to secure trafficability and workability on board, and sometimes even on block, a ship's lighting fixtures should be put into use as soon as a space is enclosed. The majority of lighting cable and fixtures are fitted on block when blocks are upside down, so that they can be lit immediately after block erection.

Usually, lighting cable pulled from reels comprises about 5% of total cable length required.

- 3) On-Block Outfitting - In addition to lighting cable end fixtures, cable trays, foundations and supports, penetration pieces associated with electrical systems, are also outfitted on block. This accounts for about 85% of required electrical fittings.
- 4) Bundled Wiring - Pulling several together, applies to cables that are relatively straight over long runs and that pass together through the same MCTs. If care is taken to avoid abrading cable insulation during the pulling process, manpower savings are realized by using small pneumatic winches and pulleys.

CABLE PROCUREMENT

Figure 4 shows a flow diagram for cable procurement processes. First, and initial purchase order is placed, based on preliminary quantity by cable type as produced by CLIP. Generally, the order is placed 90 or more days before the earliest pallet delivery date. A specific pallet delivery instruction, complete with MLF, cutting, identification and marking information, is issued 45 or more days before each required pallet-delivery date. For the purpose of assessing about when pallets should arrive, Figure 5 shows typical expected progress for cable installation work relative to key dates.

As a consequence of purchasing cable already precut, palletized and designated for just-in-time delivery by pallet, there is a great reduction in shipyard man-hours, space required for material handling, and in the total amount charged (interest) for the money used to purchase cable. Shipyard personnel are freed from reception and storage of hundreds of reels, precutting cables in warehouses or on board, and from other material marshaling chores.

Suppliers benefit also because demand on them does not fluctuate as much and their remuneration is greater because of the additional services they render. As long as they maintain sufficient supplies to assure shipyard deliveries on time, they have more freedom in serving other customers compared to having huge stocks in a shipyard warehouse, perhaps on consignment, that are not needed by the shipyard for quite some time.

Although supplier precutting, identifying and marking increases cable unit costs, the cost benefit from improved material and production control surpasses, by far, the cost increases. The result is unquestionably advantageous.

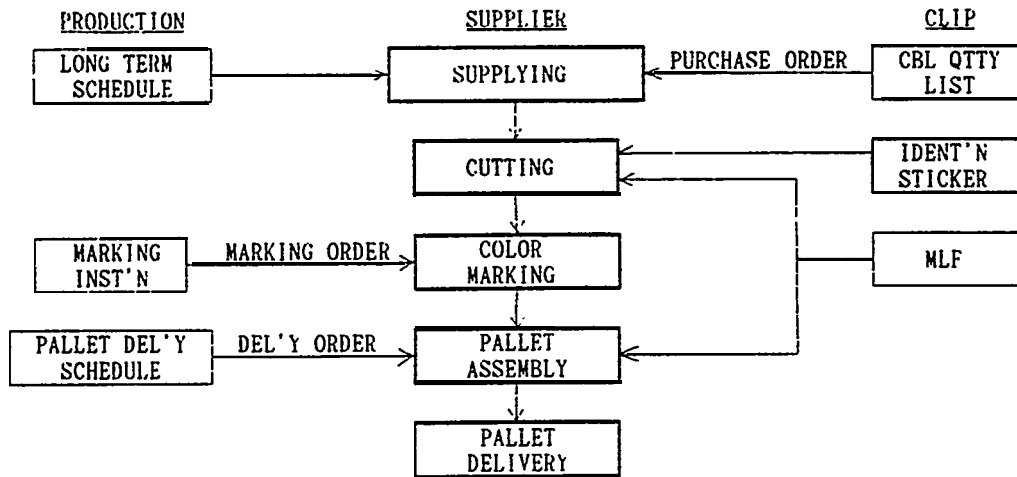


FIGURE 4 CABLE PROCUREMENT PROCESSES

Even if a cable supplier cannot be found to provide the increased services at reasonable added cost, precutting, identifying, marking and palletizing cable should be performed within a shipyard before cable is released to production. There is no question about it; there will be justifying savings resulting from improved production control through control of material.

EVALUATIONS

The various effects brought about in IHI shipyards by the approach described in this paper are:

- 1) There were substantial improvements in both design and production productivity. Accurate tracking of cable-pulling work progress was greatly facilitated. All that has to be done is "cross off" on cable-point and route lists as work progresses. As the work is classified by problem category per GT logic, productivity indicators such as man-hours per cable-length pulled, became very accurate and became sound bases for budgeting and scheduling for the normal performance of work, in a statistical sense. Thus, trends toward schedule lapses were immediately detected before they became of serious consequence. With prompt and appropriate remedial actions, unexpected delays were completely eliminated.
- 2) More efficient coordination was achieved between cable-pulling work and other types of work because interface problems were identified in advance. Such potential problems were discussed and priority countermeasures were incorporated during the planning and/or scheduling for all types of work involved.
- 3) The beneficial results of using group leaders to perform production planning, who were later to be in charge of cable installation work, were conspicuous during the production phase.

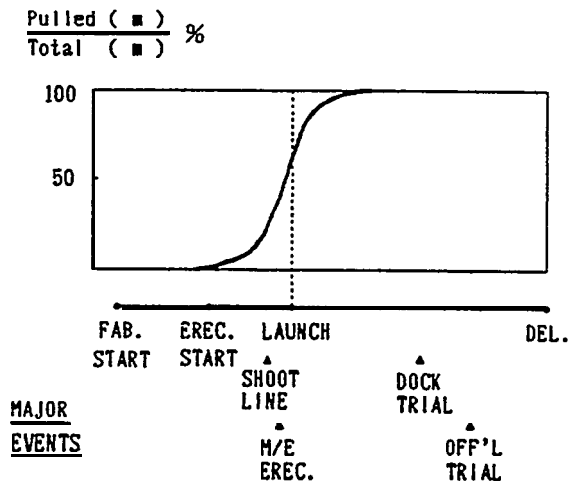


FIGURE 5 CABLE INSTALLATION PROGRESS

Besides what they contributed to planning documents, every small unwritten detail that they had detected while performing production planning, was recalled and applied by them, as they supervised cable installations, to manifestly further improve efficiency.

- 4) CLIP significantly streamlined design work. Noteworthy simplification was realized in the wiring arrangement which before, required many man-hours, skilled designers and large drafting tables. The skilled designers and saved man-hours are now applied for more sophisticated design duties. The CLIP processing system and data base are absolutely indispensable for transforming data by system to data by zone. The application of zone logic to facilitate cable installations is impractical without a processing system like CLIP and an appropriate data base. Moreover, CLIP made it practical to precut cable because of its reliability when calculating cable lengths.

- 5) Since all cable information for a ship are conserved in the CLIP data base, design data so filed can be easily reapplied when building different ships of the same type. Moreover, because all significant aspects of cable usage are captured as corporate data that is readily recallable, cost estimating with a high degree of accuracy has become practical. In addition, the conserved data base has also proven to be very useful for modernizing, overhauling and repairing ships.

CONCLUSIONS

Cable installation work was once always regarded as the most difficult to plan and control with zone logic. But, after CLIP made it practical to transform system-oriented data to zone-oriented work packages, zone logic has been successfully applied and reapplied for installing cable in ships. The zone approach is now routine in IHI shipyards.

Improvement in coordination with other trades during the busiest stage of cable installation, is still being realized. The improvement process is not likely to stop.

Emphatically, the more complex that a ship is, the more CLIP is essential for cost, scheduling and quality matters. The fact that CLIP is applicable and effective for modernization, overhaul and repair work, in addition to construction work, is reiterated.

While cable installation work is generally held to be very important, its importance is increasing with the increasing density of cables required for the seemingly unlimited sophistication of numerous electric and electronic equipments of every kind, that are now being fitted in ships. CLIP is being improved to keep up with this extraordinary demand.

The addition of computer-aided design (CAD) functions for automatic design and drafting of fittings, and automatic determination of cable routes, are regarded as priority subjects to be dealt with in the future. But, at the same time, IHI is also applying priority efforts for the development of fiberoptic systems and multiplexed communication systems, for the purpose of reducing cable requirements.



Simulation of Shipyard Material Handling Operations

Richard L. Storch, Member, University of Washington, Seattle, WA

ABSTRACT

The initial phase of a two part study to develop a simulation procedure for shipyard material handling operations is described. This phase involved investigation of software alternatives available for simulation, optimization, material handling and data base management. Additionally, material classifications, equipment choice figures of merit and a material handling equipment data base have been developed. The paper presents a discussion of the software investigation and presents choices and rationales to be used in the second phase. Additionally, the format and typical entries in the material handling data base will be presented. A detailed discussion of the final figure of merit equation developed and to be used is also included. Finally, the results of a feasibility study concerning the potential for successful simulation of the problem is presented.

INTRODUCTION

Effective management and control of modern product-oriented shipbuilding systems is based on control and monitoring of material. Work packages are organized around pallets, which are conceptual and physical groupings used for production scheduling and control. Numerous choices of material ordering, fabrication, storage, marshalling and handling systems are possible. Optimal selection from among these choices can significantly impact overall productivity of the shipbuilding process. Simulation modeling is a tool that can be effectively employed to optimize choices in a complex decision making environment. Specifically, for a given objective function, such as total cost, a minimum can be obtained by simulating the results of a series of possible solutions. In this case, the desired solution is a choice of material handling equipment to be used to move particular items from one work

station to another. By coupling a simulation of the entire series of moves associated with a shipbuilding or ship repair project, with the computation of the total cost associated with the moves, a least cost assignment of material handling equipment to specific moves can be accomplished. The research reported on here involved the formulation of the procedures and necessary data bases with which to generate a minimum total cost for planned material movement.

DATA BASE DEVELOPMENT

Three data bases are required in order to analyze the material handling choices. These describe (1) the material handling equipment available, (2) the material to be moved, including time and location it is needed for the succeeding work operation, and (3) the facility layout, indicating the work stations to and from which material must be moved. The data bases will provide input data to the simulation model. Therefore, they must contain information in sufficient detail to permit valid analyses to be conducted. They should not, however, contain more detail than can be effectively used in the simulation. The actual flow of the simulation model proposed will be presented later in the paper. However, there are certain prerequisites associated with each of these data bases.

Material Handling Equipment Data Base

The material handling equipment data base must contain information that will enable two major functions to be accomplished. First, the feasibility of using a particular piece of material handling equipment for a given move must be verified. This is a necessary condition for further consideration of the piece of equipment. The feasibility verification requires a determination that the equipment is capable of handling the weight, size and route required for the move. It

also implies that the equipment is not currently being used for another move. The second function involves making an optimum choice of available equipment based on a computation of the cost of using a particular piece of equipment. Since there are likely to be many possible choices, the simulation model should be run making different choices, so that these options can be compared after evaluating total project costs. The data categories for equipment must enable the model to determine these characteristics. Figures 1-5 show the heading categories for the files that comprise this data base. These files are for specific types of material handling equipment, including, bridge/gantry cranes, mobile cranes/crane trucks, jib cranes, transporters/trucks/rail cars, and forklifts. The first two columns are the individual equipment model and name. The next set of columns indicate handling capacities of the equipment. This data can be used to determine the material category classifications for which this piece of equipment may be used. The next column indicates the work station combinations (source and destination) which the equipment can service. The travel speed, used to indicate the length of time required for a given move is included next. This includes both loaded and empty travel speeds. The type of energy used is provided in the next column. There is also a category, indicated by a code, that directs the user to a file that describes the equipment manufacturer. Figure 6 is an example of this file. The remaining columns contain equipment specific cost data. These costs are described in detail in the section that presents the figure of merit formula.

These files are used to develop a new file, called the potential equipment list. This file is continually updated for each move and over time during the simulation. A more detailed description of the flow of the simulation and the use of this file will be presented later. This file, an example of which is shown in Figure 7, also identifies the piece of equipment by name. It then has a capacity code to indicate the number of items within a material classification that can be handled by this piece of equipment. A column, updated throughout the execution of the simulation indicates the status of the equipment, including available, in use, or down. Another column indicates the location status, i.e. where a piece of equipment is located in the facility at a given time. This information is also updated during the simulation. Finally, a series of columns indicate the cost categories, including labor,

energy, maintenance, down time, purchase, installation and debt service costs. The last column is one total cost associated with the use of a given piece of equipment up to the current time in the project (for a given simulation run). Note that while most of the data categories are constants, some are variables that are updated during the simulation and some may be stochastic, i.e., represented by a distribution. These variables are evaluated using typical random number generators during the running of the simulation. The optimization, equation, used to compute total cost, is shown later in the paper.

Material Class Data Base

Since the number and variation of individual items to be moved during a shipbuilding or major ship repair/overhaul project is extensive, a means of limiting the size of this data base to manageable proportions is required. In order to accomplish this, a material classification scheme is used. This scheme employs ten major classes, with the ability to subdivide the classes into sub-categories based on the specifics of the material handling problem. The classes include:

1. Structural raw materials
2. Outfitting raw materials
3. Pipe and tubing fittings and valves
4. Electrical system components
5. Hull and superstructure components
6. Fastening materials
7. Motors and pumps
8. Major equipment
9. Sheet metal components
10. Miscellaneous materials

The specific sub-categories within these major equipment categories are shown in the table in the appendix. Also, in addition to these categories, the data base must handle five assembly stage outputs, including sub-assemblies, outfit units, sub-blocks, blocks, and grand blocks. These outputs are primarily identified by the material handling constraints, including size, weight and special considerations [1,2].

Facility Layout Data Base

This data base is a direct function of the simulation software to be used. Most manufacturing simulation software packages include a simple structure for input of the facility layout. Consequently, no specific recommendations on the format of the layout input is made in this phase of the research. Following development of a case study of the material handling

		Maximum				Travel	Travel				Labor	Energy		Emergency	
		Moving	Bridge	Moving	Under	Speed	Speed				Cost	Cost	Maint	Down	Purchase
Model	Name	Capacity	Span	Distance	Bridge	Loaded	Empty	Energy	Manu		Cost	Cost	Cost	Cost	Cost
		(ton)	(ft)	(ft)	(ft)	(mph)	(mph)	Type	Code	No	(\$/hr)	(\$/hr)	\$	(\$)	(\$)
TDC (top running)	TDC1	3.00	25.00					E		1					
	TDC2	3.00	45.00					E		1					
	TDC3	3.00	60.00					E		1					
	TDC4	5.00	25.00					E		1					
	TDC5	5.00	45.00					E		1					
	TDC6	5.00	60.00					E		1					
	TDC7	7.50	25.00					E		1					
	TDC8	7.50	45.00					E		1					
	TDC9	7.50	60.00					E		1					
	TDC10	10.00	25.00					E		1					
	TDC11	10.00	45.00					E		1					
	TDC12	10.00	60.00					E		1					
	TDC13	15.00	25.00					E		1					
	TDC14	15.00	45.00					E		1					
	TDC15	15.00	60.00					E		1					
USG (under running)	USG1	1.00	12.50					E		1					
	USG2	1.00	30.00					E		1					
	USG3	1.00	40.00					E		1					
	USG4	2.00	12.50					E		1					
	USG5	2.00	30.00					E		1					
	USG6	2.00	40.00					E		1					
<hr/>															
											Install	Interest			
											Cost (\$)	Cost (\$)			
<hr/>															

Figure 1 Bridge/Gantry Cranes

Model	Name	Capacity (ton)	Under Boom (ft)	Span (ft)	Maximum Height (ft)	Rotation (degree)	Travel	Travel	Energy Type	Manu Code	No.	Labor Cost (\$/hr)	Energy Cost (\$/hr)	Maint Cost \$
							Speed Loaded (mph)	Speed Empty (mph)						
200-BPM	2001	0.25	10.00	8.00	10.58	360			E		1			
	2002	0.25	10.00	14.00	10.75	360			E		1			
	2003	0.25	10.00	20.00	10.92	360			E		1			
	2004	0.25	12.00	8.00	12.58	360			E		1			
	2005	0.25	12.00	14.00	12.75	360			E		1			
	2006	0.25	12.00	20.00	12.92	360			E		1			
	2007	0.50	10.00	8.00	10.58	360			E		1			
	2008	0.50	10.00	14.00	10.92	360			E		1			
	2009	0.50	10.00	20.00	11.08	360			E		1			
	2010	0.50	12.00	8.00	12.58	360			E		1			
	2011	0.50	12.00	14.00	12.92	360			E		1			
	2012	0.50	12.00	20.00	13.08	360			E		1			
	2013	1.00	10.00	8.00	10.75	360			E		1			
	2014	1.00	10.00	14.00	11.08	360			E		1			
	2015	1.00	10.00	20.00	11.33	360			E		1			
	2016	1.00	12.00	8.00	12.75	360			E		1			
	2017	1.00	12.00	14.00	13.08	360			E		1			
	2018	1.00	12.00	20.00	13.33	360			E		1			
	2019	1.50	10.00	8.00	10.92	360			E		1			
	2020	1.50	10.00	14.00	11.08	360			E		1			
	2021	1.50	10.00	20.00	11.58	360			E		1			
											Emergency			
											Down	Purchase	Install	Interest
											Cost (\$)	Cost (\$)	Cost (\$)	Cost (\$)

Figure 2 Mobile Cranes/Crane Trucks

Model	Name	Maximum Lifting At Max. Radius (ft)	Maximum Lifting At Min Radius (ft)	Rotation Degree	Mobile Method: tire rail, crawler	Highest Working Point Of Hook (ft)	Travel Speed Loaded (mph)	Travel Speed Empty (mph)	Energy Type	Manu Code No.	Labor Cost (\$/hr)	Energy Cost (\$/hr)	Maint Cost \$
3911001										3			
3911002										3			
3911003										3			
3911004										3			
3911005										3			
3911006										3			
3911007										3			
3911008										5			
3911009										5			
3911010										5			
3911011													
3911012										3			
3911013										3			
3911014										3			
3911015										3			
3911016													
3911017													
3911018										5			
3911019										5			
3911020													
3911021													

Emergency						
Down	Purchase	Install	Interest			
Cost (\$)	Cost (\$)	Cost (\$)	Cost (\$)	Cost (\$)	Cost (\$)	Cost (\$)

Figure 3 Jib Cranes

Model	Name	Maximum Load Capacity (ton)	Width Of Platform (ft)	Length OF Platform (ft)	Height OF Platform (ft)	Width OF Equip (ft)	Length OF Equip (ft)	Minimum Turning Radius (ft)	Mobile Require. tire, rail, crawler	Travel Speed Loaded (mph)	Travel Speed Empty (mph)	Energy Type	Manu Code No.
3906001													7
3906002													7
3906003													7
3906004													7
3906005													7
3906006													7
3906007													7
3906008													7
3906009													7
3906010													7
3906011													7
3906012													7
3906013													7
3906014													7
3906015													7
3906016													7
3906017													7
3906018													7
3906019													7
3906020													7
3906021													7

Labor	Energy	Emergency				
Cost	Cost	Maint	Down	Purchase	Install	Interest
(\$/hr)	(\$/hr)	Cost \$	Cost (\$)	Cost (\$)	Cost (\$)	Cost (\$)

Figure 4 Transporters/Trucks/Rail Cars

Model	Name	Max Lift Capa (ton)	Max lift Ht (in)	Maximum Moving/ Reaching Capacity (ton)	Width Of Truck (in)	Length Of Truck (in)	Outside Turning Radius (in)	Travel Speed Loaded (mph)	Travel Speed Empty (mph)	Load Type: forward, backward	Road: special, hard, normal, any	Energy Type	Manu Code No.
GLC 040A	GL1	4.00	100.00		38.10	82.30	71.90	9.30	9.90	F	Tire	Gas	2
GLC 040A	GL2	4.00	140.00		38.10	82.30	71.90	9.30	9.90	F	Tire	Gas	2
GLC 040A	GL3	4.00	148.00		38.10	82.30	71.90	9.30	9.90	F	Tire	Gas	2
GLC 040A	GL4	4.00	168.00		38.10	82.90	71.90	9.30	9.90	F	Tire	Gas	2
GLC 040A	GL5	4.00	213.00		38.10	82.90	71.90	9.30	9.90	F	Tire	Gas	2
GP090H/GLP	GP1	9.00	96.00		56.10	132.00	110.20	13.40	14.90	F	Tire	Gas	2
GP090H/GLP	GP2	9.00	116.00		56.10	132.00	110.20	13.40	14.90	F	Tire	Gas	2
GP090H/GLP	GP3	9.00	136.00		56.10	132.00	110.20	13.40	14.90	F	Tire	Gas	2
GP090H/GLP	GP4	9.00	176.00		56.10	134.00	112.20	13.40	14.90	F	Tire	Gas	2
GP090H/GLP	GP5	9.00	206.00		56.10	134.00	112.20	13.40	14.90	F	Tire	Gas	2
GC 100L	GC1	10.00	96.00		45.30	103.90	90.90	11.00	11.50	F	Tire	Gas	2
GC 100L	GC2	10.00	116.00		45.30	103.90	90.90	11.00	11.50	F	Tire	Gas	2
GC 100L	GC3	10.00	136.00		45.30	103.90	90.90	11.00	11.50	F	Tire	Gas	2
GC 100L	GC4	10.00	139.00		45.30	103.90	90.90	11.00	11.50	F	Tire	Gas	2
GC 100L	GC5	10.00	146.00		45.30	105.20	90.90	11.00	11.50	F	Tire	Gas	2
GC 100L	GC6	10.00	176.00		45.30	105.20	90.90	11.00	11.50	F	Tire	Gas	2
GC 100L	GC7	10.00	206.00		45.30	105.20	90.90	11.00	11.50	F	Tire	Gas	2

Labor	Energy	Emergency											
Cost	Cost	Maint	Down	Purchase	Install	Interest							
(\$/hr)	(\$/hr)	Cost \$	Cost (\$)	Cost (\$)	Cost (\$)	Cost (\$)							

Figure 5 Forklifts

MFG CODE	MFG NAME	MFG TELEPHONE	MFG ADDRESS
1	STANSPEC CORP.	(216) 451-8900	13600 Deize Avenue Cleveland, Ohio 44110.
2	YALE	(206) 762-1777	Northwest, Inc. 7001 N.E. Columbia Boulevard, Portland OR 97218.
3	ACCO	(717) 843-1523	1110 East Princess Street, York, Pennsylvania 17403.
4	HARRINGTON	(800) 233-3010	401 West End Avenue, Manheim, PA 17545.
5	BAXER	(800) 627-1700	1 South Ideho Street, P.O. Box 3581, Seattle, WA 98124.
6	CUSHMAN	(800) 228-4444	P.O. Box 82409, Lincoln, NE 68601.
7	INDUSTRIAL CRANE & EQUIP. CO.	(312) 378-0100	4701 West Iowa Street, Chicago, IL 60651.
8	CLYDE	(218) 722-7451	29th Avenue West & Michigan Street, Duluth, Minnesota 55806.
9	AMERICAN HOIST & DERRICK CO.	(612) 293-4567	63 South Robert Street, St Pul, Minnesota 55107.
10	AUTO CRANE COMPANY	(918) 438-2760	PO Box 581510, Tulsa, Oklahoma 74158.
11	LORAIN	(414) 873-3400	PO Box 422, Milwaukee, WI 53201.
12	NATIONAL CRANE	(402) 786-2240	11200 North 148th Street, Waverly, Nebraska 68462.
13	MTSUI ZOSEN (USA) INC.	(212) 308-3350	Suite 501, 405 Park Avenue, New York, NY 10022
14	GROVE	(717) 597-8121	PO Box 21, Shady Grove, Pennsylvania 17256.
15	HIAB CRANES & LOADERS INC.	(302) 328-5100	Airport Ind. Pk., 258 Quigley Blvd., New Castle, DE 19720.
16	MULTILIFT	(800) 821-9966	2000 S. Cherokee, Denver, Colorado 80223.
17	RPC CORP	(919) 599-3141	PO Box 451, Roxboro, North Carolina 27573.
18	STELCO INC.	(913) 287-1500	5500 Kansas Avenue, Kansas City, KS 66106.
19	LINK BELT	(312) 295-5500	2800 Lakeside Drive, Bannockburn, Illinois 60015.
20	NEI CLARKE CHAPMAN LTD.	(091) 477-1009	Victoria Works, Gateshead, Tyne & Wear NE8 3HS, UK.
21	WASHINGTON CRANES	(205) 622-4421	2925 First Avenue South, Seattle, Wa 98134.

Figure 6 Manufacturers

Name	Capac Code	Location Status	Usage Statu	Labor Cost \$/hr	Energy Cost \$/hr	Maint Cost \$	Emergency Down Cost \$	Purchase Cost \$	Install Cost \$	Interest Cost \$	Total Cost \$

Figure 7 Potential Equipment List

simulation (phase II of the research), the specifics of inputting the layout will be explained.

SOFTWARE CHOICES

Data Base Management

The choice of software to be used in developing the data bases was made based on two primary factors. These are the ability of the data base software to perform the necessary functions, and the transferability of the software between shipyards. Consequently, a relatively powerful data base handling software package is required. Additionally, it must be a system that is readily available or already in common use. One such software system that satisfies these requirements is LOTUS 1-2-3 [3].

LOTUS 1-2-3 offers a typical spreadsheet approach to data base management. The software is readily available for PC operation on most commonly used machines. It provides ample space for the major data bases required, offering 256 columns and 8192 rows for data entry. The information required per piece of material handling equipment is considerably less than the 256 column capacity. Similarly, shipyards are not likely to have in excess of 8192 individual pieces of material handling equipment to be managed and scheduled. The spreadsheet format is one with which most computer users are familiar. It is also quite

powerful, providing considerable computational and sorting capability.

Simulation

There are many manufacturing simulation software packages available for consideration for use in optimizing material handling. Summaries of these packages are generally presented and updated annually by a number of journals, including INDUSTRIAL ENGINEERING [4] and MODERN MATERIALS HANDLING [5]. More than 50 such software packages are currently on the market. Consequently, choices cannot be made based on trials of these various packages. Again, simple criteria must be applied and choices made. The major criteria are flexibility, capability, availability and relative cost. Use of packages that are commonly used and readily available is prudent. Given this need to make a choice without the benefit of comparative testing, this recommendation is based on availability and common use. Most simulation packages that have been developed for manufacturing application using PCs are capable of dealing with the problem to be addressed in this research. Of the packages available, SLAM II, perhaps with the graphical add on package TESS is recommended [6]. This software is commonly available, has been used in numerous applications and is backed by an on-going support service. It is relatively easy to use and has both the power and flexibility needed to develop a material handling optimization simulation program for a shipyard.

Should an individual shipyard have another standard simulation package available, switching from SLAM II should be relatively easy using the model developed in this and the second phase of the research.

OPTIMIZATION/SIMULATION FEASIBILITY

The actual material handling simulation and optimization program will require the development of a number of parts. These can be subdivided into optimization and simulation. The optimization is based on the development of a "figure of merit" or total cost formulation. The feasibility of conducting the simulation will be addressed by considering the data required, the outputs expected, and by developing a flow chart of the simulation procedure.

Figure of Merit Formula

In order to evaluate optional choices

of material handling equipment, a figure of merit (cost) formulation must be developed. Using this formula, applied to each move and the associated piece of material handling equipment used, a total cost of material handling equipment choices can be determined for a given plan. The total cost of various plans can then be compared. The cost formula computes cost in four basic categories. These include the labor cost associated with the use of a given piece of material handling equipment, the energy cost, the cost associated with "emergency" or unanticipated breakdowns of the equipment, and the cost of having the equipment available, including purchase, depreciation, scheduled maintenance, etc. These costs are combined on either an hourly use rate or over a total projected project duration and then summed for the project. The figure of merit formulation is given below.

Total Cost (\$ /Project) =

$$\begin{aligned} & \text{SUM} \quad [\text{labor cost} * \text{actual working time (hrs)} \\ & \text{all moves} \quad + \text{energy cost} * \text{actual working time (hrs)} \\ & \quad + \text{emergency breakdown cost} \\ & \quad + ((\text{purchase cost} = \text{installation cost}) \\ & \quad \quad * \text{depreciation coefficient} + \text{interest cost} \\ & \quad \quad + \text{maintenance cost}) * \text{project utilization} \\ & \quad \quad \text{coefficient (partial yearly usage of equipment} \\ & \quad \quad \text{on a specific project)}] \end{aligned}$$

where:

$$\text{Labor Cost (S/hr)} = \text{Number of operators} * \text{Average wage/hour/operator}$$

$$\text{actual working time} = \text{travel time} + \text{load time} + \text{unload time}$$

$$\begin{aligned} \text{Energy Cost (S/hr)} &= \text{Cost per unit of energy type used} \\ &\quad * \text{energy consumption at maximum output} \\ &\quad \text{per hour} \\ &\quad * \text{energy utilization coefficient} \end{aligned}$$

$$\text{Maintenance Cost (S)} = \text{Constant or stochastic (distribution)}$$

$$\begin{aligned} \text{Emergency Breakdown Cost (S)} &= (1 - \text{reliability coefficient}) \\ &\quad * (\text{delivery delay cost per/hr} \\ &\quad \quad + \text{inventory cost per hour} \\ &\quad \quad + \text{overtime cost per hour} \\ &\quad \quad + \text{idle time cost per hour;} \\ &\quad * \text{repair time (hrs)} \\ &\quad \text{stochastic (distribution)} \end{aligned}$$

$$\text{Purchase Cost (S)} = \text{constant}$$

Installation cost (\$) = direct installation cost
+ area utilization cost
+ additional facility (building)
construction cost

Interest Cost (\$) = (purchase cost + installation cost)
* interest rate

The constant values must be input to the individual shipyard material handling equipment data base. Given these data, the simulation can then be run to provide a means of evaluating alternative choices of material handling equipment usage and scheduling. Note that in the total cost equation, labor and energy costs for a particular 'piece of equipment and a specific move must include unloaded moves (if required) to position the equipment where it is needed. The simulation model will account for this requirement. Additionally, capital costs (purchase and installation), must be based on present value computations.

Simulation Approach

The simulation is used to provide and compare material handling equipment choices and schedules. Initially, the overall project schedule must be defined by work and material category. In effect, a combined graph of work control parameter versus time is required for each work station pair, i.e. source and destination, involved in material movement [7,8]. This will be nearly every work station. The

major exceptions will be work stations that are directly linked to succeeding or preceding work stations, such as a panel line. Here there is no material handling choice since there is a direct connection and most likely dedicated equipment for material handling. For the remainder, the graphs are as shown in Figure 8. The predominant parameter, as in product oriented scheduling, is weight. However, where other parameters are used, such as number of pipe piece connections, a parameter to relate the work schedule to the material handling schedule is required. The material classification categories previously defined will be used here.

Given this material handling schedule to support the master production schedule, the simulation may begin. The inputs to the simulation from the material handling schedule are the feasible material handling equipment for each move, the distance of each move, and the handling weights per material category for each move. my piece of material handling equipment that is in the feasible data file may be ready to be used at the beginning of a working period, or only

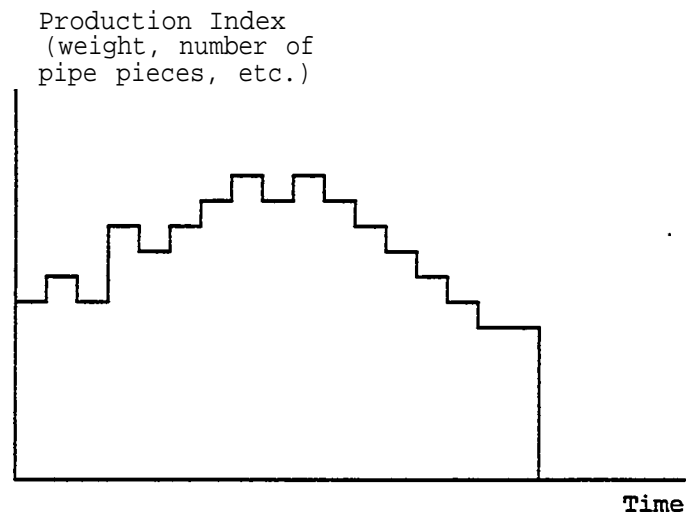


Figure 8 Material Movement Schedule

for some portion of that period. The equipment may need to be moved empty to the required work station, and it may be used for a single move, or for a series of moves in sequence. Similarly, materials to be moved may be ready and prepared to be moved at a given point in time, or a distribution of probability of it being ready can be used.

The simulation is then run. It will produce outputs which define the piece of material handling equipment utilized for each move, the utilization time for each piece of equipment, and any delays associated with either lack of

availability of material handling equipment or materials to be moved. Based on these outputs, the total cost for the project of that option can be computed. A simplified flow chart for this simulation is shown in Figure 9. The primary feedback loops are from the simulation to the potentially useable equipment data file, to update and choose for the next move scheduled, and from the analysis and result storage back to the potentially useable equipment file to run a new simulation of the project. A series of simulation runs can be compared to choose a least total cost material handling equipment utilization schedule.

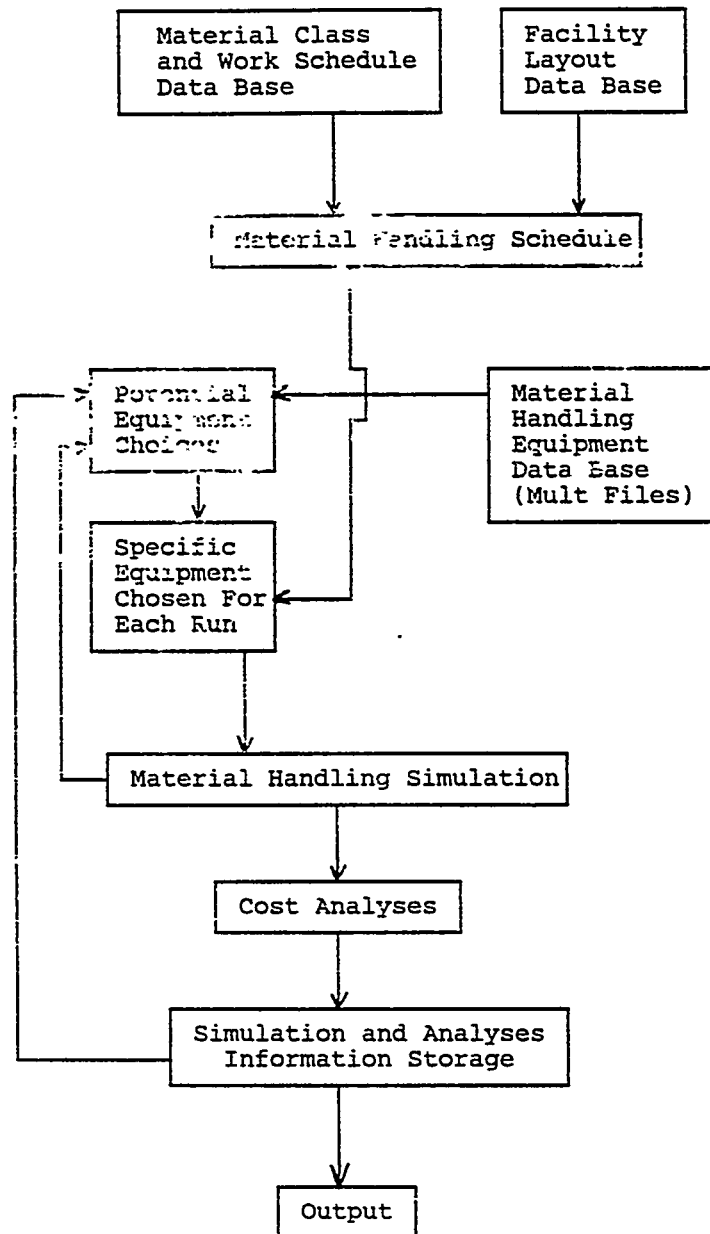


Figure 9 Simulation and Optimization Flow Chart

A significant consideration in this proposed simulation is the method of choosing a piece of equipment for a specific move. Two suggestions are presented and will be incorporated in the final model. First, manual (possibly interactive) selection is recommended. In effect, this is the way moves are currently scheduled in most shipyards. The manager of the department responsible for providing material handling equipment commonly uses some combination of a schedule and immediate requests to make short term decisions and assignments. The model should therefore permit this expertise to be applied to provide a starting point. The simulation can then be run to evaluate this proposal and to generate similar but alternative approaches. The second approach is to automate these decisions based on a set of heuristics. The model will employ such a set of heuristics, but in actual use, each manager should have the opportunity to adjust the heuristics to suit an individual shipyard's needs and capabilities. These two approaches can be combined, either by providing interactive override of heuristic choices by the manager, or by using the heuristics to develop alternate schedules based on the initially input material handling equipment utilization schedule.

Simulation Feasibility

There are two primary issues of feasibility. The first involves the size and therefore running time of the model. The use of material categories and the scheduling parameters is a means of limiting the size of the simulation model. There are fifteen material categories, including the ten for specific individual material items, plus the five assembly categories. There are likely to be between 15 and 30 work station locations required to model the production process. This size model should be well within the capabilities of the PC based version of SLAM II recommended for use. Additionally, the material handling equipment data base should not be difficult to develop or handle. Similarly, the project schedule, if appropriately developed using the schedule parameter approach should also not be too large or cumbersome to handle. Clearly, the movement of every single item is not intended to be incorporated in the model. Rather, preplanned moves of equipment, manufactured parts and assemblies between work stations only are evaluated by this model. Thus the large frame material handling issues are involved. Subject to project specific needs, however, the model can

be used to evaluate "critical" moves no matter what category (including size, weight, etc.) material is involved. Therefore, preplanning of moves is a prerequisite to the use of the model. The simulation model should be an effective tool to evaluate changes from the plan and to alter the material handling schedule to deal with such changes.

The second feasibility issue is more difficult to analyze prior to actually attempting to develop the model. This involves the heuristics development for making individual equipment choices. Heuristics can be extremely difficult to develop. This seems to become a more significant problem as they more closely model the actual decision process employed by an experienced decision-maker. In developing the simulation model, less meaningful but simple heuristics can be a useful starting point. The accuracy (utility) of the heuristics can then be increased incrementally until they are either satisfactory or the efficiency of the model begins to deteriorate significantly. While there is no assurance that such a set of heuristics can be obtained, the increasing success of such simulation modeling in other manufacturing environments provides some optimism [9, 10, 11].

OTHER USES OF THE MODEL

There are a number of possible uses for the model proposed in this paper. The two primary areas of use involve material handling equipment decisions and scheduling. In the first area, the model should be effective in two significant areas. First, decisions on buying and selling material equipment can be justified by running the model with the material handling equipment data base appropriately changed. Benefits in cost and schedule will be readily apparent. Additionally, maintenance and breakdown records can be used to improve the accuracy of the data base, and then can be used to improve the scheduling of maintenance and prediction of breakdowns.

In the area of project scheduling, the model can be used to consider the impacts of schedule changes on material handling requirements and costs. Such an analysis can highlight bottleneck operations and therefore permit critical review of the manufacturing system. Similarly, the model can be used to evaluate the shipyard layout, and to provide material handling cost figures for layout alterations. The use of manufacturing simulation in other industries has lead to improvements in system problem

identification and solution. This includes not only scheduling, equipment and layout, but also quality, batch size, labor utilization, etc. It is this author's belief that simulation holds similar promise for shipyard operations improvement.

CONCLUSIONS

This paper reports on the first phase of a two phase research project concerning the use of simulation to aid in the choice of material handling equipment for use in a shipbuilding or ship repair/overhaul project. The paper describes the results of attempts to carefully formulate the problem, both to indicate the data required and to evaluate the feasibility of producing software that would be useful to shipyard material handling department managers. Although only completion of phase II of the project can definitely establish the viability of simulation to solve this problem, the author is encouraged by these results. Additionally, while the size and scope of shipyard projects represents a significant problem in utilizing simulation, it appears possible to handle a problem of this size, if it is formulated in the manner recommended. A key factor, as in any simulation, is the accuracy of input data. In particular, schedule and work progress parameter data must be valid in order to produce valid simulation results. Despite this potential difficulty, the use of simulation shows considerable promise as a tool to help reduce costs and improve planning of material handling operations in a shipyard.

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APPENDIX

Major Equipment Sub-catagories

Group 1: Structural Raw Materials

ITEM	NASSCO NO.	BIW NO.
Steel (plates and shapes)	82	40,41
Stainless Steel	83	-
CRES and non-Ferrous (Except Aluminium)		
Plates and Sheets	-	42
CRES, Tool Steel and non-Ferrous (Except Aluminum)		
Bars and Shapes	-	43
Other Steel. Includes: Chrome-Moly, CU-NI, Brass, etc.	84	-
Manufactured Bill of Material Items (Tees, Angles)	85	-
Metal (Ingots, Ores)	86	-
Steel Inventory (Flat Bar, Round Bar, Small Shapes, etc.)	88	-
Miscellaneous Surplus Steel	89	-
Spec. Material	90	-
Spec. Material	91	-
Spec. Material	92	-
Castings and Forgings		44
Aluminum (Plates and Shapes)	81	55,56

Group 2: Outfitting Raw Materials

ITEM	NASSCO NO.	BIW NO.
Pipe, Steel, ASTM A53	01	10
Pipe, Steel, ASTM A106, Chrome-Moly, Stainless Steel	02	10
Pipe, Aluminum, Copper, Brass, CU-NI, Misc.	03	10
Pipe, Plastic, Polyethylene, Nylon	04	10
Tubing, Stainless Steel	05	10
Tubing, Steel Carbon	06	10
Tubing, CU-NI, 90-10	07	10
Tubing, CU-NI, 70-30	08	10
Tubing, Copper, Brass, Misc.	09	10

Group 3: Pipe and Tubing Fittings and Valves

ITEM	NASSCO NO.	BIW NO.
Adapters, bushings, nipples	10	13,14
Caps, plugs, locknuts	11	13,14
Couplings, connectors	12	13,14
Elbows, 45°	13	13,14
Elbows, 90°	14	13,14
Flanges, expansion joints	15	15
Reducers, returns, inserts	16	13,14
Crosses, tees, laterals, branches	17	13,14

Unions	18	13,14
Deck drains, deck plates, refrigerator space drains	19	13,14
General plumbing fixtures and fittings includes: faucets, spouts, flush valves, "p" traps, water closets, etc.	20	18
Socklets, elbowlets, brazoletts, nipolets, weldoletts, thredoletts, latroletts, bosses, chill rings, coupletts, tube fittings	21	
Tube fittings	22	13,14
Separators, traps, strainers, air-eliminators, filters, flame arrestors	23	
Gauges and gauge valves, liquid level and sight flow indicators, meters, regulators, thermometers, etc.	24	16,20
Aeroquip fittings and hose	25	20
Mechanical telegraph and voice tube fittings	27	17
Hose and hose fittings, emergency fresh air breathing apparatus, fire extinguishers, gas masks	29	
Angle valves	30	11,12
Butterfly valves	31	11,12
Measurflo control valves, liquid level control valves, temperature and pressure control valves, pressure reducing valves, solenoid valves	32	11,12
Gate valves	33	11,12
Globe valves	34	11,12
Cock valves	35	11,12
Relief valves	36	11,12
Check valves	37	11,12
Manifolds	38	11,12
Other valves includes: ball valves, scupper valves, eductors, vent terminal valves, vent check valves, plug valves, blow-off valves	39	11,12

Group 4: Electrical

ITEM	NASSCO NO.	BIW NO.
Cable and wire	60	25,26,27
Fittings and supplies, includes: packing assembly, wave guide bends, terminal blocks, connectors, caps, conduits, fuses, terminals, stiffing tubes, etc.	61	28,30
Connector boxes, fluorescent light fixtures	62	
Plastic tape, braid	63	
Lighting (lamps)	64	28
Miscellaneous electric	65	
Coils and relays	66	
Switches and controllers, includes: circuit breakers	67	37
I.C. Equipment and parts	68	31,32
Navy symbol electrical, includes: feeder distribution boxes, fuse boxes, jack boxes, switch boxes, terminal boxes, indicator lights, light panels, receptacles, switches, pressure transducers, etc.	69	29,30
Wave grids and fittings		33
Power generation and transformation equipment		34
Instruments, electrical/electronics		35
Electronic compounds		38

Group 5: Hull and Superstructure Components

ITEM	NASSCO NO.	BIW NO.
Deck cleats, chocks, fairleads, hawse pipe material	40	
Blocks, sheaves	41	

Rigging material includes: clevis, hooks, shackles, snaps, links, turnbuckles, etc.	42	
Doors and closures	44	
Furniture and fixtures	45	
Anchoring device, stair treads, railing, gratings, etc.	48	
Laundry, barber shop, galley, messing and scullery equipment		4
Lumber	73	45
Medical and laboratory equipment and supplies		69
Office equipment, furniture, supplies and ships outfit	79	71
Coverings, floor and deck		73

Group 6: Fastening Materials

ITEM	NASSCO NO.	BIW NO.
Bolts and studs	50	53
Nuts	51	53
Pins	52	53
Pivots	53	53
Screws	54	53
Washers	55	53
Weld rod, flux, solder	56	61
Tools	78	80,81,82
Misc., includes: hangers, uristruts, clamps, sway braces	57	54
Gear and shifting boxes, couplings for flex shaft and rigid rods	59	
Rope, thread, chain, twine, and wire (non-electrical)	43	50

Group 7: Motors and Pumps

ITEM	NASSCO NO.	BIW NO.
Motors		90
Pumps		91

Group 8: Major Equipment

ITEM	NASSCO NO.	BIW NO.
Major equipment - Hull	94	97
Major equipment - Machinery	96	98
Major equipment - Electrical	93	99

Group 9: Sheet Metal Components

ITEM	NASSCO NO.	BIW NO.
Vent fittings		3
Air-Conditioning units and supplies, heaters, vent fittings, and ducting includes: intake and exhaust bellmouths, thermostats, spiral fittings, access covers, regulators, diffusers, ventilators, grills	28	93

Group 10: Miscellaneous Materials

ITEM	NASSCO NO.	BIW NO.
Chemicals, grease, oil, gases	70	60,62,63,64
Compounds, includes: adhesive, cement, epoxy, etc.	71	49
Government furnished material	74	
Paint	47	48
Insulation	46	57,47
Cleaning supplies		72
Finishing, decorative materials and accessories		74
Vendor service items		86
Fabrics, plastics, glass, tapes		46
Safety and protective equipment		70



Harnessing Simulation of Naval Shipyards

Cynthia V. White, Member, Naval Sea Systems Command, Washington, D.C.

HARNESSING SIMULATION FOR THE NAVAL SHIPYARD

Managers in the shipyard environment, no less than any other industry, want a reliable and cost-efficient method for analyzing information and guiding decisions. The bottom line is discovering the most productive utilization of limited resources for the maintaining of nation's defense. With personal computers on the desks of many technical managers and industrial engineers, computer simulation has become a realistic and valuable tool for planning, evaluating, and implementing industrial processes.

Simulations make it possible to study the behavior of systems so complex that known analytical models cannot represent them accurately. Simulations model real systems. The models capture the key relations among elements of systems. Discrete-event models represents processes as sequences of independent events. Discrete-event simulation projects and evaluates the impact of changes that could be made to a system, without incurring the expense and risk of trial and error within the system itself.

Simulation development systems for the microcomputer offer analysts and managers tools that can fit any number of decision support uses. Simulation software is being used by the military, civilian government, and private enterprise for applications ranging from transportation, warehousing and materials *resource* planning to Flexible Manufacturing System uses. These tools are proving invaluable for the evaluation of proposed systems or policies.

Simulation provides Naval Shipyard personnel an important opportunity to utilize existing hardware to meet new challenges. The approach has been applied only minimally in the shipyard environment. The Simulation Workshop planned for mid June in the Washington D.C. area, will provide an opportunity for managers and engineers to explore the uses of simulation to meet real needs. This workshop will prepare participants to evaluate shipyard

activities as subjects for simulation, estimate the investments required to perform simulation, and project the potential benefits.

HARNESSING SIMULATION FOR THE NAVAL SHIPYARD

I. THE CHALLENGE

The Naval Shipyard presents a full spectrum of management challenges and engineering applications. Work packages that include detailed specifications and time schedules must be prepared. Consider the headaches of berth scheduling, on-board ship maintenance, inspections, component disassembly, refurbishment and reassembly in the shipyard machine shop, materials handling and transportation. All of these demand careful distribution of resources: space, equipment, tools, labor, and skills.

Where are the potential bottlenecks in your new assembly line design? Do you need eight forklifts or ten? How often does such and such a piece of equipment fail? Would an extra shift be a cost-effective means of improving performance? The bottom line is discovering, within the confines of time and budget restrictions, the most productive utilization of limited resources for the maintaining the nation's defense. Accomplishing this *ongoing* task requires the analysis to vast amounts of information.

Managers in the shipyard environment, no less than any other industry, want a reliable and cost-efficient method for analyzing information and guiding decisions. We naturally turn to computers. They can help us make decisions by gathering, organizing, evaluating and displaying information in forms we can assimilate and understand. Computers have long been familiar to us as managers of information, whether for our personal checkbook accounting, the automobile dealers' parts inventory, census data, airline flight schedules, or, of *course*, the IRS. As sophisticated software tools have been developed, computers have become an integral component of every major weapons system. Computers also have become prominent in manufacturing for process control, plant management and *engineering* design. In recent years computers of ever-increasing power and speed have become available to lower costs. The microcomputer explosion has placed personal computers on the desks of many technical managers and engineers. This trend is providing access to a computer tool tremendous potential benefit to the Industrial Engineering World. The tool is Simulation.

Computer simulation is serving military and civilian government, and private enterprise. The spectrum applications range from determining a realistic launch schedule for the Space Shuttle to optimizing service at McDonalds. Simulations have been used to analyze air traffic control, telephone switching systems, and factory layouts. The illustrations are abundant. For ex-

ample:

- ° Hughes Aircraft used simulation to help determine equipment and *personnel needs* as well as the factory layout for their ADCAP Torpedo production facility.
- ° Caterpillar, Inc. has simulated the impact of two FMS (Flexible Manufacturing System) design alternatives, and the transportation of parts by van versus flatbed.
- ° The U.S. Army used simulation to evaluate and validate the capacity and line balance of production activities and work station sequences for new facilities at the Red River Depot.

II. THE APPROACH

To examine computer simulation as a valid approach to industrial analysis, we need to consider a general description of what simulation has to offer. Secondly, we can better envision the potential of simulation through a practical illustration of a discrete event simulation model. Thirdly, with the illustration in mind, we will look briefly at the basic methodology, and finally, survey the potential Output.

A. GENERAL DESCRIPTION OF SIMULATION

Simulations differ from many computer applications *in* the view they present. They enable us to view what can be, rather than what has been. Simulations make it possible to study the behavior of systems so complex that known analytical models cannot represent them accurately. Analytical methods fail to provide answers to many of the questions that managers have to ask when making real decisions. Simulation methods help analysts and managers organize their intuitive understanding of industrial processes that involve complex interactions and uncertainties. In turn, better understanding of industrial processes leads to strategies for improving operations.

Simulations model real systems. Typical subjects include queueing networks, non-linear, multivariable stochastic processes, and feedback in networks. The models capture the key relations among elements of the real systems. We may believe, for example, that a parts bin behaves as a queue and down time of a machine has an exponential distribution. We may have data describing the behaviors of these elements, but no idea of how they affect each other or the larger process. Simulation helps us understand the interactions involved. It may also show us how to change the elements to improve the larger process.

The dynamics of some processes can be simulated by continuous simulation methods, others by discrete-event methods. Continuous models represent

processes as systems of differential equations. Discrete-event models represent processes as sequences of independent events. A checkout counter and its customers are a "discrete event system"; a swinging pendulum is not. Continuous models are deterministic; they assume that rates of change remain fixed over time. A discrete-event model may be stochastic. That is it can accommodate random variables. This allows us to study the behavior of the system as it is influenced by random events of different moments in time.

B. PRACTICAL ILLUSTRATION OF A DISCRETE EVENT MODEL

To understand the potential usefulness of a discrete-event model, let's examine a discrete event system that most people have experienced: a typical "deli". We'll call ours Phlasch's Deli. A deli is the culinary equivalent to a custom machine shop.

The manufacturing process of a sandwich surely should be familiar to the shipyard manager: getting components from inventory, processing products to precise tolerances (only golden brown toast), maintaining quality control of materials and workmanship, and avoiding rework. (It's not appropriate for the deli operator to sample or test the finished product before delivering it to the customer). Then there is assembling and packaging and maintaining quick turnaround. Other similarities come to mind: irregular ordering schedule, process bottlenecks, equipment breakdowns. Sound familiar?

Our task is to model this total system we know as a deli. To define the model we must:

- 0 Describe the deli
- 0 Identify the processes
- 0 Define the variables

1. DESCRIBING THE DELI

If we asked someone to describe Phlasch's Deli, they might respond: "Phlasch's Deli. ..a little shop on 34th and 8th, good hot or cold sandwiches, okay salad, a great bratwurst, quick service". Accurate enough -- if you are a potential customer. But not the right perspective if you want to model the deli as a discrete event system.

Our description of the deli must be expressed in terms of events, actions, processes, and elements that cause or influence them.

PHLASCH'S DELI

Just off the beaten track; mixed residential and office; near a subway station busy period from mid-morning through early evening; frequent surges of customers; most people in a hurry; room for only ten people to wait in line inside the shop.

THE MENU

All sandwiches made from scratch; some require toast; some hot meat; some baking; soups, salads, bratwurst prepared in quiet periods.

J.J. PHLASCH

Owner and sole employee; order taker; sandwich maker; server; and cashier. (This is a very small deli.)

THE EQUIPMENT

Toaster; steamer for heating meats; oven for baking subs with melted cheese; one hot plate each for soup; bratwurst, and sauerkraut.

2. IDENTIFYING THE PROCESSES

From these descriptions of system elements, we must identify the information that has a bearing on the occurrence of events. With this information we can identify the interaction of the elements in terms of system processes or sequences of events.

PHLASCH'S DELI

The real item of interest here is

"customers", specifically:

- 0 how frequently customers arrive
- 0 how long customers are willing to wait
- 0 what customers order how often

We can gather this data by observing the deli for a few days and recording what we see (in the form of distribution tables.) We will record the intervals between customer's arrivals, the number of customers not joining or leaving a line (when it's one, two..or twenty people long), and which items on the menu are ordered how often.

THE MENU

A customer's order begins a sequence of events that is determined by what the customer chooses from the menu--the order type. Orders are typed according to the actions and equipment required to prepare them. The order types are sequences of tasks processed by J.J. Phlasch. Reubens and steak and cheese subs are of a type that requires assembly actions and use of the oven to melt the cheese. The order type including egg salad on whole wheat and roast beef with lettuce and mayo on pumpernickel, requires only assembly actions.

J.J. PHLASCH

J.J. executes the tasks and arbitrates the priority of tasks when two or more tasks are presented simultaneously. He is governed by a set of rules that can

be determined from observation. These rules might include being sure, when ever there is a line, that at least x number of customers have. given their orders. A customer that has given his order is less likely to leave. Another rule might be that the cash must be collected as each order is served, no matter how many customers are waiting. These rules tend to "Batch" J.J.'s tasks but they do not necessarily make the most efficient use of the equipment.

THE EQUIPMENT

The toaster, steamer, and oven each represents a potential bottleneck as a limit on the source of supply at any one time. For each one, we need to know the process duration (length of time it takes to toast, melt cheese, etc.) and the capacity (the maximum number of items that can be handled at one time). We also need to know the maximum number of servings the containers of salad, soup, bratwurts, and sauerkraut will hold, and the length of time it takes to replenish the supply when the containers are empty.

3. DEFINING THE VARIABLES

Now we can express the system, Phlasch's Deli, as a set of specifications:

```
0      Customer's arrival interval
0      Customer's tolerance (likelihood
      of joining the waiting line)
0      Customer's menu preference
0      Task sequence for each type of
      menu selection
0      Processing rules by task priority
      for J.J. Phlasch
0      Process duration and capacity for
      each item of equipment
```

We must collect observations for each of these variables and construct tables of sequence of values. Our model will require distribution tables for customer arrivals, customer orders, customer tolerance (for waiting in line), order type processes, the duration and capacity of the equipment, and any other variables we have defined.

c. BASIC METHODOLOGY

The computer program that would execute the deli model we have just described has three parts. The first is a program that generates a schedule of customer arrivals. We choose a "period of interest" to model, for example, 11:00 a.m. to 2:00 p.m. The program begins by setting the model clock. The starting time must be earlier than the period of interest so the model can reach a steady state. To model the hours of 11:00 - 2:00, the clock will start at 10:30 a.m.

The program selects the first ran-

dom number between 0 and 99. The model clock is moved ahead by an increment of time. The increment is determined by the Customer Arrival Table according to the range of random numbers in which the selected random number falls. The process is repeated until the model clock time exceeds 2:00 p.m., the time of day we have chosen as the end of the period of interest. The list of customer arrival times that has been created by the program "primes the pump" for the model.

The second and central component of the model, the event processor, starts with the first customer. It uses the Customer Order Table plus the random number generator to determine an order type. The events generated by ordering a meal are meshed chronologically with the arrival of customers. The process rules that represent J.J.'s decisions about which events take priority are executed as program logic. The rules might include deleting a customer from the input queue if the number in line exceeds the customer's tolerance for waiting (determined by a role of the dice and the Customer Tolerance Table). The event processor will reschedule an event that needs a piece of equipment that has reached its capacity.

The event processor documents the occurrence of key events that will contribute to the model analysis. For example, customer arrival, meal selection and selection time. Optimum process time (if this were the only customer) and real process time will be documented, as well as the delay time for events waiting on full equipment or a busy J.J.

The third component of the system is a program that gathers up the output of the event processor, and aggregates the data. Reports from this component can be used to identify the loss of customers due to line lengths, and the delay time due to J.J., or to each piece of equipment. The products of the entire model could be represented as a single report or could be input to a statistical or graphics applications for further processing and display.

D. POTENTIAL OUTPUT

A single execution of a discrete event model such as our deli model would create one arrival schedule and one set of output data. This single iteration would not shed much light on system performance. For the output data to be useful, the model needs to be executed against a randomly generated schedule for arrivals. Then performance characteristics can be observed under different loading conditions. The model is validated by matching specific sets of observable data against observed sets of results.

Our operational model will measure the efficiency of the deli. The output data tell us how close to optimum time

customers are processed through the deli. The two factors within the model that impact the efficiency are resource limitations (J.J. and his equipment), and process complexity (menu options).

Our model can be used to examine the impact of resource changes, such as adding another toaster, bringing in J.J.'s brother-in-law to work part time, etc. It can be used to evaluate the impact of various changes in the menu.

In other words, the benefit of this discrete event simulation is to project and evaluate the impact of changes that could be made to the system, without incurring the expense and risk of trial and error within the system itself.

The random element in our model has been introduced in the input queue of customers and meal selection. But random events such as equipment failure or dropout rates, could be incorporated as well. The value of discrete event simulation is the capability of evaluating the system under changing load conditions or unusual sequences of events.

III. RESOURCES

As useful as simulation may be, is it accessible to the shipyard manager or engineer, and is it affordable? To answer the question of resources, we will survey computer technology possibilities, and describe the software available.

A. COMPUTER TECHNOLOGIES

"Simulations use up all the money and all the time. . .", Bjarne Stoustrup, AT&T researcher and former simulation addict, explains to an audience of programmers. Stoustrup says that he developed the first versions of the C++ compiler, the subject of his popular seminar, because he had used up the department's monthly computer budget during one series of simulations. The C++ compiler helped make it economically feasible to perform the simulations on a powerful mainframe. (1)

Many of the managers who have tried to keep simulation projects within budgets share Stoustrup's assessment of mainframe simulation technology. While useful for some applications, mainframe simulation programs can easily get out of control. However, many of today's engineers and technical managers have personal computers available to dedicate to simulations and other operations planning tasks.

Complex simulations which run smoothly on upgraded versions of desktop computers provide distinct economic advantages over their mainframe ancestors. For one thing, the microcomputer programs cannot drain computer resources away from other users. Just as important, users find the programs much more

accessible than the mainframe simulation languages. The wide range of microcomputer products available for developing simulations offers the potential user a choice of capabilities and costs. And alternative and complementary modeling systems further extend the user's options.

B. SOFTWARE PACKAGES

A number of vendors offer simulations development systems for microcomputers. Four of the most widely used are:

SIMAN/CINEMA by Systems Modeling Corporation
SIMSCRIPT II.5/SIMANIMATION/SIMFACTORY by CACI
SLAMII/PC ANIMATION by Pritsker and Associates
GPSS/H by Wolverine Software Corporation

These are complete development systems that produce separate program modules for model and experiment. They are capable of supporting discrete-event and continuous simulations, sequences and time schedules, graphs and full animation. They include varying combinations of capabilities including macro sub-modeling, dynamic memory allocation, program development tools, special functions for materials handling and robotics, support for autocad and other popular software, real-time and interactive animation, and EGA bit-mapped graphics. Some permit the transfer of microcomputer models to mini and mainframe computers.

Developer programming is requisite with these systems. They compile simulation programs written by a developer, and display the simulation program output in graphic mode. A simulation developer typically needs from one day to one week of formal simulation training, some programming experience, and operations analysis experience in order to get started. Complex model development requires more training and experience. The manufacturers usually offer free technical support for varying lengths of time, support users' groups, and distribute newsletters.

These systems run on an IBM AT or compatible with 4-6 MB of fixed disk space, an 80287 or comparable floating point numeric co-processor, an EGA graphics card and display, and a FORTRAN compiler version 4.1. These total software systems sell for \$5,000 to \$15,000.

Cost of simulation development and use vary widely; so do benefits. The costs of the development packages we are discussing actually seem low, relative to purchase and lease fees for mainframe software. Often these costs exceed the costs of the microcomputer software. 1 Bjarne Stoustrup - C++ Seminar

and hardware combined. Replacing main-frame simulation development systems with microcomputer systems usually lowers the cost for the same result.

Development of large simulations from scratch realistically requires a week of formal training for each developer, a week or more of programming time, a minimum of several weeks of data collection and a week of running the simulation and analyzing the results.

Large-scale projects with substantial benefits for improvements provide the best justification for the set up costs of simulation. However, a simulation development system set up on a PC largely dedicated to simulations, but shared by several users, would bring costs down to an appropriate level for small projects. Cost efficiency can be increased by using the PC's for demonstrations, planning exercises and training, as well as for simulations of operations.

IV. APPLICATION

Microcomputer simulation development systems offer analysts and managers tools that can fit any number of decision support uses. Simulation programs are valuable to manufacturers, who have a strong interest in Flexible Manufacturing System (FMS) applications. They are used for transportation, warehousing and materials resource planning (MRP) applications. And they are invaluable for the evaluation of proposed systems or policies.

By replacing the usual flow diagrams and schedules with computer graphics and worksheets, simulation helps analysts to quantify work flows. Simulation adds another dimension to computer graphics and displays. It lets analysts introduce effects of uncertainty on work flows and scheduling. Since the choice of such production strategies as "Just in Time" (JIT) or "Optimised Production Technology" (OPT) depends on uncertainties in the production process, simulations work when methods based on certain knowledge do not.

Simulation can help streamline and improve any operating plan that requires a formal "walk through" before implementation. Animated simulations show objects on a screen behaving as actual objects should. A game based on simulation can help train a person to identify radioactive contaminants. Planners can study how on-site assembly might interfere with installation operations. Simulation can help us cope with complex interactions among uncertain events.

Simulation provides Naval Shipyard personnel an important opportunity to utilize existing hardware to meet new challenges. The tool has been applied only minimally in the shipyard environment. NAVSEA 07's PIERS product has

produced a test version of a product that approaches simulation. It is a program using a Lotus 1-2-3 worksheet and macro that simulates the effect of variability and allowance factors in the completion of work packages. The work packages include tasks involved in implementing an industrial process. Though useful, the program provides only a preview of the complex simulation available through the full simulation development packages we have discussed.

B. NEXT STEPS THE WORKSHOP

From examples of successful applications of simulation we can begin to appreciate the potential results that this tool might yield in the shipyard. However, the investment in computer resources, simulation software and user training is not insignificant. The Naval community needs to continue to explore the possible range of applications, the potential value, and the means for acquiring this capability. This exploration is the purpose of the Simulation Workshop planned for mid June in the Washington D.C. area. (2)

The workshop will bring together the shipyard experience of Industrial Engineer and the modeling experience of the simulation product specialist. The real needs of the shipyard will be examined and evaluated as candidates for simulation. Shipyard managers and engineers will have the opportunity to examine the technology first hand.

Busy managers and engineers engaged with the everyday workload are hard pressed to take a creative look at problem areas, much less at long-range solutions. But unless our shipyard personnel identify needs, they cannot use simulation to discover improvements in their working processes. The workshop will provide an objective environment for exchanging information and brainstorming.

At the end of the workshop managers and engineers will be able to view the shipyard environment with a modeling perspective. They will learn to recognize where simulation could be useful and what sort of results they can expect. They will also have a better understanding of the software tools available to them and the resource investment required.

This workshop will prepare participants to:

- 0 Evaluate shipyard activities as subjects for simulation
 - 0 Estimate the investments required to perform simulation
 - 0 Project the potential benefit
- 2 The Simulation Workshop was still planned as of the writing of this paper, and hopefully will be completed by the time this paper is presented.

The synergy of a workshop exchange can lead to new understandings of the potential of simulation and constructive planning for its utilization. Our goal is to develop a commitment to simulation as an approach to problem solving and a consensus for a coordinated approach to its use in the Naval Shipyard.

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The First Time Integration of Product by Stage of Construction with Cost/Schedule Control Application

Matthew Reid, Visitor and John J. Dougherty, Visitor,
Saint John Shipbuilding, Saint John, NB

ABSTRACT

There is nothing upon which shipbuilding managers and planning theorists are more solidly agreed than the need to optimize the integration of a steel hull with the maximum outfitting that can be achieved, at a point in time that considers the facility, material, and available manpower, in other words, OPPORTUNITY.

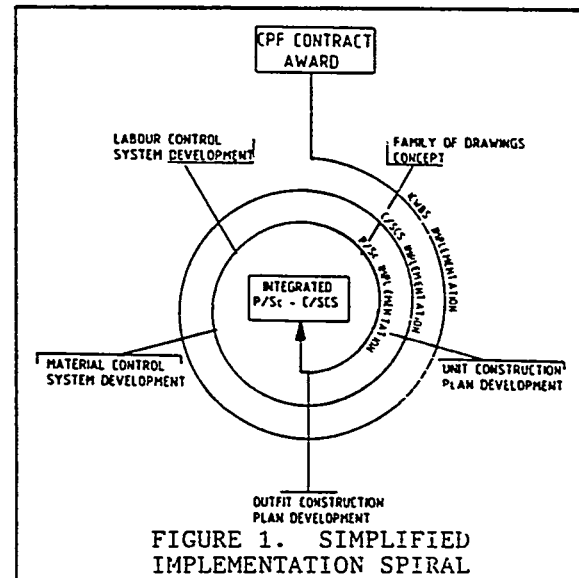
Now, couple this OPPORTUNITY with a doorway through which a manager can enter the whole domain of COST/SCHEDULE CONTROL (C/SC) objectives. Through these objectives the manager has access to a system capable of dealing with the multiple dimensions of organizational and product performance.

This paper addresses the successful integration of PRODUCT BY STAGE OF CONSTRUCTION (P/Sc) with the fundamental principles of C/SC and the specific requirement to provide meaningful performance data in managing a major military defense program on schedule and within cost.

1. BACKGROUND

1.1 THE CANADIAN PATROL FRIGATE PROGRAM

In July 1983, the Canadian Government awarded Saint John Shipbuilding Limited (SJSL) a \$3.26 billion contract to design and construct six city class frigates. The scope of the Canadian Patrol Frigate (CPF) project includes the design, construction, trials, delivery and life cycle support of six fully supported, operational warships and provides for training facilities and programs, logistical support and spare parts.



The CPF project represents a landmark in Canadian military procurement history. For the first time, the Government's procurement strategy has delegated total systems responsibility and risk management to a civilian contractor.

To meet the CPF challenge, SJSL as the prime contractor has developed in Saint John, New Brunswick a Center of Excellence for warship design and construction second to none in North America. Expertise has been established in the areas of Program Management, Design and Engineering, Ship Construction, Integrated Logistics Support, Quality Assurance and Industrial Benefits.

In recognition of this Center of Excellence, the Government of Canada awarded an amended contract for six additional frigates to SJSL in December 1987. The combined contract value of this twelve ship program is \$6.2 billion. It should be noted that, while construction responsibility in the original six ship contract was split evenly

between Quebec and New Brunswick for reasons of regional distribution, the second six frigates will all be built in Saint John, further acknowledging SJSL's excellence Ship Construction and Program Management.

SJSL's stated objectives to meet the challenges of the future are:

- o continued implementation of new technologies to increase productivity and performance
- o development of facilities to accommodate modern naval ship construction and support
- o development of facilities to provide life cycle support and maintenance for the Canadian Patrol Frigates.

1.2 COST/SCHEDULE CONTROL ON THE CANADIAN PATROL FRIGATE PROGRAM

Cost/Schedule Control (C/SC) is a relatively new concept to Canadian industry, although it has been used for performance measurement on major acquisition contracts in the United States for over twenty years. While the initial design for the Canadian Patrol Frigate was still being put to paper, specifications were being written to adapt the United States Cost/Schedule Control System Criteria to the requirements of the CPF program. This adaptation would slightly change the distribution of the elements of the Criteria, but the effectiveness and efficiency would not be impacted (see Figure 2). The acceptance of C/SC Criteria was motivated by the Canadian Contracting

U.S. C/SC CRITERIA <u>SUB-SYSTEMS</u>	CANADIAN c/se CRITERIA <u>SUB-SYSTEMS</u>
-ORGANIZATION	-ORGANIZATION
-PLANNING AND BUDGETING	-WORK PLANNING AND AUTHORIZATION
-ACCOUNTING	-SCHEDULING
-ANALYSIS	-BUDGETING AND -CONTRACT BUDGETING
-REVISIONS AND ACCESS TO DATA	-ACCOUNTING
	-DATA ACCUMULATION
	-ANALYSIS
	-REVISIONS

FIGURE 2. DIFFERENCES BETWEEN CANADIAN AND U.S. C/S CRITERIA

Authority's concern about the proper management of cost and schedule performance on this multi-billion dollar contract.

The primary objective of the Canadian C/SC Criteria was to ensure that the resultant systems would provide the basic principles of cost and schedule management and ensure that:

- o all CPF work was defined and assigned
- o an integrated baseline plan for the performance of the contracted work be established, including:
 - definition of work scope and assignment of responsibility
 - scheduling of the outputs of each segment of work scope, as well as sufficient overall scheduling to provide proper integration of all program work scope
 - the timephasing of all program budgets
 - the establishment of controls to monitor and measure the performance of the work
 - recording of all program costs against the baseline structure
 - identification and monitoring of deviations from the plan
 - control of changes to the baseline plan
 - maintenance of valid estimates of cost to complete the work of the CPF program.

The refined Canadian Cost/Schedule Control Criteria reads like a primer of basic management principles. So basic was the Criteria that it remained unchanged through all the contract negotiations preceding contract award. A further endorsement of the Criteria is SJSL's adoption of this approach to cost and schedule control for its own internal management systems.

2. IMPLEMENTING A COST/SCHEDULE CONTROL SYSTEM

Through the Canadian Government's approach to implementing the Cost/Schedule Control Criteria, SJSL and its three major subcontractors were encouraged to develop an effective planning and control system suited to their own needs.

The Criteria was designed to allow prime and subcontractors to use the management procedures of their choice, while providing an outline of characteristics and capabilities which the Canadian Patrol Frigate Program Management Office (CPF PMO) deemed necessary for an effective

This system would provide valid, timely and auditable information indicative of progress, would properly relate cost, schedule and technical performance and satisfy the Canadian Government's requirement for summarized program information and visibility into potential problems.

The Criteria was intended to provide SJSL with maximum flexibility in managing internal operations. From the start, it was a CPF PMO policy to avoid imposing unnecessary changes on existing SJSL systems and to minimize other changes whenever possible. Originally, CPF PMO envisioned a single internal system which would satisfy both SJSL's management requirements and CPF PMO's need for information. The system must also provide for the clear definition of total CPF contractual effort with an Integrated Contract Work Breakdown Structure (ICWBS). The ICWBS is simply a sub-division in family tree format of products, components, work tasks and services required to achieve a desired goal or produce an end-product (see Figures 3 and 4).

2.1 THE CANADIAN C/SC CRITERIA

A major strength of the Canadian C/SC Criteria is that it does not prescribe specific methods of organization operation, but rather, provide: vigorous standards against which to measure the adequacy of management control systems. The CPF contract granted SJSL the freedom to organize its C/SC system in a manner consistent with its own management philosophy. However, the composition of that system must successfully embrace the following sub-systems:

I. ORGANIZATION: The Criteria elements applicable to Organization require that SJSL arrange all contract-authorized work in the framework of the Work Breakdown Structure (WBS) down to a manageable level (see Figure 5). Designated key management personnel at SJSL are assigned responsibility for portions of the manageable levels of the WBS, resulting in a number of control points. All SJSL activities (planning, scheduling, budgeting, work authorization, cost accumulation) operate on this basis. Elements for identifying work scheduled, work performed, actual costs incurred, budget and estimate

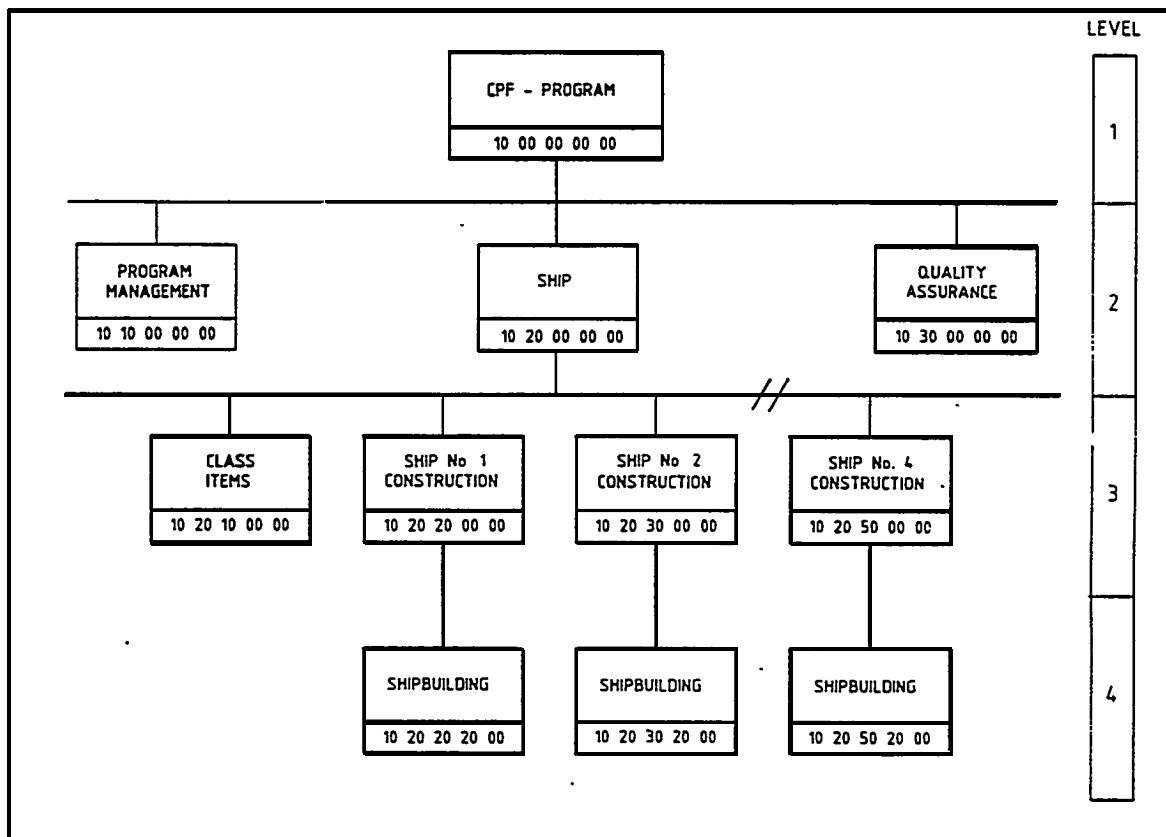


FIGURE 3. THE CPF INTEGRATED CONTRACT WORK BREAKDOWN STRUCTURE (LEVEL 1-4)

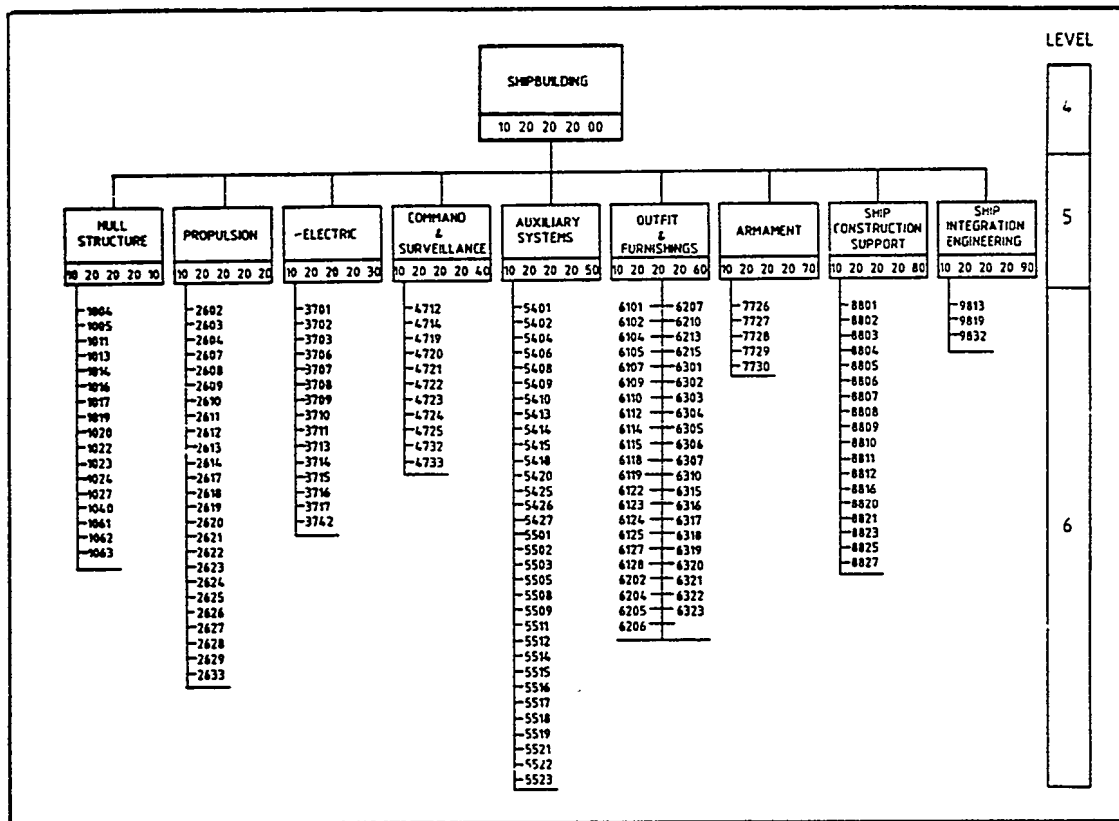


FIGURE 4. THE CPF INTEGRATED CONTRACT WORK BREAKDOWN STRUCTURE (LEVEL 4-6)

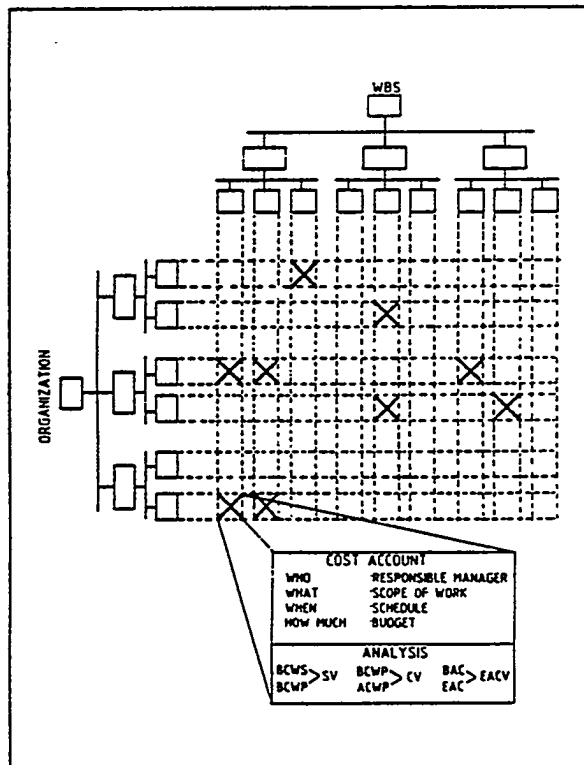


FIGURE 5. CPF WORK BREAKDOWN STRUCTURE EXTENSION

at completion, and cost and schedule variances must be utilized at the selected control points. The criteria apply to all work, whether direct, overhead or subcontractor oriented.

11. WORK PLANNING AND AUTHORIZATION: Criteria elements relating to Work Planning and Authorization require that SJSL plan all contract-authorized work to the extent practicable and ensure that near term work is planned in detail. Work must be planned in the manner in which it is to be performed, and be amenable to in-process objective measurement. Finally, all work must be adequately budgeted on the basis work content.

III. SCHEDULING: Criteria elements applicable to Scheduling require SJSL to develop a top down scheduling system with a top level schedule containing key contract requirements, supported by lower level schedules identifying areas interface/interdependency of key completion dates (Figure 6). The scheduling system must descend to the lowest level where work is performed. At this level, and from this level through to the top level schedule, SJSL must be able to report progress against stated requirements/key events, and use this progress

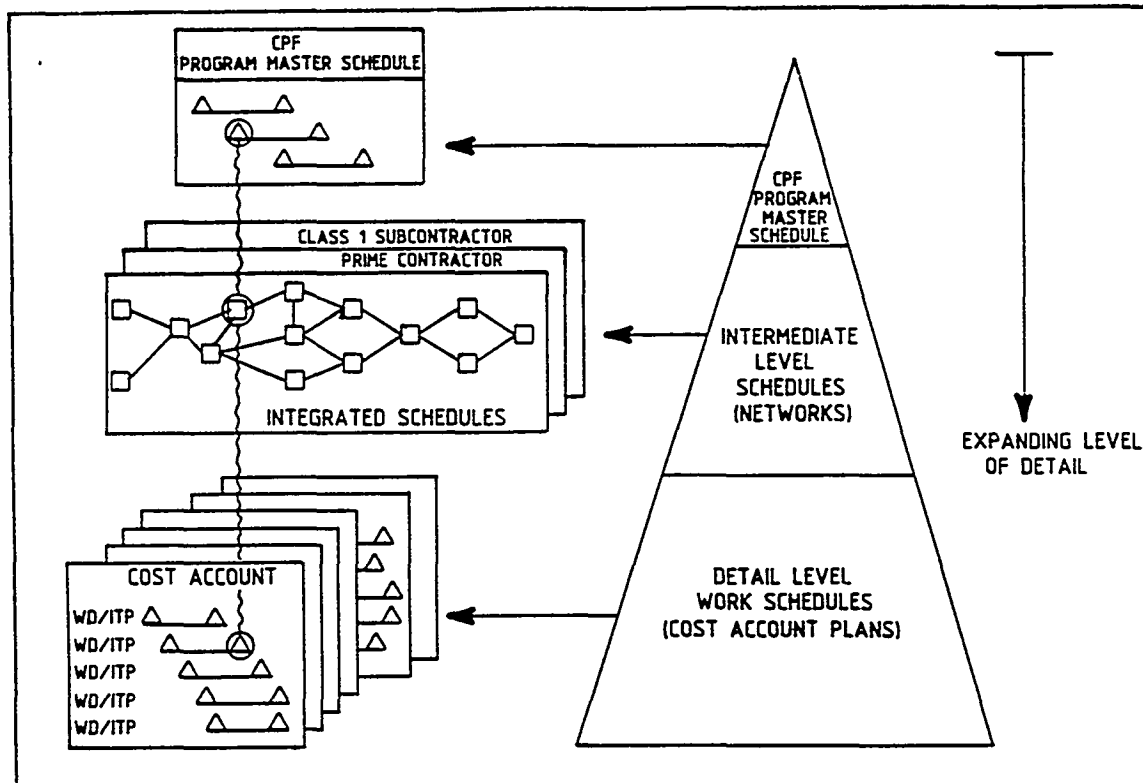


FIGURE 6. CPF INTEGRATED MASTER SCHEDULE

information to forecast completion dates for all events. The Integrated Master Schedule (IMS) was developed to meet these needs.

IV. BUDGETING AND CONTRACT BUDGETING: Criteria elements applicable to Budgeting and Contract Budgeting require SJSL to establish and maintain a timephased budget baseline for performance measurement purposes. Overhead budget determination is to be a rational, traceable process based on SJSL's anticipated business base. All overhead projections beyond the current year must be applied systematically and adjusted in a timely manner.

v. ACCOUNTING: Criteria elements applicable to Accounting require SJSL to manage the utilization of Management Reserve and Undistributed Budget, reconcile the Contract Target Cost and all budgets for internal work, record direct cost on an applied or other acceptable basis consistent with the budgets in a formal system controlled by the General Books of Account, and ensure the Material system further effects performance measurement. Direct costs from the lowest level of cost collection must be summarized to the total contract level through the WBS and the functional organization in a consistent manner. Indirect costs

must be summarized as well, and work accomplishment against the schedule must be identified. Finally, SJSL must ensure that only that work which cannot be planned in discrete, short span or measured effort work packages is classified as Level of Effort (LOE) work.

VI. DATA ACCUMULATION: SJSL is required to provide CPF PMO access to all pertinent records and documentation.

VII. ANALYSIS: Criteria elements applicable to Analysis require that SJSL generate cost, schedule and at-completion variance data and be able to explain the problem cause, impact and proposed corrective action associated with significant variances. This performance measurement is to be applied to both subcontracted and internal work (direct and overhead). Internally, this performance measurement must address the total contract level to the level where work is performed, through both the functional organization and the WBS. SJSL management use this data and corresponding variance narrative to detect and avert potential problems.

VIII. REVISIONS: SJSL is required by the Criteria to incorporate approved internal and contractual changes in a timely manner and ensure that the net

effects of these changes are provided for in existing budget, schedule and work scope. All such changes must be documented and logs maintained to demonstrate traceability to original assignments of budget, schedule and work scope. Retroactive changes, with the exception of errors and routine accounting adjustments, are prohibited.

2.2 THE OUTPUT OF A FUNCTIONAL C/SC SYSTEM: DATA CATEGORIES

C/SC allows Canadian Government personnel to review cost and schedule performance data, and thereby determine the status of the CPF project, without detailed knowledge of the SJSL management system. The Government relies on accurate, consistent information from SJSL and understands the C/SC reasoning upon which the information is based.

The information generated from the SJSL C/SC system is grounded in sound management practices:

- o all work is defined/assigned
- o all work is scheduled
- o all work is budgeted
- o actual costs are properly collected
- o status evaluations are made
- o final cost predictions are derived.

The Cost/Schedule Control system accommodates formalized, established methods for communicating contractor performance.

Upon successful integration of the eight sub-systems (discussed in Section 2.1) which support the C/SC system, information as to the status of the CPF contract work scope becomes available. This information consists of:

Budgeted cost of Work Scheduled (BCWS)

Budgeted cost of Work Performed (BCWP)

Actual Cost of Work Performed (ACWP)

Budget at Completion (BAC)

Estimate at Completion (EAC)

These five data categories depict the precise schedule and cost position, both incrementally and cumulatively, of SJSL and its major subcontractors for a specific scope of work at a specific point in time. They are defined as follows:

BCWS: The budgeted value of work that is planned to be completed in a

specific period. Regarding ship components which are purchased this value represents the budget that has been assigned for vendor work in a specified period.

BCWP: In direct relation to contract work that is scheduled to be completed in a specified period, BCWP represents the value budgeted for work which was completed in a specified period. For work which has been completed, BCWP equals 100% of the total budget assigned. When considering in-process work an objective determination of progress must be made.

ACWP: As a result of the performance of work, expenditures are incurred. cost data accumulated in the accounting system includes employees' completed timecards specifying assigned work activities and invoices for payment to vendors.

BAC : This budgeted value represents the total budget for work to be accomplished. In distinguishing this term from BCKS it is relevant to note that BCKS is a budgeted amount for a specified period (eg. month), while BAC is total budgeted at completion, a summarization of each period BCWS.

EAC : In relation to the BAC, which summarizes the total bud-get for assigned work scope, SJSL as the responsible authority shall periodically assess performance to date and estimate the final cost at completion of all assigned work.

These five data elements are derived at the lowest level within the organization where responsibility is assigned. This information is summarized through a matrix by functional departments and by work breakdown structure element. This breakdown provides immediate focus on areas where there are deviations from the plan.

Figures 7 and 8 illustrate the relationship between the five data elements and the analysis that is performed employing them.

2.3 SUBCONTRACTOR INTEGRATION

In the early stages of the CPF program it was determined that, in the interest of maximizing Industrial

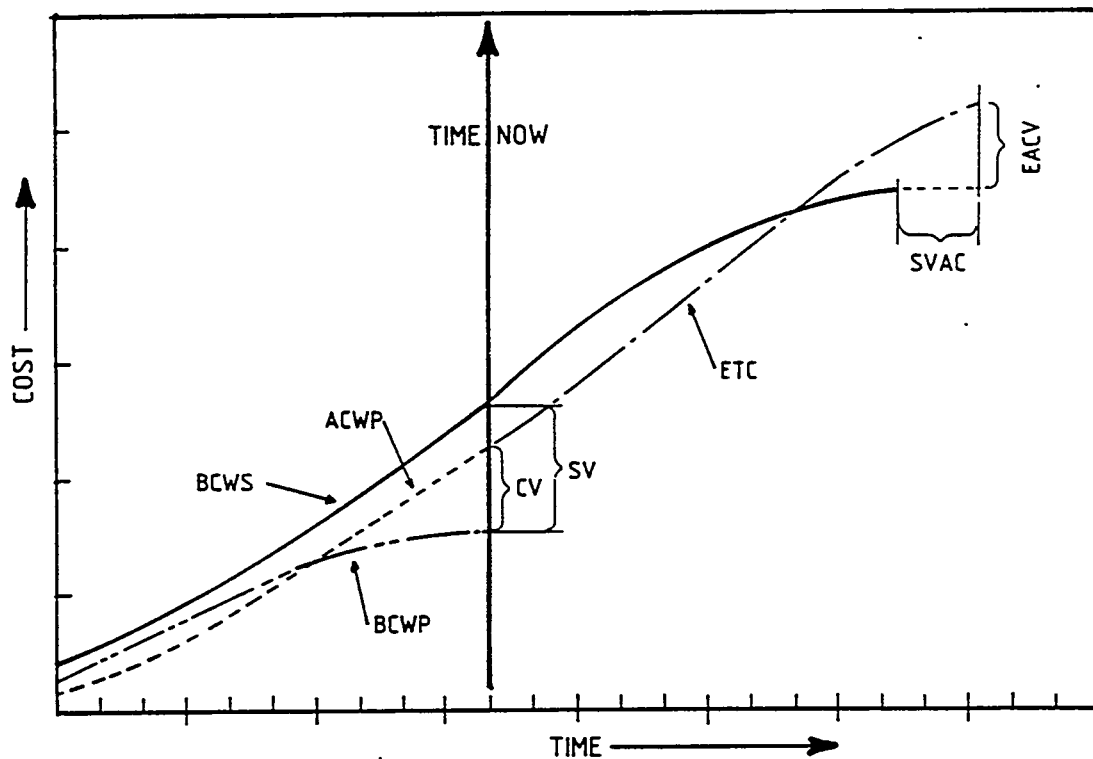


FIGURE 7. CUMULATIVE PERFORMANCE ANALYSIS

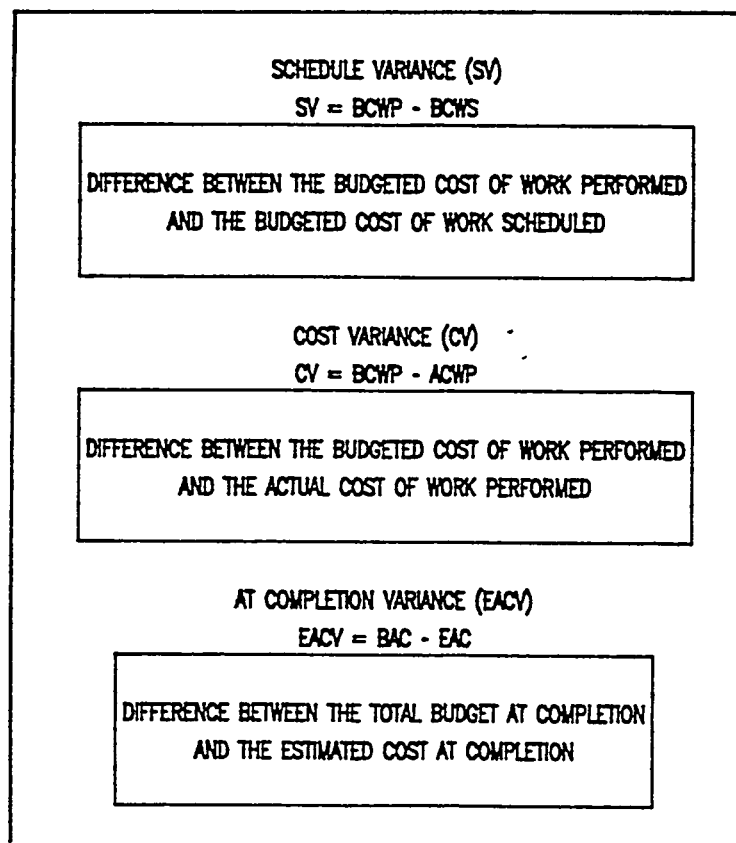


FIGURE 8. THE FIVE DATA ELEMENTS

Benefits throughout Canada and in consideration of the inherent complexities of CPF, certain defined work scope would be subcontracted. As a result of this decision many subcontracts were let. Although all subcontracts may have a potential impact on prime contract cost and schedule parameters, certain large subcontracts were determined to be critical contributors to the successful execution of CPF. These contractors have been assigned an integral role on the CPF contract and therefore require close scrutiny. As a result, SJSL has included in these contracts the requirement for an operational C/SC system combined with monthly cost Performance Report submission.

In relation to the total CPF contract SJSL has maintained responsibility for a significant portion of the contract work scope. The entire combat and communication system was subcontracted, encompassing design, procurement, construction, installation, integration, and testing of all the associated combat systems for six shipsets. Ship system engineering work was also subcontracted; this was integrated with the effort of the SJSL Engineering function in comprising the entire ship design package. Finally, SJSL subcontracted work for the construction of three of the first six city class frigates to a Canadian shipyard in Quebec.

Figure 9 depicts the percentage contribution of each critical subcontractor in terms of contract value. Note that the criticality of the supporting design agent is based more on schedule impact than on cost.

In December of 1987, SJSL's CPF contract was amended to include six additional frigates. This lengthened and increased the value of the prime contract and had an associated effect on the combat/communications subcontract (see Figure 10).

The requirements imposed on critical subcontractors are similar to those placed on SJSL. Each subcontractor is required to demonstrate that its system meets the criteria contained in the contract. SJSL's role is to determine whether the system satisfies contractual obligations and is consistent with and supportive of the SJSL system. CPF PMO as the customer oversees this system demonstration and provides input through SJSL.

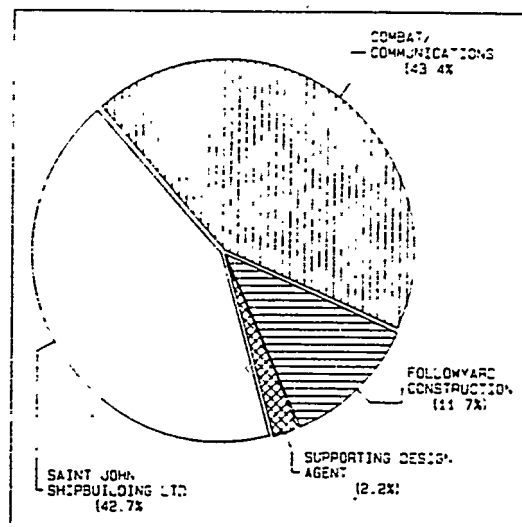


FIGURE 9. THE CPF CONTRACT SPLIT OF WORK (ORIGINAL CONTRACT)

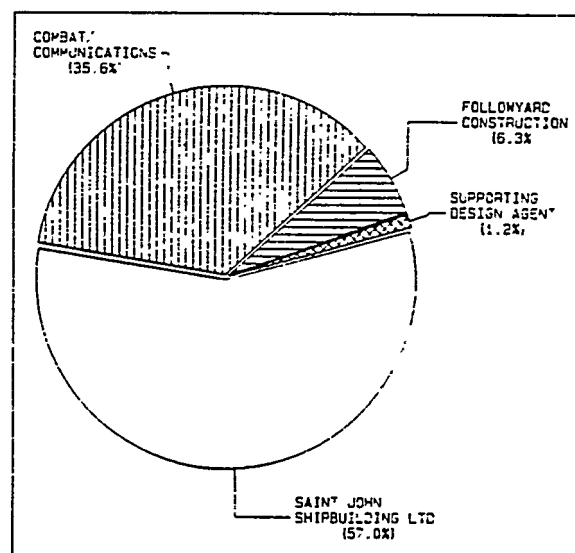


FIGURE 10. THE CPF CONTRACT SPLIT OF WORK (AMENDED CONTRACT)

2.4 THE OUTPUT OF THE COST/SCHEDULE CONTROL SYSTEM: THE COST PERFORMANCE REPORT

Critical subcontractors are required by contract to submit monthly Cost Performance Reports (CPRs) which contain pertinent cost and schedule data. These subcontractor cost Performance Reports provide SJSL with the requisite visibility to manage the CPF contract. Upon receipt, subcontractor reports are distributed to the appropriate management for

action and inclusion in the analysis which is forwarded to CPF PMO as part of the prime contract deliverable, SJSL's CPR.

The CPR consists of five standard formats (Figure 11) which summarize cost and schedule status and provide a complete overview of the CPF contract so that issues, program impacts and performance trends are identifiable. The CPR contains:

- o Contract data (headings)
- o ICWBS and Product by Stage of Construction performance (informal reports), budgets and EAC (Format 1)
- o Prime and subcontractor organizational performance, budgets and EAC (Format 2)
- o Baseline budget distribution and record of changes (Format 3)
- o Timephased manpower plan and/or forecast (Format 4)
- o Discussion of problems (Format 5).

This information from the major subcontractors is integrated with SJSL's data to form the Total Program Cost Performance Report (see Figure 12).

FORMATS 1 AND 2

The same principles apply to review the data contained in Formats 1 and 2 as they display the same overall performance data in the same format. However, Format 1 shows a line item breakdown of ICWBS elements at the reporting level, while Format 2 shows a breakdown of the performance of the major functional organizations and three major subcontractors.

Additionally, Formats 1 and 2 provide the data necessary to perform trend analysis. Cumulative performance (BCWS, BCWP and ACWP) may be plotted monthly to provide the classic S-curve of the three performance elements.

FORMAT 3

This format shows the timephased contract budget baseline, performance measurement baseline (PMB). It also quantifies all approved changes to the PMB, provides visibility into the effect of changes, and recognizes any application of Management Reserve.

FORMAT 4

This format reports the timephased estimate of labor required to complete the CPF contract and contains the data best suited for trend extrapolation and regression analysis.

FORMAT 5

Format 5 provides an analysis of performance with both graphic and narrative explanations of cost, schedule and at-completion variances which meet or exceed the CPF contract variance thresholds (Figure 13). This Format is divided into three sections:

SECTION 1 Contains an executive summary which discusses major problem areas.

SECTION 2 Contains narrative which explains ICWBS reporting level variances.

SECTION 3 Covers any additional variances exceeding CPF contract thresholds as well as changes not covered in Sections 1 and 2.

2.5 C/SC VALIDATION

The CPF contract contains the Criteria requirements for a C/SC system. SJSL developed a C/SC system using these Criteria as a guideline. The necessary computer software program was written and the management systems were established. On numerous occasions during the implementation phase, SJSL invited CPF PMO to review the development of the system; CPF PMO provided valuable input regarding their interpretation of the Criteria requirements. To ensure that SJSL's system would meet the newly designed C/SC Criteria, SJSL was contractually obligated to demonstrate its system's sufficiency to a CPF PMO review team. Once this team approved (validated) SJSL's C/SC system, further demonstrations would not be necessary, provided CPF PMO surveillance indicated SJSL's continued compliance with the Canadian C/SC Criteria.

In December of 1987 CPF PMO provided formal notification that SJSL's C/SC system was validated, representing the FIRST validation granted by the Canadian Government to a Canadian Company on a Canadian Military Contract. SJSL is fully committed to maintaining the C/SC system as validated, however modifications will be made to meet future requirements of both SJSL and the customer. CPF PMO shall monitor the system in a surveillance mode to ensure continuing compliance with the C/SC Criteria.

Reviews of CPF critical subcontractors have been conducted by

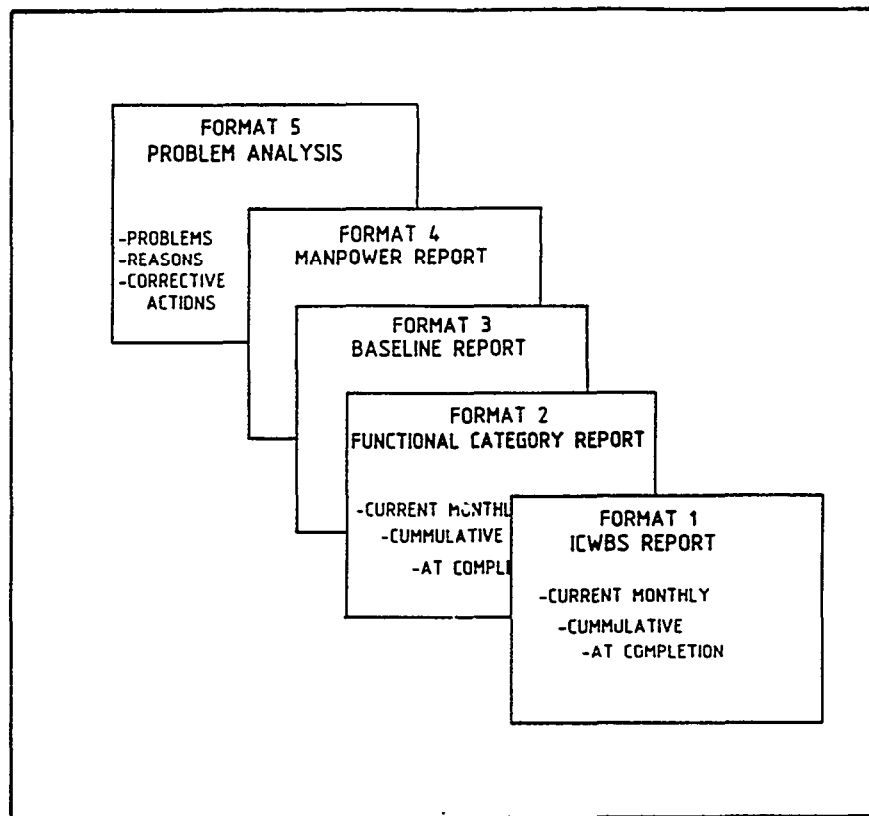


FIGURE 11. THE FIVE FORMATS OF THE CPR

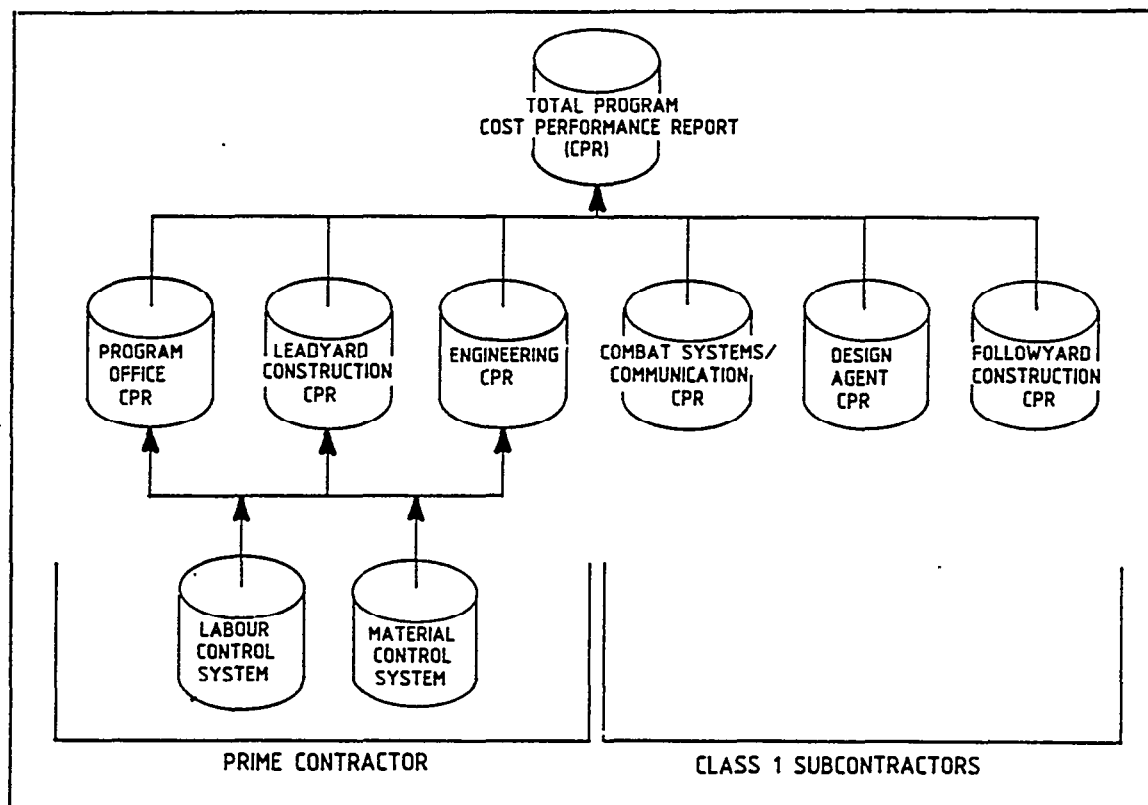


FIGURE 12. THE INTEGRATION PROCESS TO LINK THE CLASS 1 SUBCONTRACTORS INTO THE PRIME CONTRACT CPR

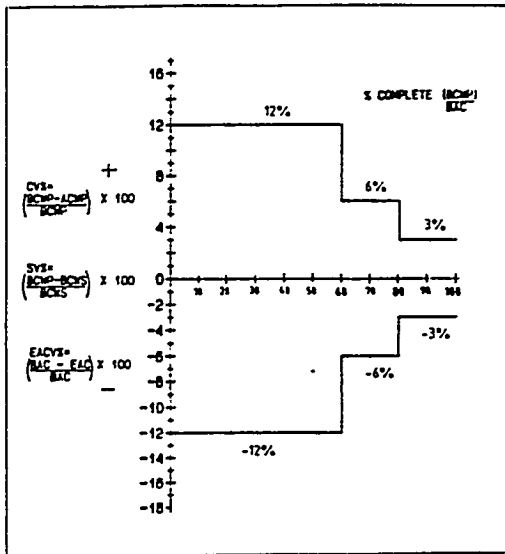


FIGURE 13. CPF CONTRACT VARIANCE THRESHOLDS ENVELOPE

SJSL and observed by CPF PMO, however none of these organizations has received C/SC system validation at time of writing. SJSL is expending considerable effort assisting its subcontractors to achieve acceptable C/SC system implementation based on experience gained during SJSL's validation process.

3. IMPLEMENTING PRODUCT BY STAGE OF CONSTRUCTION (P/Sc)

3.1 INTRODUCTION

SJSL defines Product By Stage of Construction (P/Sc) in one word - OPPORTUNITY.

In understanding OPPORTUNITY it is important to realize that a shipyard decision to commit resources to some specific early use on a stage of construction, or to utilize more rather than less resources to accomplish a task at the optimum time, is also an implicit decision not to commit these resources to traditional ICWBS approaches. What these resources accomplish when committed at the optimum stage of construction is OPPORTUNITY.

3.2 DEFINITION OF P/Se

P/Se is the sub-division of the ship into readily identifiable pieces of work. Each piece of work is called an interim identifiable objective of production (eg. a fabricated part or sub-assembly, an assembly unit or module).

The sub-division of the ship is accomplished using the zone-by-stage approach, that is by considering each area of the ship and determining the optimum stage at which to do the work. OPPORTUNITY.

P/Se breaks the ship down into groups of similar parts, interim products, which are then designed and manufactured in batches at the most logical stage. OPPORTUNITY.

3.3 STAGES OF CONSTRUCTION (PRODUCTION OPPORTUNITY LEVELS)

Planning ship construction in eight production OPPORTUNITY levels is a practical way to promote the optimization of work flow.

P/Se views ship construction as a series of OPPORTUNITY levels, called stages or work centres, through which interim products pass to culminate in the complete ship.

Figures 14 and 15 illustrate the ship's eight production OPPORTUNITY levels, from delivery of raw materials and components to final acceptance by the customer.

NOTE : An OPPORTUNITY level is the optimum level at which the work can be accomplished.

This sub-division is the key to P/Sc. The overlay of defined levels of outfit and painting, coded according to the production OPPORTUNITY level in question, allows planning and control of progress on the ship.

3.3.1 LEVEL 1: KITTING/PART FABRICATION

Part Fabrication is the first production OPPORTUNITY level. Part Fabrication produces components for the ship which cannot be further sub-divided. Typical work orders are issued by unit, stage, and standard manufacture (batch).

Within the classifications, problem areas may be sub-divided by machine requirements, type of material, size, etc.

STAGE	TYPE OF WORK
1110	Shotblasted Plates & Shapes
1120	Marking, Cutting Plates & Shapes
1130	Forming Plates & Shapes
1150	Drain Plugs, Thermometer Plugs

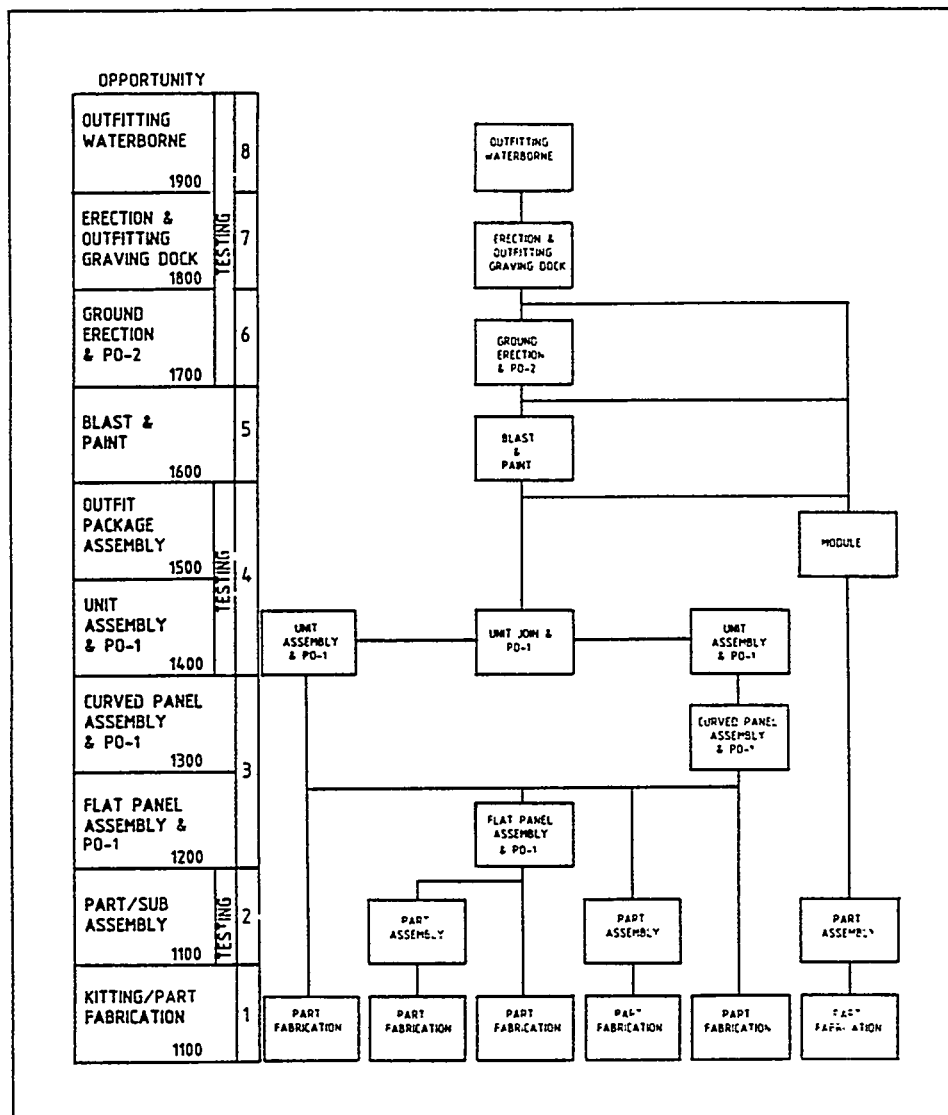


FIGURE 14. TYPICAL PRODUCTION OPPORTUNITY LEVELS FLOW CHART

STAGE	TYPE OF WORK
1160	Material Kitting, Bending or Cutting
1170	Marking, Cutting Plates & Shapes
1180	Marking, Cutting Wood Panels
1190	Marking, Cutting Electrical Cables

3.3.2 LEVEL 2: PART/SUB-ASSEMBLY

Part/Sub-assembly is the second production OPPORTUNITY level. Typical work orders are issued by unit and area.

STAGE	TYPE OF WORK
1140	Fitting Beams, Girders, Web Frames
1150	Fitting Liner on Shaft
1160	Fitting, Welding Pipe Pieces
1170	Fitting, Welding Foundations & Tanks

STAGE	TYPE OF WORK
1180	Fitting Cabinet Pieces Together
1190	Fitting Connectors To Cables

3.3.3 LEVEL 3: FLAT AND CURVED PANEL ASSEMBLY AND PRE-OUTFITTING

The third production OPPORTUNITY level is a sub-unit and initial pre-outfitting level consisting of a number of fabricated and/or assembled parts. Typical work orders are issued by unit and area.

STAGE	TYPE OF WORK
1200	Flat Panel with Penetrations Foundations & Backing Structure
1300	Curved Panel with Overboard Discharges, Foundations & Backing Structure

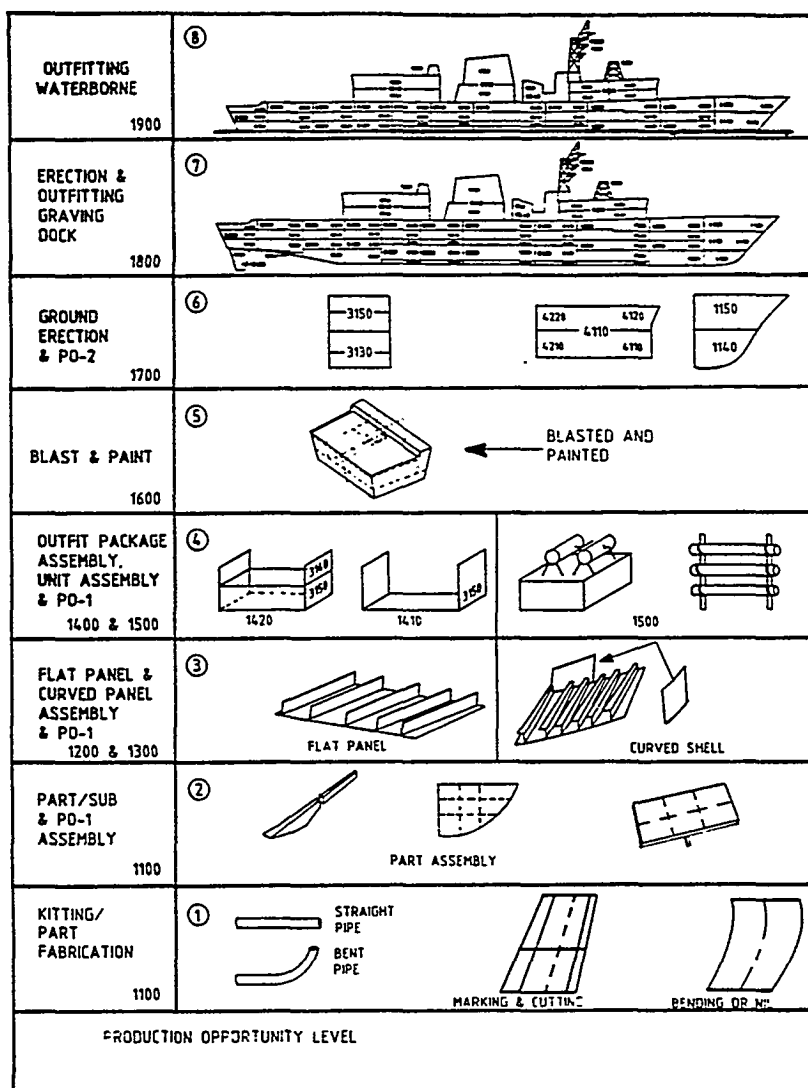


FIGURE 15. WORK ORGANIZATION BY STAGE OF CONSTRUCTION

3.3.4 LEVEL 4: MODULE - ASSEMBLY /PRE-OUTFIT AND JOIN

The fourth production OPPORTUNITY Level involves final module production, including integration of flat panel units with pre-outfit, curved panel units with pre-outfit to form a block which can be further outfitted and tested.

STAGE TYPE OF WORK

1410	Pre-outfit 1 (PO-1) Inverted
1410	Pre-outfit 1 Upright
1420	Assembly Unit Join
1420	Final Pre-outfit 1
1500	Modules

3.3.5 LEVEL 5: BLAST & PAINT

The fifth production OPPORTUNITY level is Blast & Paint, the stage at

which surface preparation and painting take place. Considerable planning is performed at this stage to minimize the on-board painting.

3.3.6 LEVEL 6: GROUND ERECTION AND PRE-OUTFIT 2

The sixth production OPPORTUNITY level is clearly defined by its output of erection units which will require additional pre-outfit (the remainder of PO-1 as well as PO-2, which is cold work pre-outfit).

3.3.7 LEVEL 7: ERECTION & OUTFITTING IN GRAVING DOCK

The seventh production OPPORTUNITY level is Erection & Outfitting in the Graving Dock, and entails the fitting and welding together of erection

units to form the ship. It includes a defined level of outfit covering major component installation (e.g. gas turbines, cruise diesel, main cable runs) and the remainder of outfitting in way of erection unit butts.

3.3.8 LEVEL 8: OUTFITTING WATERBORNE

The eighth and final production OPPORTUNITY level, Outfitting Waterborne, is the most expensive. Level 8 includes the installation of all miscellaneous outfit components, final compartment completion and final system testing and acceptance of the ship.

3.3.9 STAGES OF CONSTRUCTION (PRODUCTION OPPORTUNITY LEVELS & NUMBERING)

A four digit number is used for identifying material and labor to a work center at the shipyard as listed below:

STAGE	TYPE OF WORK
1100	Kitting, Part Fabrication & Assembly
1200	Flat Panel Assembly & PO-1
1300	Shell Assembly & PO-1
1400	Unit Assembly Join & PO-1
1500	Outfit Assembly
1600	Package Blast & Paint
1700	Ground Erection & PO-2
1800	Erection & Outfitting in Graving Dock
1900	Outfitting Waterborne

3.4 THE PRODUCT

The ship is divided into five different types of products: Units; Outfit Zones; Special Installations; Modules; and Standard Manufacturing Jobs.

The following discussion describes the products in detail and illustrates the manner in which they are coded according to their position within the ship.

3.4.1 UNITS

Units are geographically oriented divisions of the ship by Superzone, Girth, and Level. The configuration of the unit is determined by the structure and design of the ship, the facilities which are available, and the construction and outfitting plan.

Units and pre-outfit zones comprise the pre-erection product. An assembly unit is a defined single deck level

structure, usually shell to shell but occasionally broken into port, starboard and centerline sections. Erection units are typically composed of more than one assembly unit. (See Figure 16.)

3.4.1.1 UNIT NUMBERING

A four digit number in the format XYZO is used to label and schedule material and labor resources for a unit/pre-outfit zone. Unit zone numbers have a geographical significance within the ship and allow personnel to rely on logic rather than memory to control material and labor.

x Represents one of four major Superzones of the ship:

1. Forward of Machinery spaces
2. Machinery spaces
3. Aft of Machinery spaces
4. Superstructure

Y Within a Superzone the ship is sub-divided further and is numbered forward to aft (see Figure 17). This represents Girth sub-divisions (1 through 9) based on major vertical sub-divisions.

z Represents the deck level. Numbers run consecutively (1 through to 9) from the inner bottom to the weather deck for hull unit/zones. For superstructure, the numbering runs from bottom to top as well, using major structural horizontal sub-divisions.

o Reserved for further sub-division of the basic assembly unit for more efficient design and production cost control as required.

3.4.2 OUTFIT ZONES

Outfit zones are geographically oriented divisions of the ship by Superzone, Girth and Level. The configuration of the outfit zone is determined by the structure of the ship and the plan for outfitting the zone.

Outfit zone boundaries are typically bulkhead to bulkhead and deck to deck. They are the basis for outfit design as well as outfit work, beginning after unit erection. If desired, these boundaries can be to the level of "compartment" for work after erection to monitor cost and schedule for specific areas (eg. electronic spaces).

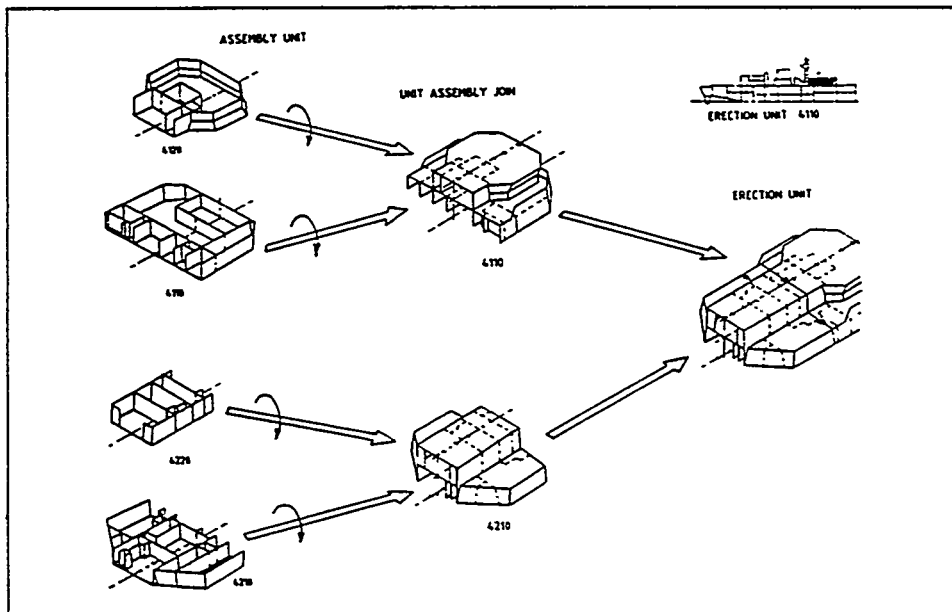
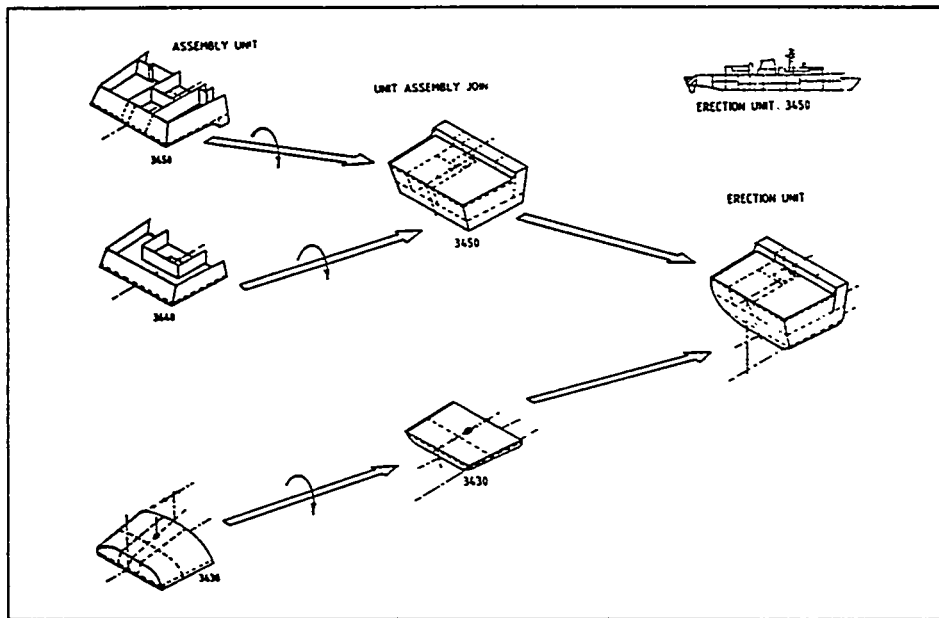
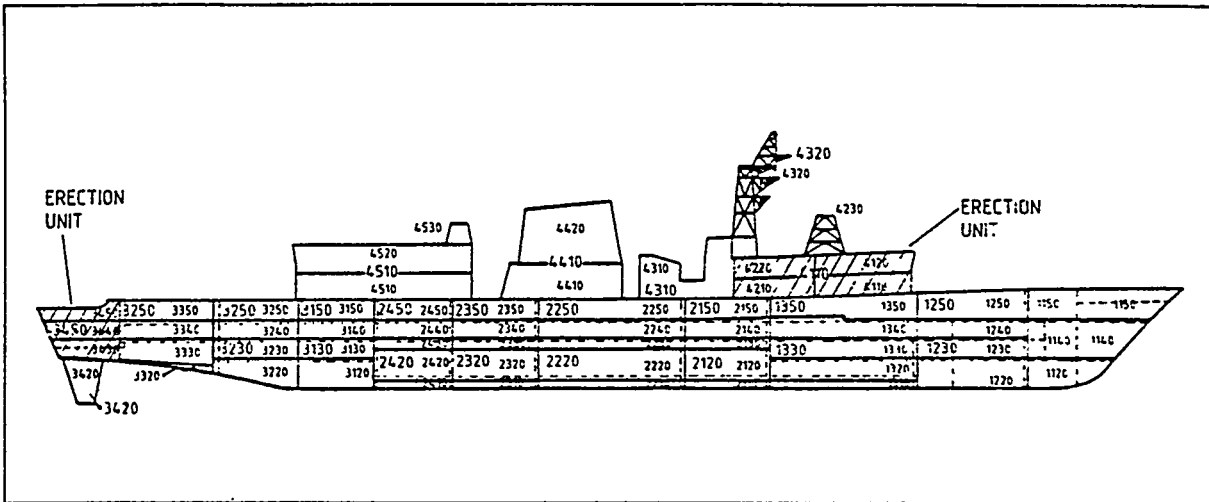


FIGURE 16. THE PRODUCT - UNIT

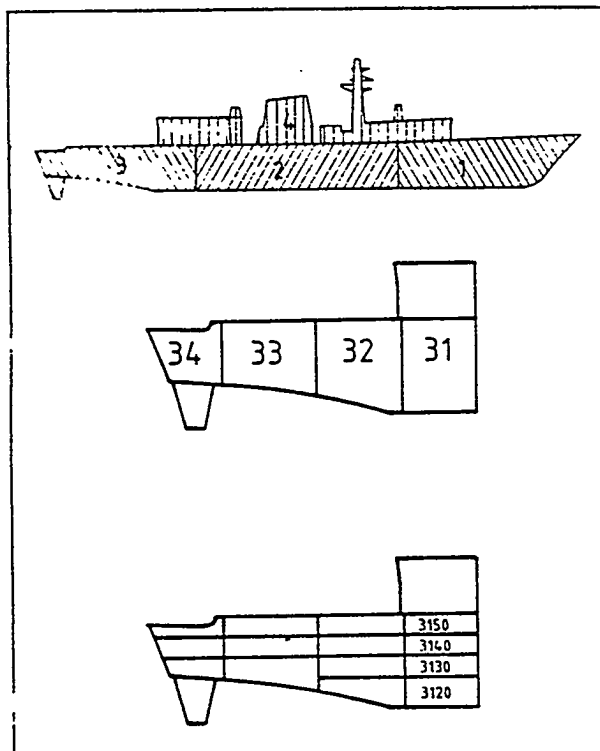


FIGURE 17. AN EXAMPLE OF UNIT NUMBERING

3.4.2.1 OUTFIT ZONE NUMBERING

A four digit number of the XYZO is used for identifying and scheduling material and labor resources to an outfit zone product (Figure 18). Outfit zone numbers have a geographical significance within the ship and allow personnel to rely on logic rather than memory to control material and labor.

X Represents one of four major Superzones of the ship:

1. Forward of Machinery spaces
2. Machinery spaces
3. Aft of Machinery spaces
4. Superstructure

Y Represents Girth sub-divisions (1 through 5) based on watertight bulkhead locations, forward to aft, for the hull zones and major structural vertical sub-divisions for superstructure zones. The number 0 is used to represent applicability to the entire Superzone. The numbers 6 through 9 are used to designate the exterior shell, weather deck and house sides.

Z Represents a deck level within a Girth. Numbers run consecutively (1 through 9) from the innerbottom to the weather deck for hull zones and major structural horizontal sub-divisions for superstructure zones.

O The number zero is reserved for general outfit zone work. Numbers 1 through 9 are reserved for further sub-division of the basic outfit zone for more efficient design and production cost control.

Figure 19 shows the outfit zone for No. 3 Deck. However, in order to expand on the specialized outfitting required within the electrical equipment area, 2442 has been established as a (sub) outfit zone or sub-zone.

Outfit zones may also span more than one deck level: Figure 19 shows No. 2 Deck with outfit zone 2460, the exhaust casing, shaded. This same outfit zone appears on No. 3 Deck as well.

Figure 20 shows the outfit zone breakdown with vertical design/outfit zones. The further sub-division of the basic outfit zone will allow.

- o More efficient use of design resources
- o Smaller and more controllable work packages during outfitting phases
- o More efficient use of production resources
- o More discrete scheduling of the on-board outfitting activities.

3.4.3 SPECIAL INSTALLATIONS

Special Installations are complex installation jobs which require work to be organized around a particular task rather than a geographic area.

Special Installations often require multi-discipline co-ordination and work sequencing between two or more outfit zones.

3.4.3.1 SPECIAL INSTALLATION ZONE NUMBERING

A four digit number in the format XYZO will be used for identifying and controlling production material and labor to Special Installation zones (see Figure 21).

XY Assigned the numbers 61 through 65 to indicate Special Installation, while the second digit (1 through 4) indicates which Superzone the module is in. The number 5 in the Y digit indicates multi-zones. The number 0 in the Y digit represents main cable pulls.

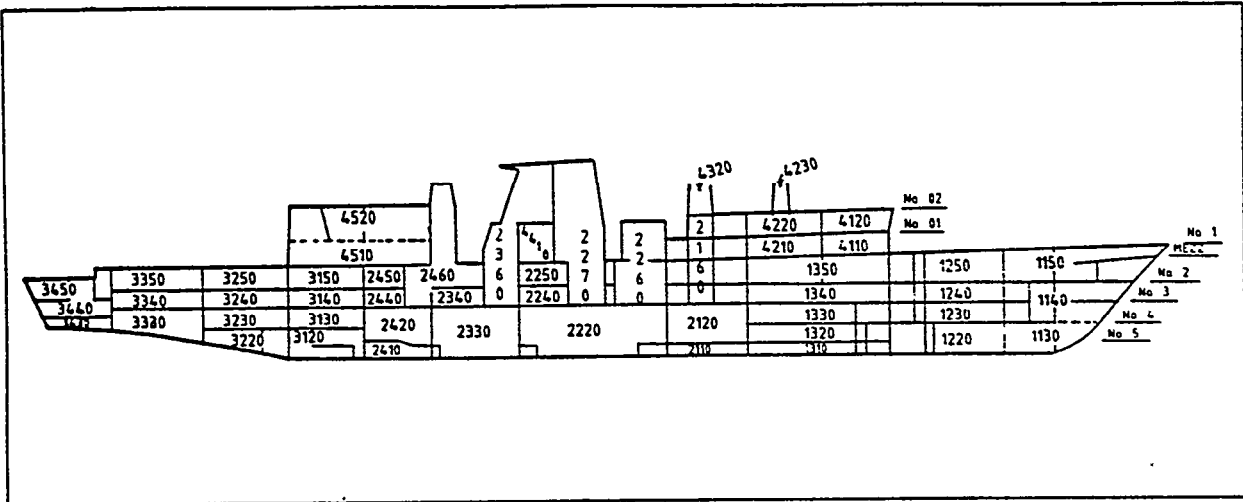


FIGURE 18. THE PRODUCT - OUTFIT ZONE

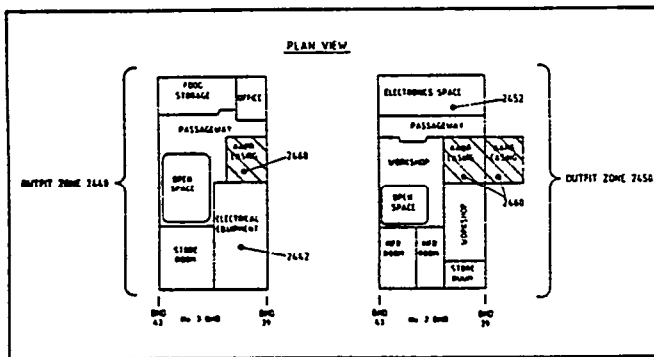


FIGURE 19. AN EXAMPLE OF OUTFIT ZONE

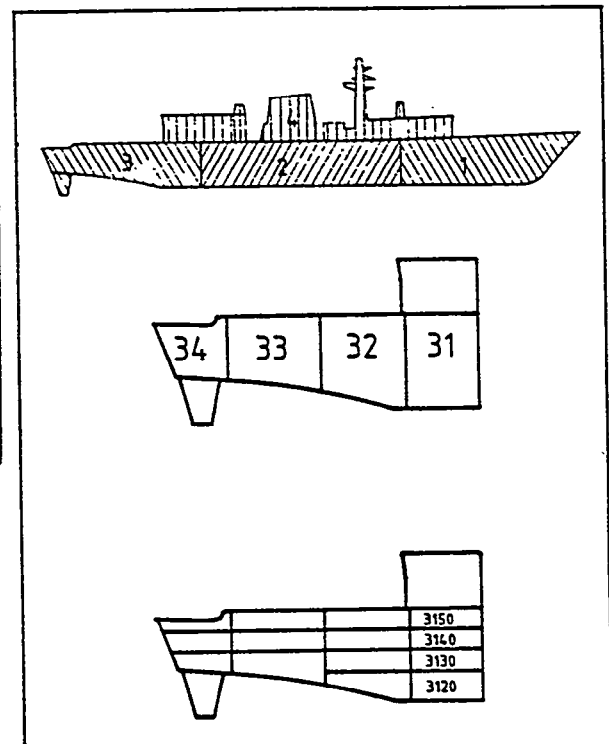


FIGURE 20. AN EXAMPLE OF ZONE NUMBERING

20 A field of consecutive numbers (00 through 99), used to identify the individual Special Installation.

3.4.4 MODULES

A Module is an off-ship and off-unit assembly of outfit equipment, components, material and fittings (often mounted on a common base) which may be installed as a single unit.

Modules are classed by their physical make-up and work content. There are four types of Modules:

- 0 Piping Modules - Major runs of piping and their supports.
- 0 Component Modules - Equipments mounted in shipboard location on their own foundations or mock-ups to allow piping to be run. Depending upon complexity, modules may be broken apart for installation.

PRODUCT

STAGE OF CONSTRUCTION									
PRODUCT	KITTING/PART FABRICATION & SUB ASSEMBLY	FLAT PANEL ASSEMBLY & PO-1	CURVED SHELL ASSEMBLY & PO-1	UNIT ASSEMBLY & PO-1	OUTFIT PACKAGE ASSEMBLY	BLAST PAINT	GROUND ERECTION & PO-2	ERECTION & OUTFITTING IN GRAVING DOCK	OUTFITTING WATERBORNE
	1100	1200	1300	1400	1500	1600	1700	1800	1900
UNITS	WD/ITP	WD/ITP	WD/ITP	WD/ITP		WD/ITP	WD/ITP	WD/ITP	
OUTFIT ZONE	WD/ITP							WD/ITP	WD/ITP
SPECIAL INSTAL- LATIONS	WD/ITP			WD/ITP			WD/ITP	WD/ITP	WD/ITP
MODULE	WD/ITP				WD/ITP				
STANDARD MANUFAC- TURING JOBS	WD/ITP								

FIG. 23. THE PRODUCT BY STAGE OF CONSTRUCTION WD/ITP MATRIX

3.5 P/Se NUMBERING

Labour, material and technical information is planned, scheduled and controlled by the P/se Numbering System.

The P/Se Numbering System describes all construction products. It is also flexible enough to accommodate all construction techniques and stages (see Figure 23).

3.6 PICTORIAL EXAMPLES OF P/Se

Photographs included as Figures 24 through 35 depict products, most with pre-outfit completed at optimum stages of construction.

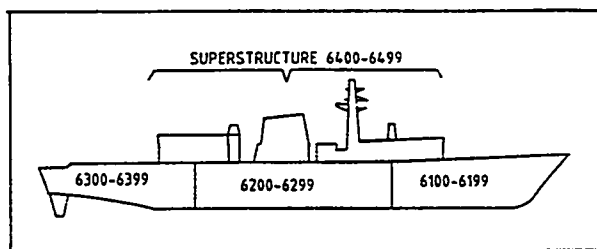


FIGURE 21. AN EXAMPLE OF SPECIAL INSTALLATIONS NUMBERING

- o Tank Modules - Completion of free standing tanks with tank level indication alarm sensors, etc. and testing in the shop.
- o Integrated Modules - The most desirable module where design permits. It includes grating, piping, equipment, ventilation, local cabling, etc. on a common foundation.

Modules can be installed in the following stages of construction:

1. Unit Assembly & Pre-outfit 1
2. Unit Joining & Pre-outfit 2
3. Hull Erection
4. On-Board Outfitting

On-Module Outfitting is targeted at performing as much outfit work as possible off-ship. It ensures that work is performed in the best possible environment and takes maximum advantage of the lowest cost factor available within the shipyard.

3.4.4.1 MODULE NUMBERING

A four digit number in the format XYZO will be used for identifying and scheduling material and labor resources to a module. As with units and zones, the module number has a geographical significance within the ship.

- XY Assigned the numbers 71 through 74 to indicate a module where the second number (1 through 4) indicates which Superzone the module is in.
- ZO Represents a consecutive set of numbers (00 through 99) used to identify individual modules.

As modules have been identified on the CPF program, the Z digit has been used to identify the Girth the module

is located in. For example, the module in forward engine room (Girth 2200) might be 7221 or 7222 or 7223. This convention only exists when less than nine modules are identified (see Figure 22).

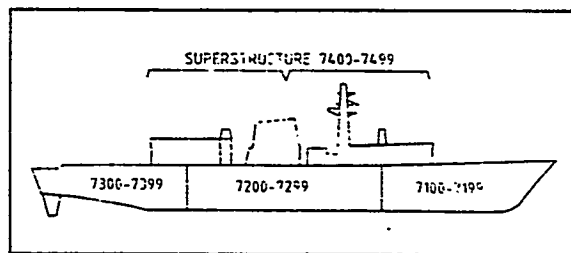


FIGURE 22. AN EXAMPLE OF MODULE NUMBERING

3.4.5 STANDARD MANUFACTURING JOBS

Standard Manufacturing Jobs are special interim products which are built off-flow, that is, outside the main hull construction flow. They are part-assemblies made at Manufacturing Level II.

It is intended that Manufacturing Jobs be grouped according to their common manufacturing characteristics in order to maximize efficiency by making parts in batches.

All Manufacturing Jobs are given **Work Description / Inspection & Test Plan (WD/ITP) numbers** which facilitate planning, scheduling and progressing. Material procurement, fabrication, assembly, painting, testing and QA/QC requirements are all controlled by the P/Se tracking number.

3.4.5.1 STANDARD MANUFACTURING JOB NUMBERING

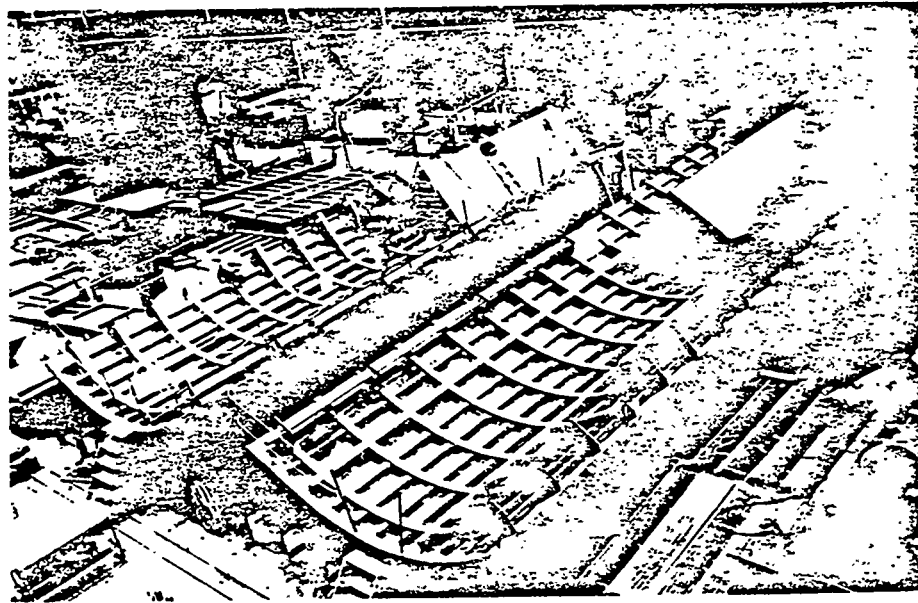
A four digit number in the format XYZO is used. Manufacturing Job numbers have no geographical significance within the ship.

- XY Assigned the numbers 75 through 79 to identify the Manufacturing Job type:

- 75 - Structure
- 76 - Pipe
- 77 - Electrical
- 78 - Sheet Metal
- 79 - Hull Outfit

- ZO A field of consecutive numbers (01 to 99) within the 75, 76, 77, 78, and 79 series to indicate a specific job.

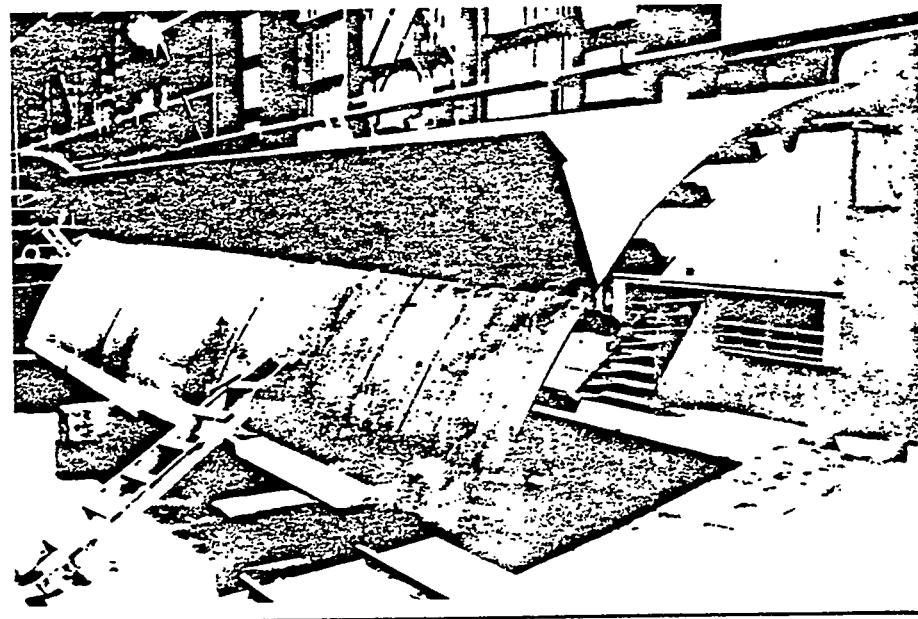
STAGE OF CONSTRUCTION 1300



PRODUCT:UNIT

FIGURE 24. SHELL ASSEMBLY STAGE

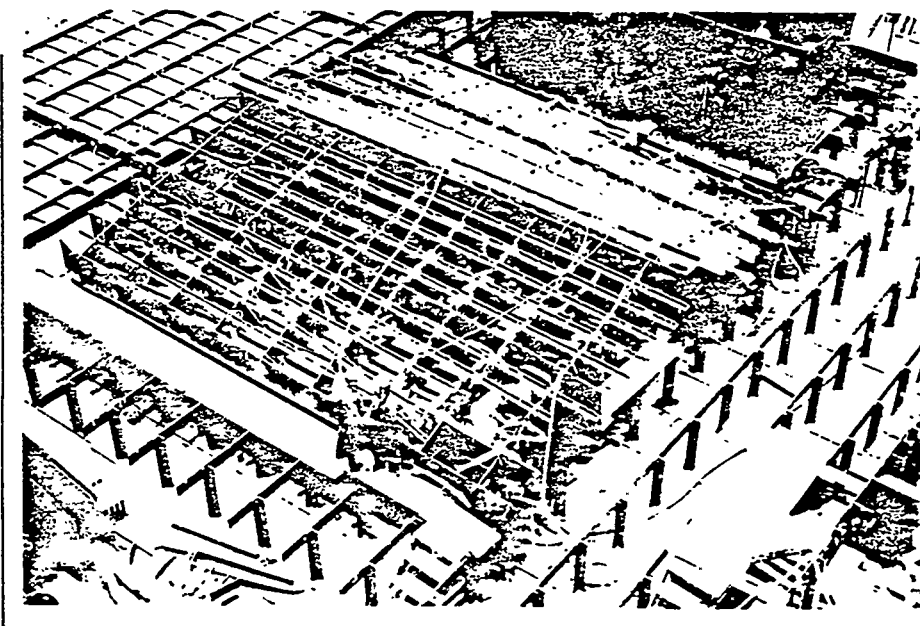
STAGE OF CONSTRUCTION 1300



PRODUCT:UNIT

FIGURE 25. SHELL ASSEMBLY STAGE. BILGE KEEL BEING FITTED INVERTED

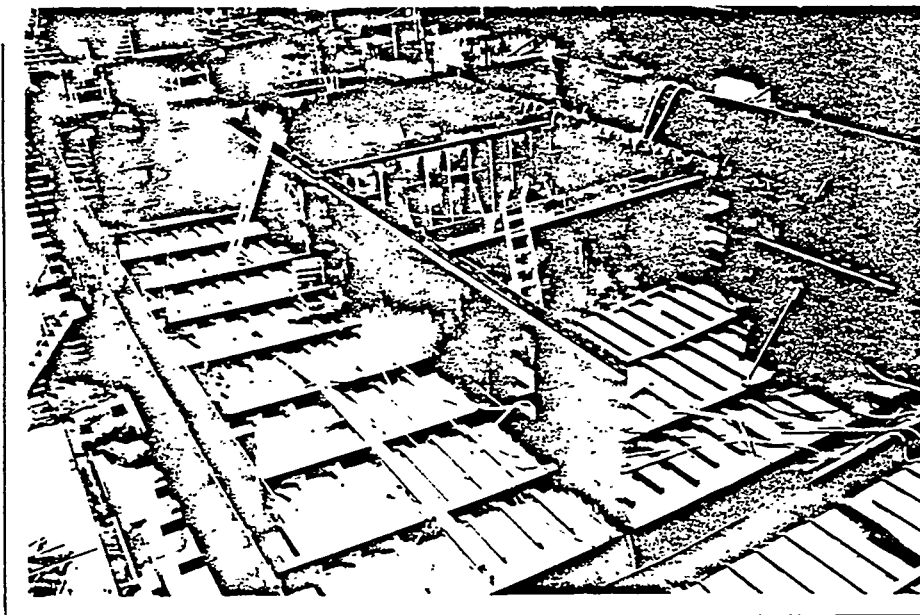
STAGE OF CONSTRUCTION 1410



PRODUCT: UNIT

FIGURE 26. THE UNIT ASSEMBLY STAGE SHOWING PIPES BEING INSTALLED IN THE INVERTED POSITION - OPPORTUNITY UNIT 2410 FUEL TANKS BELOW AFT AUXILIARY MACHINERY ROOM

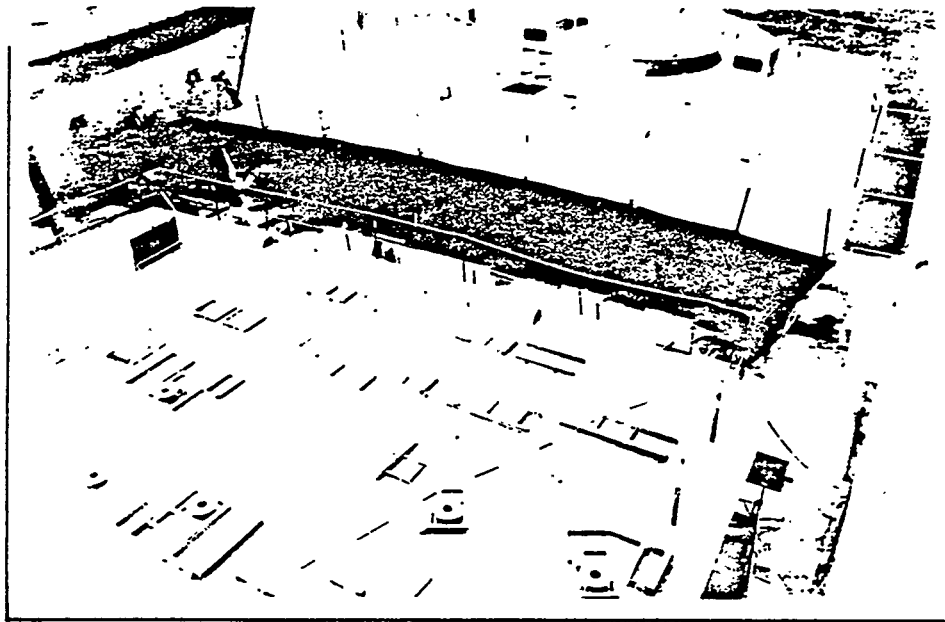
STAGE OF CONSTRUCTION 1410



PRODUCT: UNIT

FIGURE 27. THE UNIT ASSEMBLY STAGE SHOWING MINOR BULKHEADS BEING INSTALLED IN THE INVERTED POSITION - OPPORTUNITY UNIT 3130

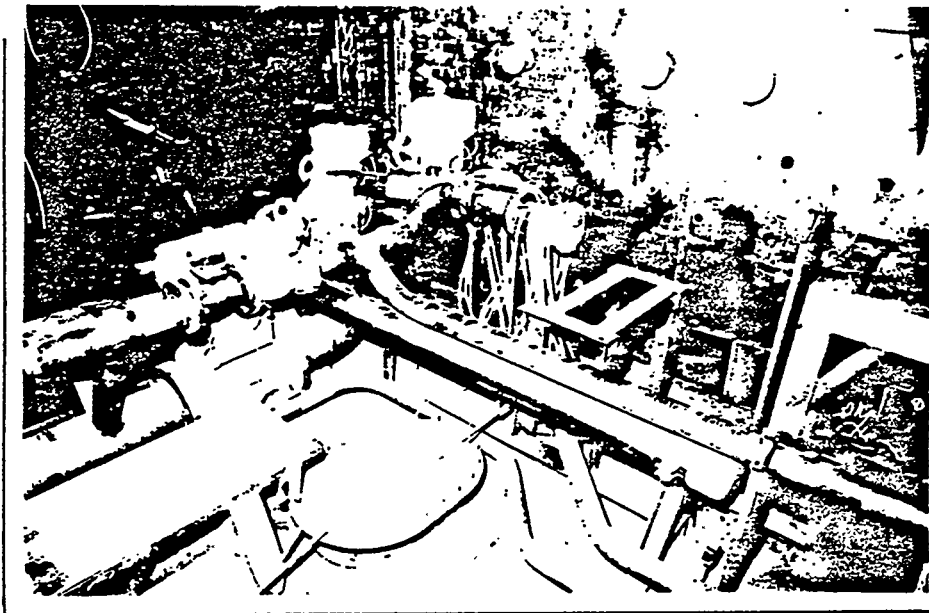
STAGE OF CONSTRUCTION 1420



PRODUCT: UNIT

FIGURE 28. UNIT 1350 SHOWING SEATING ON THE TOP SIDE OF DECK IN ZONE 4110. PRE-OUTFITTING UPRIGHT.

STAGE OF CONSTRUCTION 1420



PRODUCT: UNIT

FIGURE 29. UNIT 2120 SHOWING FOUNDATION, PENETRATION, MANHOLES, ETC. PRE-OUTFITTING UPRIGHT

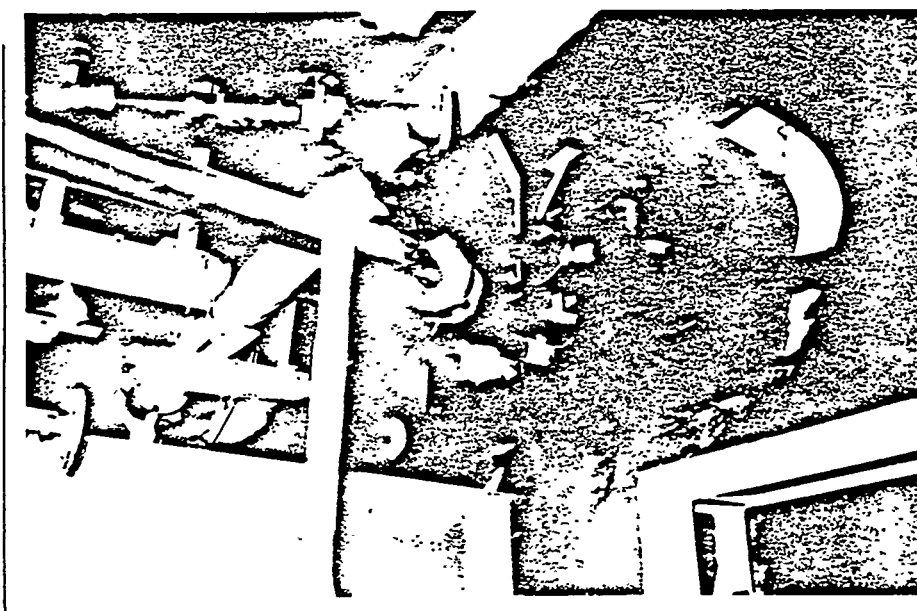
STAGE OF CONSTRUCTION 1700



PRODUCT: UNIT

FIGURE 30. PRE-OUTFIT 2 SHOWING VALVES, VENTILATION, LIGHTING AND INSULATION

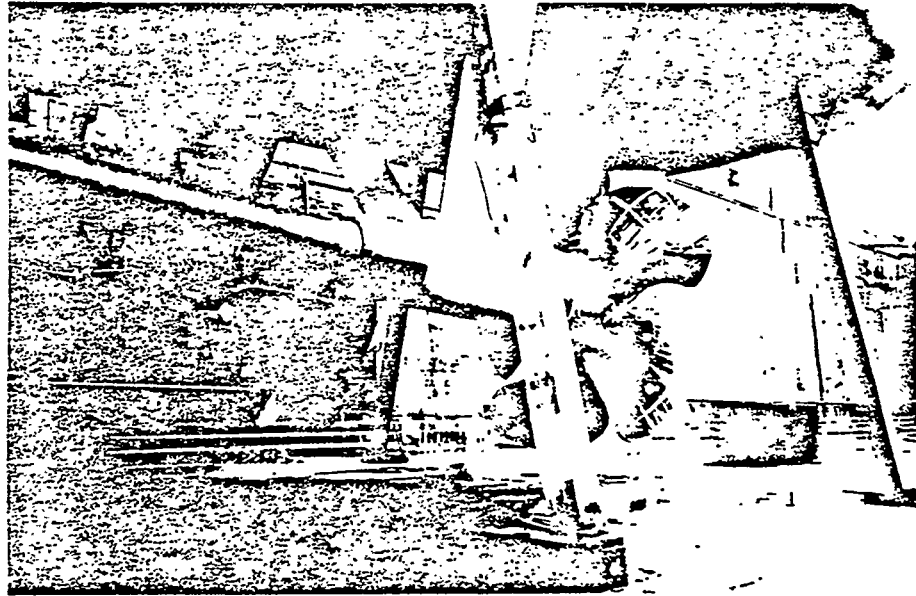
STAGE OF CONSTRUCTION 1700



PRODUCT: UNIT

FIGURE 31. PRE-OUTFIT 2 SHOWING VALVE INSTALLATION AND INSULATION

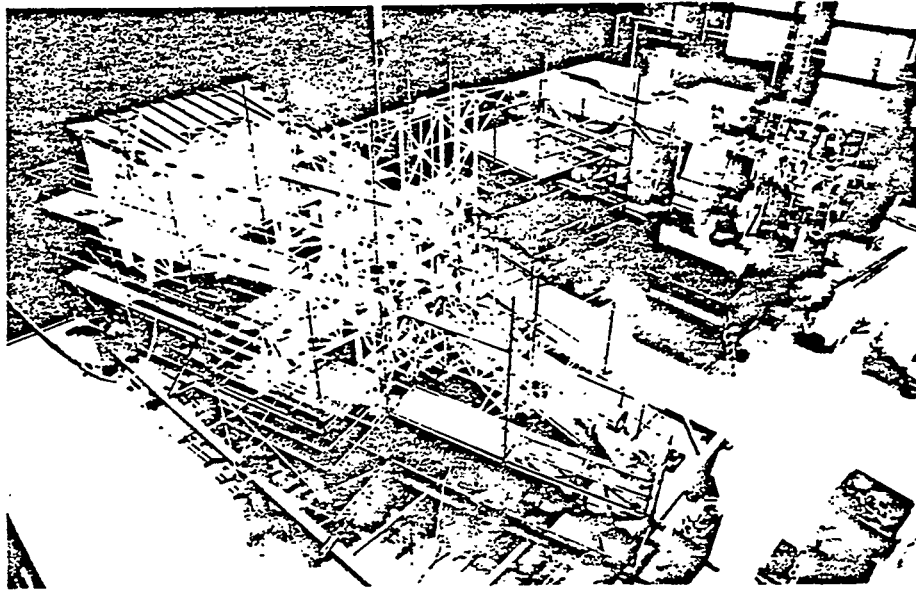
STAGE OF CONSTRUCTION 1800



PRODUCT: SPECIAL INSTALLATIONS

FIGURE 32. INSTALLING SHAFTING AND PROPELLERS

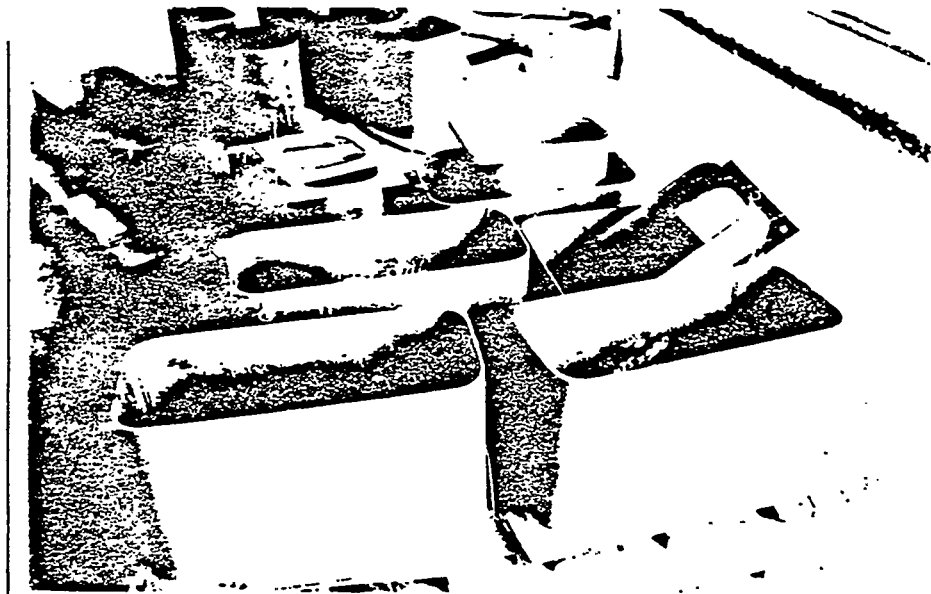
STAGE OF CONSTRUCTION 1500



PRODUCT: MODULES

FIGURE 33. INSTALLING GEARBOX AND GAS TURBINES ON RAFT. COMPLETE WITH L.O. COOLING, L.O. PUMPS AND PIPING

STAGE OF CONSTRUCTION 1160



PRODUCT: STANDARD MANUFACTURING JOB

FIGURE 34. PENETRATIONS

STAGE OF CONSTRUCTION 1170



PRODUCT: STANDARD MANUFACTURING JOB

FIGURE 35. FIRE HOSE RACKS

4. DEVELOPING THE TRANSLATION MATRIX

The original CPF contract ICWBS established the framework for performance measurement and management of the CPF program. At the time of contract negotiation and signing it was decided that the product of the contract WBS would be a ship system, that all cost/performance data would relate to that ship system, and that the ICWBS would be organized accordingly. However, shipyard functional organizations became increasingly frustrated by their inability to report and monitor performance in a manner in keeping with the way they were building the ship - by PRODUCT. Contributing to this frustration was the inability to perform the following functions accurately:

- o Adjust manning levels because of early or late shifts in product production
- o Integrate operational (or recovery) schedules into day-to-day performance objectives
- o Report timely corrective action to cost/schedule variances
- o Forecast the impacts of late material or drawing delivery
- o Identify and evaluate the impact of engineering changes on both hull construction and zone outfitting.

These analytic deficiencies, coupled with the ongoing rationalization of fundamental shipbuilding processes and concomitant redesign of the SJSI organizational structure, called the entire concept of performance reporting by ship system into question. It became increasingly clear that comprehensive performance measurement structured in the same manner in which the PRODUCT (in this case a ship) is built affords considerable analytic possibilities. It can provide that margin needed for outstanding growth and profitability, and, when coupled with sound planning, furnish a substantial framework of objectives and strategies to form the basis for responsible decision-making. There are ancillary benefits as well, including the development of a powerful communications conduit through which managers both disclose and gain visibility into problems limited to specific areas or affecting performance in the entire shipyard.

However, before a total commitment was made to move CPF contract method of reporting to a

Product by Stage of Construction (P/Sc) method, two major questions were raised concerning the Cost/Schedule Control Criteria:

Firstly, how effective will the "new direction" be in achieving the stated C/SC contract objectives (to employ effective management control systems for cost/schedule planning and control of major program elements, and provide useful data on cost, schedule and technical performance); secondly, can the "new direction" report and integrate actual cost at the proper level of the contract ICWBS for historical recording?

Considerable effort was expended to answer these questions by broadening the rationalization process to include the C/SC Criteria. Starting with the ORGANIZATION and moving progressively through the Criteria to REVISIONS, it was determined that P/se reporting is capable of supporting the contract ICWBS. Indeed, a P/Se WBS would achieve literal compliance with all C/Sc Criteria requirements. This further implied that a quantitative method of moving from the ICWBS to P/Se WBS and back to the ICWBS would be developed for reasons of traceability. Additionally, relationships between the stages of transition would have to be clearly expressed and identified. The technique for performing this quantitative movement between ICWBS and PRODUCT is depicted by the Translation Matrix (Figure 36).

4.1 TRANSLATION BETWEEN ICWBS AND PRODUCT

No single, accurate method of determining the amount of budget to be allocated to each PRODUCT from each element of the ICWBS existed. Indeed, even the most experienced estimators would employ different methods, depending upon such factors as the type of ICWBS element, the particular product in question, and the level of accuracy required.

Because of this ambiguity and lack of definition it was necessary to establish a common ground. Firstly, a definition of PRODUCT was agreed:

A PRODUCT is any physical Unit or Outfit Zone (to that level detail required for control and performance measurement), Special Installation (detailed by Engineering and Planning), Module (as designed by Engineering and incorporated into Product drawings), and Manufacturing

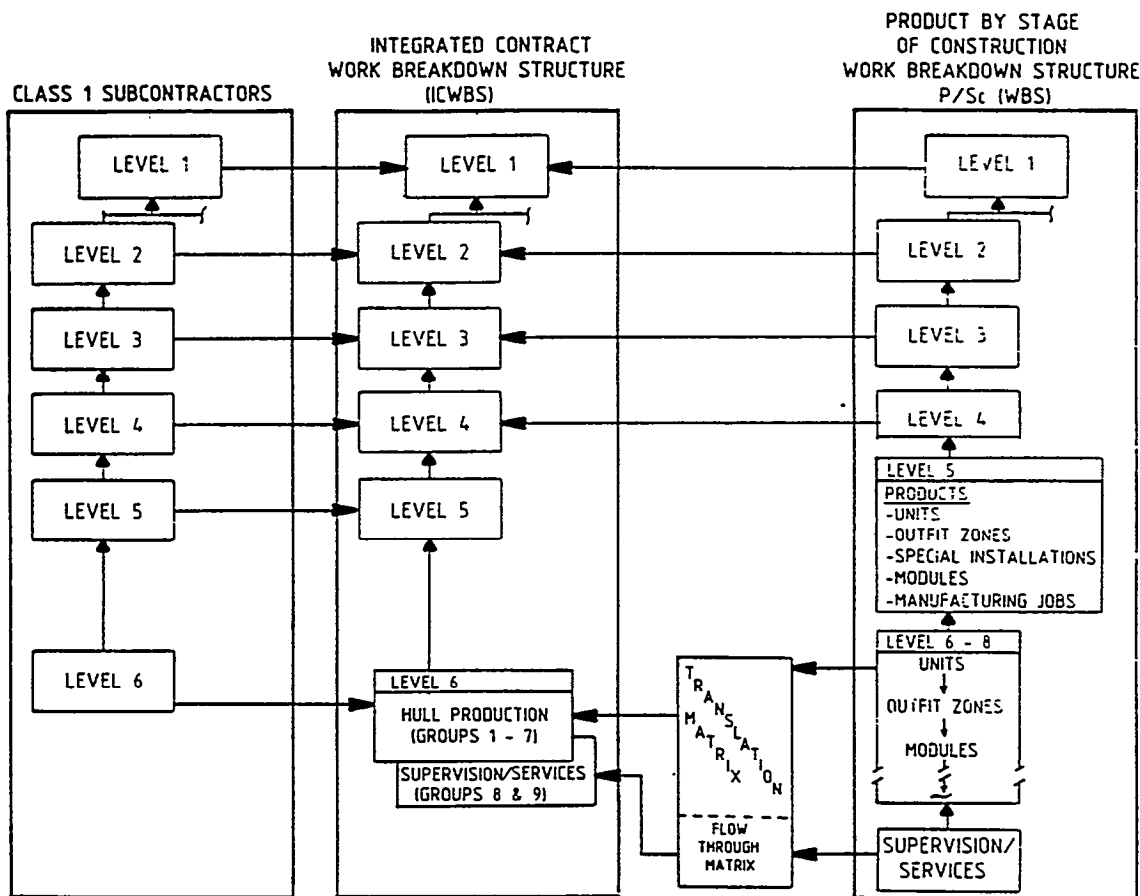


FIGURE 36. THE TRANSLATION MATRIX

Job (as defined by Engineering and Planning). A PRODUCT starts as a part to which another part is added at a Stage of Construction. The PRODUCT is always defined in conjunction with the optimum Stage of Construction.

Secondly, a fundamental theory was postulated and agreed:

There can be an allocation and effective distribution of the ICWBS budget to a PRODUCT at a Stage of Construction most opportune fabricate or install the PRODUCT. This distribution starts at a high level and is sub-divided into assembly, sub-assembly, component and part until each PRODUCT has a portion of budget correctly correlated with its particular Stage of Construction. As the allocation descends the PRODUCT hierarchy, the process of budget distribution becomes progressively more complex; final decisions of correct allocation are subject to a qualitative analysis.

Once this process is completed and the total budget is assigned by PRODUCT, the Performance Baseline Model is effectively sealed against further manipulation or modification; through linkage with the Integrated Master Schedule, it becomes a basis for TRUE PERFORMANCE MEASUREMENT.

Finally, a Translation Simulation Model was developed to compare the strengths and weaknesses of each translation and, more importantly, to track and label the assigned system budget to the PRODUCT.

At this point, the Translation Simulation Model is used only to pre-test proposed distributions of the ship system (ICWBS) budget to a PRODUCT.

The pre-testing performed by the computer and subsequent analysis by the planner trace, in detail, the implications and consequences of selected ICWBS distributions. Substantial effort was expended during the design stage of the model to incorporate the "rules of distribution". Broadly speaking, these rules focus on defining and analyzing correct algorithms for budget distribution.

Once the correct algorithms were defined, the following questions were applied:

- o Do the algorithms accomplish what is desired?
- o How do they perform?
- o How good is the distribution "on the average"?
- o How average is average? That is, what is the variance in distribution?

Analysis and manipulation of the three conceptual elements - PRODUCT, budget allocation by PRODUCT, and the Translation Simulation Model - culminated in the development of a two-axis Translation Matrix. With this matrix, it is possible to identify at any point of intersection the resources required to achieve "an element of the ICWBS by a Product" (Figure 37).

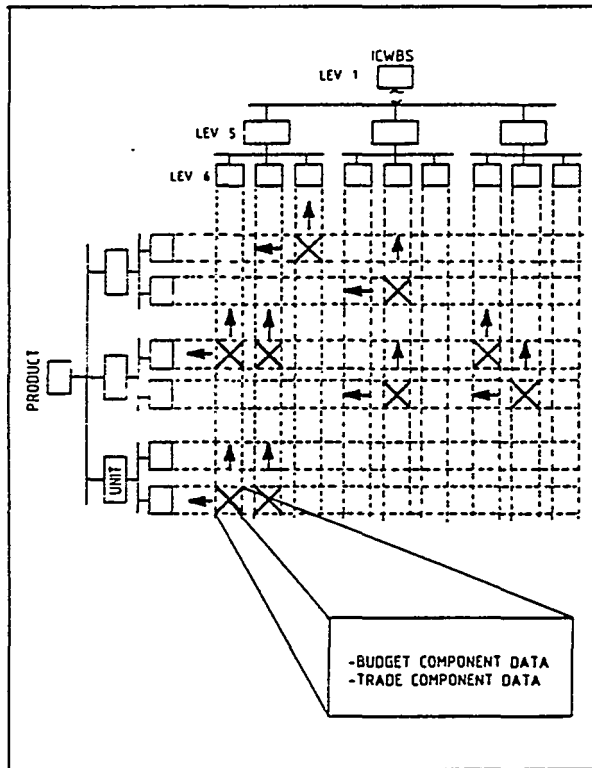


FIGURE 37. THE OUTPUT OF THE TWO-AXIS TRANSLATION MATRIX

The matrix offers a great deal of clarity in the initial translation, allowing the planner to "see" the distribution of resources (budget and trade component data) over the complete shipbuilding process (the PRODUCT). Furthermore, through the Simulation Model, the matrix may be adjusted and fine-tuned to incorporate or simulate changes.

4.2 TRANSLATION BETWEEN PRODUCT AND STAGE OF CONSTRUCTION

The effective distribution of the complete ICWBS budget across the PRODUCT paves the way for the second step of the translation process: distribution of the PRODUCT budget across the Stages of Construction.

The Translation Simulation Model was extended to make distributions and comparisons in three dimensions. This extension was taken to a sufficiently low level of detail to allow its use as a guide for finally establishing the budget for installation of a PRODUCT at the optimum Stage of Construction.

The extension of the Translation Simulation Model was controlled by designing the following characteristics into the model:

4.2.1 FEASIBILITY

Some Product/ICWBS/Stage of Construction combinations are more amenable to distribution than others in that they can be apportioned with a high level of confidence. However, combinations which must accommodate transitions through basic, functional and detail design are only "approximated"; this is because the information for these combinations is less than complete at different stages of design. As part of the extension of the Translation Simulation Model, all distributions would have an "associated accuracy" value with the final budget distribution.

4.2.2 TESTABILITY

Testability refers to the degree of ease with which corrections to the final distribution may be tested, requiring knowledge of what is correct and documentation of the mechanics for conducting that test.

4.2.3 EFFECTIVENESS

All final distributions have an impact on the analysis of Product performance. For example, a projection of percentage completion is not very reliable if analysis shows that the majority of distributions have a low degree of associated accuracy. On the other hand, accurate data would demonstrate an immediate acceptability.

4.2.4 LOCATABILITY

A sophisticated technique was devised for tagging the ICWBS number and associated budget of each proposed distribution in order to allocate actual cost back to the correct ICWBS account accurately. This technique is able to link and unlink relationships repeatable sequence distributions are iterated to their final conclusion.

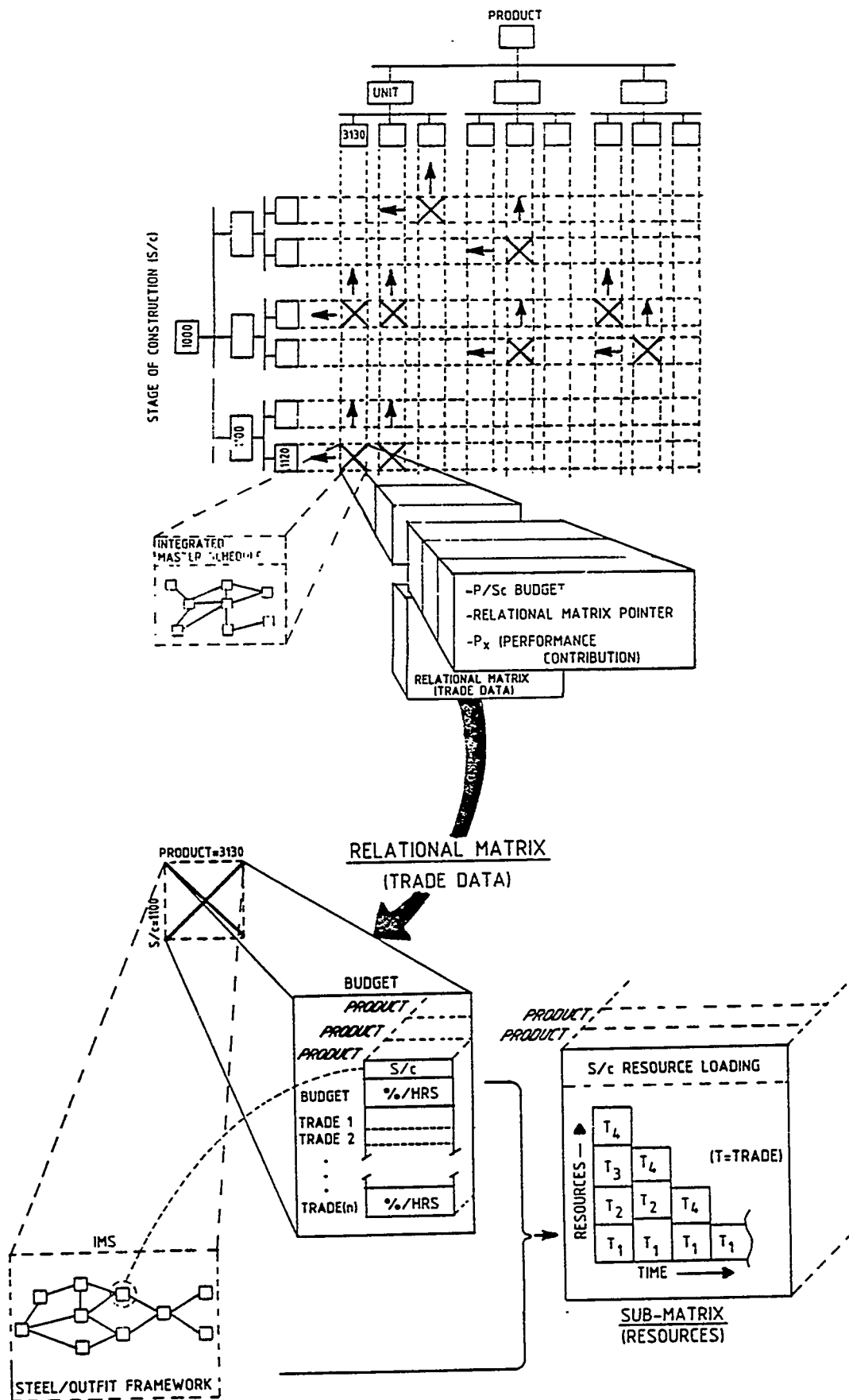


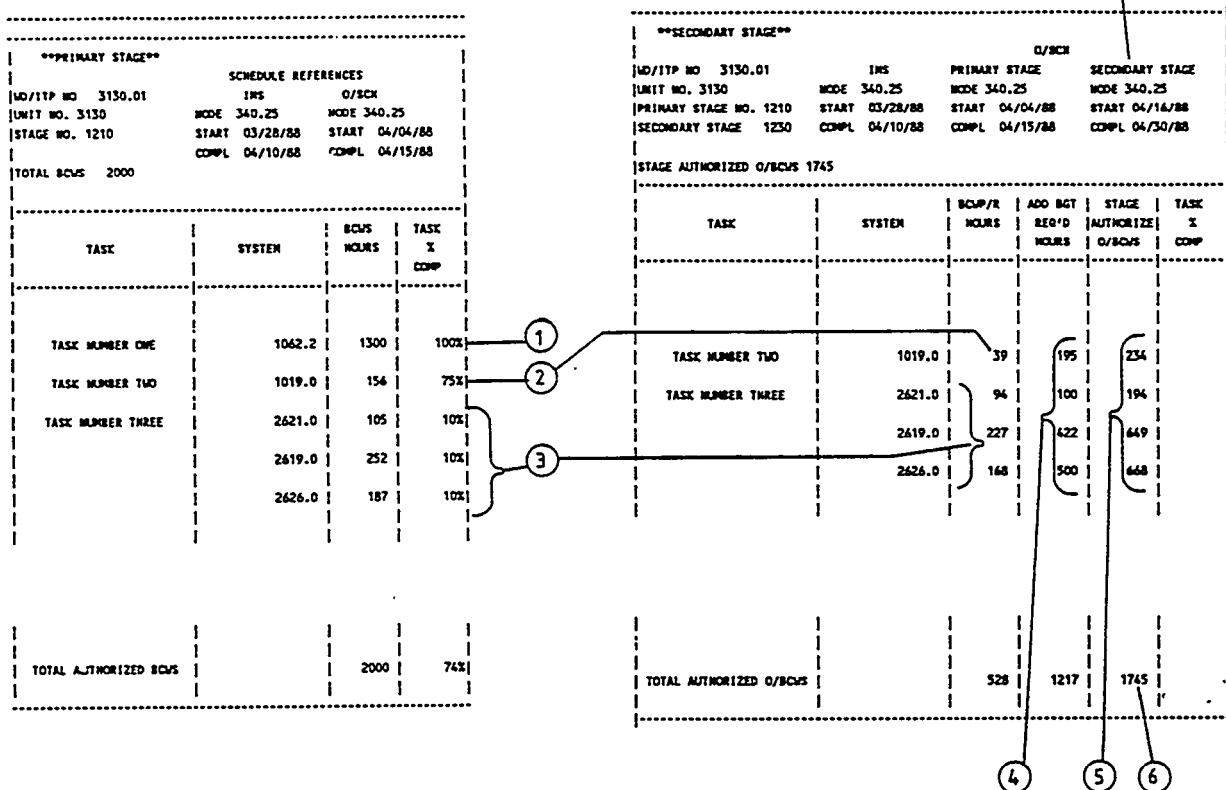
FIGURE 39. AN ILLUSTRATION OF THE RELATIONAL MATRIX POINTER POINTING TO TRADE DATA

PRIMARY DEFINITION OF WORK BY WD/ITP

1.	PRIMARY STAGE OF CONSTRUCTION	- Where all the WORK for a particular product at a particular stage of construction is budgeted and scheduled to be accomplished (OPPORTUNITY).	6.	TASK	- Description of work tasks which must be accomplished to satisfy the requirements of the WDITP.
2.	WD/ITP No.	- Unique number for WORK associated with a PRODUCT (unit) at a stage of construction.	7.	SYSTEM	- ICWBS reference for each work task.
3.	UNIT NO.	- a four digit number representing a geographical area within the ship used for identifying and scheduling material and labour resources, applicable to a unit or outfit zone (PRODUCTS).	8.	BCWS	- Budgeted Cost Work Scheduled (BCWS) for the task, by system, as developed through the TRANSLATIONAL MATRIX.
4.	STAGE NO.	- a four digit number identifying a physical area where the WORK on a PRODUCT is to be accomplished.	9.	TOTAL AUTHORIZED BCWS	- Sum of all budgets for all work tasks of the Primary Stage WD/ITP.
5.	SCHEDULE REFERENCE	- includes both Integrated Master Schedule (IMS/ Baseline Schedule) and operating schedule indicating Node Number, Scheduled Start and Scheduled Completion Dates.	10.	TASK % COMPLETE	- Cost Account Managers weekly/monthly assessment of % complete for each task (ICWBS relationship).
	IMS	- Integrated Master Schedule (IMS) the baseline Schedule representing the full work scope of a contract.	11.	WD/ITP % COMPLETE	- Overall % complete for the PRODUCT by STAGE OF CONSTRUCTION.
	OPERATIONAL	- Represents the way work is scheduled to be done versus where/when was planned to be done. REALITY.			

FIGURE 41

REASSIGNMENT OF WORK BY WD/ITP



The following describes the process followed to reassign scope (BCWP/R) from a primary stage WD/ITP to a secondary stage.

The final status (% complete) of the primary stage is evaluated with the following reassignments of work:

- ① Task 1 is 100% complete therefore no reassignment of work is required.
- ② Task 2 is 75% complete; 25% or 39 hours of scope (BCWP/R) is reassigned to the secondary stage.
- ③ Task 3, which consists of:

	TASK	PRIMARY STAGE	PRIMARY STAGE	SECONDARY STAGE
SYSTEM	% COMP	BCWS	HOURS COMP.	BCWP/R
2621.0	10%	105	11	94
2619.0	10%	252	25	227
2626.0	10%	187	19	168

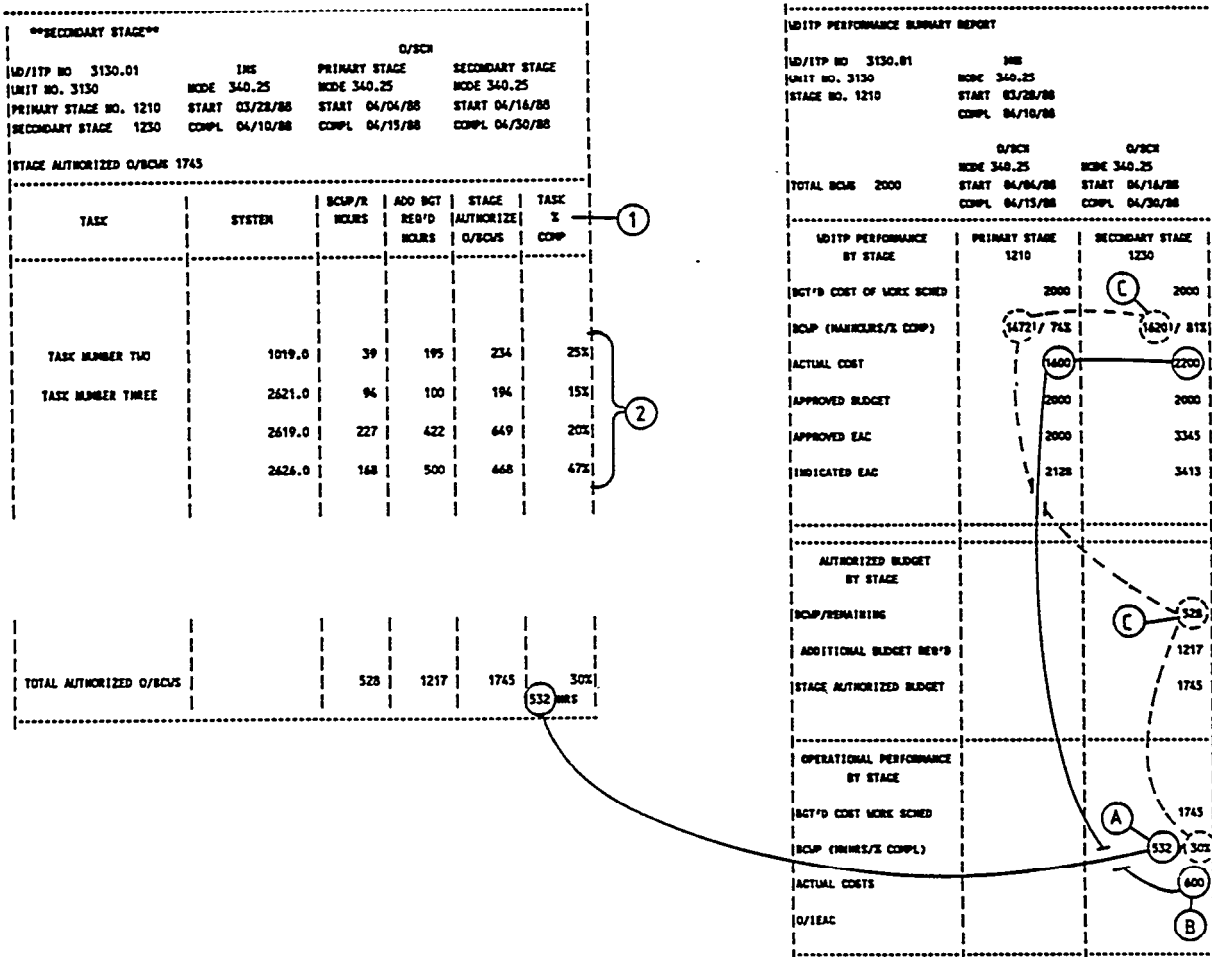
The BCWP/R is reassigned to the secondary stage, and represents the difference between the Primary Stage BCWS and the hours completed (BCWP) in the Primary Stage.

- ④ By task an estimate of the additional budget required (ABR) is performed by the work center manager for the secondary stage. This provides an accurate operating budget against which his performance may be measured.
- ⑤ The "Stage authorized O/BCWS" is the addition of the BCWP/R + ABR. (This is the budget authorized for the secondary stage portion of the WD/ITP.)
- ⑥ The sum of the authorized O/BCWS for the tasks remaining to be completed within the Secondary Stage WD/ITP.
- ⑦ An operating schedule is issued to the secondary stage, which represents that stage's schedule constraints (REALITY).

Note: Responsibility for the work always resides with the Primary Stage WD/ITP.

FIGURE 42

STATUSING OF WORK BY WD/ITP



- Weekly/Monthly performance data, in terms of % complete, is determined by the Cost Account Manager for each task and recorded within the WD/ITP.
- Once this work is statused as a percent complete for the secondary stage the same percent complete is used to automatically update the primary WD/ITP as follows:

WD/ITP				WD/ITP			
SECONDARY				PRIMARY			
TASK	% COMP.	O/BCWS	HRS	TASK	% COMP.	BCWP/M	HRS
PERFORMANCE	.15	194	29	PERFORMANCE	.15	94	14
	.20	649	130		.20	227	45
	.47	668	314		.47	168	79
TOTAL	.30	1745	532	TOTAL	.30	528	148

- This performance data is now assimilated into the WD/ITP Performance Summary Reports as described below.
 - Secondary Stage performance for the WD/ITP is updated to reflect the current % Complete for the stage authorized work (532 manhours/30%).
 - Actual costs for the Secondary Stage are recorded (600 manhours). These actual costs relate to the performance earned to date (532 manhours).
 - WD/ITP Performance is revised to reflect the secondary stage performance to date. To the previous stage BCWP manhours (1472) the Secondary Stage BCWP/R manhours (30% of 528 = 158 manhours) is added, reflecting the overall WD/ITP performance of 1620 manhours (1620/2000 = 81% of complete).
 - ACWP is revised to record all actual costs incurred to date for the primary + secondary stages WD/ITP (1600 + 600 = 2200).
 - EAC for the WD/ITP is equal to the final ACWP (HRS) of the Primary Stage (1600) plus the Stage Authorized O/BCWS for each secondary stage (1745).
 - Indicated EAC represents an appreciation of the EAC based upon the Cost Variance (ie Approved EAC - (BCWP-ACWP)).

FIGURE 43

COMPLETION OF WORK BY WD/ITP

SECONDARY STAGE					
O/SCH					
WD/ITP NO 3130.01	IMS	PRIMARY STAGE	SECONDARY STAGE		
UNIT NO. 3130	NODE 340.25	NODE 340.25	NODE 340.25		
PRIMARY STAGE NO. 1210	START 03/28/88	START 04/04/88	START 05/05/88		
SECONDARY STAGE 1250	COMPL 04/10/88	COMPL 04/15/88	COMPL 05/25/88		
STAGE AUTHORIZED O/BCWS 360					
TASK	SYSTEM	BCWP/R HOURS	ADD BGT HOURS	STAGE O/BCWS	TASK % COMP
TASK NUMBER TWO	1019.0	2	10	12	100%
TASK NUMBER THREE				0	
	2619.0	52	176	228	100%
	2626.0	20	100	120	100%
TOTAL AUTHORIZED O/BCWS					
		74	286	360	100%

WD/ITP PERFORMANCE SUMMARY REPORT				
WD/ITP NO 3130.01	IMS			
UNIT NO. 3130	NODE 340.25			
STAGE NO. 1210	START 03/28/88			
	COMPL 04/10/88			
O/SCH				
TOTAL HOURS 2000	NODE 340.25	START 04/04/88	COMPL 04/15/88	
	START 04/16/88	COMPL 04/30/88	START 05/05/88	
	COMPL 05/25/88			

WD/ITP PERFORMANCE BY STAGE	PRIMARY STAGE 1210	SECONDARY STAGE 1230	SECONDARY STAGE 1250
BGT'D COST OF WORK SCHED	2000	2000	2000
BCWP (MANHOURS/X COMP)	1472 / 74%	1926 / 96%	2000 / 100%
ACTUAL COST	1600	3300	3663
APPROVED BUDGET	2000	2000	2000
APPROVED EAC	2000	3345	3660
INDICATED EAC	2128	3300	3663

AUTHORIZED BUDGET BY STAGE	PRIMARY STAGE 1210	SECONDARY STAGE 1230	SECONDARY STAGE 1250
BCWP/REMAINING		528	74
ADDITIONAL BUDGET REQ'D		1217	286
STAGE AUTHORIZED O/BCWS		1745	360

OPERATIONAL PERFORMANCE BY STAGE	PRIMARY STAGE 1210	SECONDARY STAGE 1230	SECONDARY STAGE 1250
BGT'D COST WORK SCHED		1745	360
BCWP (MANHOURS/X COMPL)		1501 / 86%	360 / 100%
ACTUAL COSTS		1700	363
O/EAC		1700	363

The work has progressed from the Primary Stage (1210) through Secondary Stage (1230) and finally to Secondary Stage (1250) where the work was completed, as shown above.

- ① Completion of the WD/ITP only occurs when all the work tasks are statused as 100% complete.
- ② The WD/ITP Performance Summary Report records the WD/ITP performance by WD/ITP, and by each Stage of Construction.

With completion of the Work tasks the WD/ITP performance is recorded whereby

- ④ Overall BCWS for the WD/ITP does not change, regardless of the number of secondary stages through which the work is accomplished, hence BCWS remains as 2000 hours.
- ⑤ BCWP equals BCWS, and records 100% complete.
- ⑥ Actual costs are updated to record all costs incurred on the WD/ITP (including costs incurred through the primary and all secondary stages).

- ⑦ Approved Budget remains as originally issued, and cannot be revised unless a formal revision is authorized.
- ⑧ Approved EAC represents that estimate approved for the overall WD/ITP. This value is revised as the work is reassigned to secondary stages. A final adjustment is required to set the approved EAC equal to the ACWP (and hence the indicated EAC).
- ⑨ Indicated EAC, for the completed WD/ITP, equals total ACWP.
- ⑩ The flowthrough of status information from the stage WD/ITP's (secondary) occurs as follows:
 - ① The Secondary WD/ITP registers 100% complete with the finalization of all work tasks.
 - ② The 100% complete of the Secondary WD/ITP automatically picks up the BCWP/Remaining for the overall WD/ITP, as a manhour value, and assesses this portion of work as complete. (74 manhours).
 - ③ The overall WD/ITP manhour performance is revised to incorporate the completion of the BCWP/R work tasks (74 manhours). Hence BCWP is equal to 1926 + 74 manhours = 2000 or equal to the total WD/ITP Budget.

allocation of resources. Should the product be completed at any other stage, a negative cost impact could be realized; Secondary Stages of Construction accommodate performance of work but may incur cost and schedule deviations.

The work described on the WD/ITP is cracked from the Primary Stage through to its completion, regardless of the number of secondary Stages of Construction through which it might be performed. With the movement of the Product to the next construction stage, the WD/ITP tasks are statused and the remaining work is reassigned through the WD/ITP to Secondary Stages for completion. Consequently, the WD/ITP, at any point in time, represents the performance of work completed (BCWP) and the exact assessment of the performance required to complete the work remaining (EAC). This represents a major step in performance measurement systems, as it allows the shipyard to take stock of day-to-day objectives, in real time, and preclude the impact of subjective statusing of in-process work.

Formally, the process is accomplished through the systematic closing out of each completed task defined in the ND/ITP as the work moves from one stage to another. When the schedule dictates that the Product moves to another stage, but some of the work tasks have not yet been performed or are incomplete, a status is prepared and recorded. The WD/ITP for the current stage is closed, and records performance for that stage only. The work tasks which remain outstanding are then reassigned to the next stage through the same WD/ITP, with the budget remaining from the Primary Stage WD/ITP also transferred. budget (BCWS) authorized for the WD/ITP does not change from that which was authorized at the Primary Stage.

The remaining work is evaluated by the Secondary Stage Superintendent who will reassess work requirements and recommend increases (operational budgets) through an Estimate to Complete (ETC). Ultimately the total estimate authorized to production through the Secondary Stage(s) WD/ITP represents a reasonable estimate and schedule to perform the remaining work.

If need be, this process is repeated through further Secondary Stages until the work is completed. Each Stage of Construction Superintendent is responsible to perform the work on behalf of the Primary Stage

Superintendent (Primary Stage WD/ITP), but is also accountable for performance of the work within his stage.

SJSL has linked the C/SC Baseline with the Operational Baseline through the WD/ITP. The reporting mechanism supports the preservation of detailed historical data by Product, Stage and ICWBS and further supports stability of the baseline, as all reassignments of task are formally recorded.

Overall performance against the WD/ITP is recorded at each stage and variance analysis is performed where applicable.

Conclusion

The integration of Product by Stage of Construction with a Cost/Schedule Control application results in a solid framework of cost and schedule data that forms a basis for sound planning and decision making.

The Translation Simulation model described in this paper is designed not only to effect the *transition* from the ship system (ICWBS) to the Product approach, but also affords traceability for historical and control purposes and provides a sealed model against which to measure and report progress.

As illustrated in Figure 44, P/Se and ICWBS data are synthesized through the model and correctly assembled in the WD/ITP. The application of Integrated Master Schedule requirements and actual cost of accomplished work (ACWP) to the WD/ITP represents a comprehensive technique for measuring exact performance (BCWP) at a given point in time.

At time of publication, Saint John Shipbuilding Limited is engaged in dialogue with the Contracting Authority to integrate Product by Stage of Construction reporting formally into existing C/SC performance documents, and looks forward to validation of the P/Se system as implementation progresses and matures.

Concurrent combined use of P/Se and C/SC systems breaks new ground in Canadian and perhaps North American shipbuilding industry. It is hoped this paper will stimulate and provide a basis for further investigation into this comprehensive approach to project management, reporting and control.

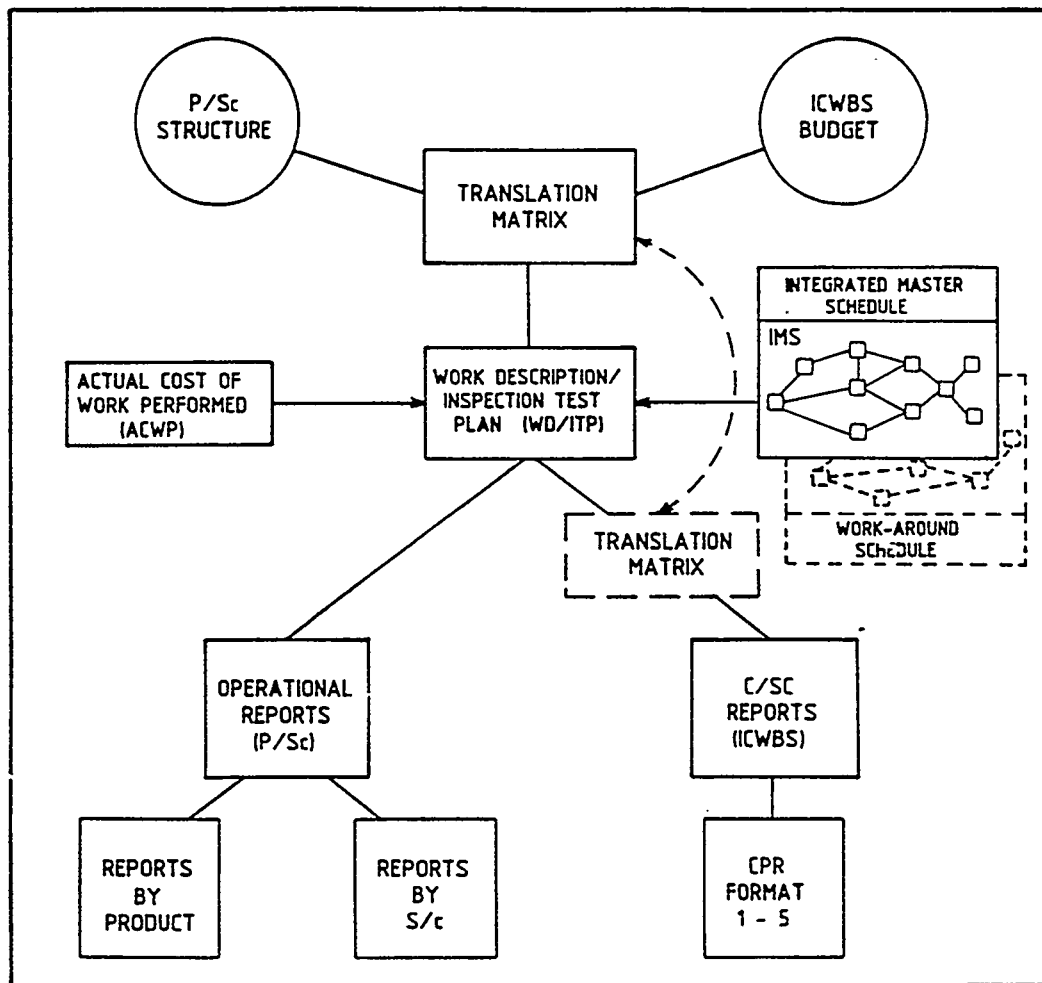


FIGURE 44 . THE SUCCESSFUL INTEGRATION OF PRODUCT BY STAGE OF CONSTRUCTION WITH COST/SCHEDULE CONTROL APPLICATION
ACKNOWLEDGEMENTS

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No. 13

NIDDESC: Meeting the Data Exchange Challenge Through a Cooperative Effort

John Kloetzli, Member, JJH Inc., Rookville, MD and
Dan Billingsley, Member, Naval Sea Systems Command, Washington, D.C.

[The opinions expressed herein are those of the authors and not necessarily those of the Department of Defense, the Department of the Navy, the National Shipbuilding Research Program, or member organizations.]

ABSTRACT

The application of Computer Aided Design (CAD) and Manufacturing (CAM) techniques in the marine industry has increased significantly in recent years. With more individual designers and ship yards using CAD within their organizations, the pressure to transfer CAD data between organizations has also increased. The Navy/Industry Digital Data Exchange Standards Committee (NIDDESC) pro-ales a mechanism for public and private organizations to cooperate in the development of digital data transfer techniques.

Organizationally NIDDESC is a cost-sharing venture, between private firms and government organizations. This effort arose from the Naval Sea Systems Command (NAVSEA) in cooperation with the National Shipbuilding Research Program. The members include leading professionals in the marine industry from several major design firms, private ship yards, naval ship yards, and government laboratories. All members are directly involved in CAD/CAM in their organizations and together represent a broad spectrum of experience and perspectives.

NIDDESC has many sub-committees devoted to specific areas of digital data transfer. The basic objective is to develop an industry-wide consensus on product data models for ship structure and distribution systems. Efforts include contributions to the Initial Graphics Exchange Standard, the Product Data Exchange Standard, preparation of a Recommended Practices Manual and the analysis of ship production data flows. NIDDESC has made contributions to the development of CALS standards including MIL-STD-1840, DOD-IGES, SGML, and MIL-D-28000.

INTRODUCTION

Nature of The Ship Design Process

The information exchange problem of the Navy and the marine industry is one of the most

challenging faced by any group of organizations in the world. This is due to:

- * The complexity of the product,
- * The life span of the product, and
- * The number of participants in the design, construction and service life support process.

Naval ships are among the most complex devices known to man. Their design and construction requires from 7 to 12 years. They roam the oceans for 30 years following their construction. They accomplish complex missions in hostile environments while providing hotel accommodations for their operators. Only a few of each type are built, with each hull differing to some extent from her sisters. By the standards of most industries, these collections of 8,000,000 or so parts are all engineering prototypes.

Unlike aircraft and most mechanical products, ships are not designed, built, operated, maintained, and modernized by vertically integrated corporate giants. Rather these functions are accomplished by a series of government activities and private companies. Competitive pressures make it impossible to know in advance who the participants in the process will be. Further, the process itself tends to vary somewhat from ship to ship.

All of the activities and companies involved have improved this process by utilizing computer tools. For example, many major builders have found Computer Aided Design (CAD) applications a cost-effective means of avoiding costly interferences during construction.

The automation efforts within each activity or company have required substantial investments in hardware and software (both custom and commercial), in training, orientation, and adaptation of work processes to capitalize on computer capabilities. The range and extent of investment is even more impressive considering the general decline and low profitability of the marine industry. There can be no denying that the marine industry is serious about CAD!

Investment choices made by different activities and companies have quite naturally led to the selection of different systems. Even companies with identical systems have developed different application techniques. Together with the variations in the process noted above, the Navy

and the marine Industry are squarely faced with a requirement to be able to transfer product information between and among all activities and companies. This transfer must take place at all stages of the product life cycle including design, construction, and service life support.

Purpose of NIDDESC

One primary effort by the Navy and the marine industry to address this requirement is the Navy/Industry Digital Data Exchange Standards Committee (NIDDESC).

NIDDESC is a cost sharing, cooperative effort involving Navy & Industry technical experts in CAD applications.

NIDDESC seeks to avoid costs associated with regeneration of data bases by enabling the exchange of digital data between successive agents during the ship life cycle.

Cost Sharing Cooperative Effort. The NIDDESC effort is being executed through a National Shipbuilding Research Program (NSRP) style cooperative agreement between the Maritime Administration and Newport News Shipbuilding. Newport News has executed purchase orders with each of the commercial participants. Under the terms of the cooperative agreement, each commercial participant has waived profit and all but direct labor fringe overhead. Thus, the companies involved are absorbing one-third to one-half of the labor costs.

Technical Experts. The Working Group is comprised of the CAD Manager or a principal deputy from each of the companies and activities. Each member typically has 5-15 years experience developing and introducing CAD to complex ship design, construction, and support activities. As a result NIDDESC is a standard-setting activity working at the leading edge of CAD application technology.

Avoid Cost. The costs associated with the regeneration of ship technical data by successive agents during the ship life cycle are substantial. These costs are usually budgeted as expected costs of doing business using traditional techniques. A few examples hint at the cost avoidance potential:

* Bath Iron Works was able to avoid 96% of the labor (approximately a manyear) usually associated with production lines fairing on the DDG51 by capitalizing on digital hull form information made available by NAVSEA. This was possible as a result of a technology transfer developed under the Research and Engineering for Automation and Producibility of Ships (REAPS) Project in the 1970's.

* PDS 350 and PMS 400 have spent several million dollars each on digital data exchange programs for the SEAWOLF and DDG51 classes respectively. In each case, they were able to justify the costs of the digital data exchange program based on an expected reduction in the rate of follow builder claims for geometric discrepancies.

Enable the Exchange of Digital Data. This is the ultimate challenge. Following a history of NIDDESC and identification of the participants, is a description of how NIDDESC has broken this problem into manageable pieces and is developmg solutions for the critical ones.

History of the Program

NAVSEA has responsibility for the design, acquisition, and service life support of Naval ships. During the course of the ship life cycle, NAVSEA contracts with numerous design agents, shipbuilders, equipment vendors, and logistics agents to fulfill this responsibility. These organizations have individually developed or acquired various computer systems to support their efforts. The result of their individual selections and the highly competitive nature of the Naval ship design, construction, and service life support process present a generic need on the part of the Navy and the marine industry, to transfer digital data among different computer systems.

This need was foreseen by many Navy and industry leaders, and was formally articulated in Toward More Productive Naval Shipbuilding, a National Academy of Sciences/National Research Council report sponsored by NSRP and issued in December 1984. As a result of several meetings following the issue of this report, NIDDESC was formed in June 1986 as a joint project of NAVSEA and NSRP. The Honorable Everett Pyatt, Assistant Secretary of the Navy for Shipbuilding and Logistics was instrumental in the formation of NIDDESC. His office, together with various ship acquisition projects and the Computer Aided Acquisition and Logistics Support (CALS) program, has provided most of the financial support. The participants in NIDDESC are shown in Table I.

Table I. NIDDESC Participants

<u>Navy</u>	<u>Industry</u>
CHENG-L	Bath Iron Works
CEL-PA	Designers & Planners
DTRC	Electric Boat
PDS 350	Gibbs & Cox
Puget Sound NSY	Ingalls Shipbuilding
NAVSEA 05	JJH
NAVSEA 06	NASSCO
NAVSEA 93	Newport News Shipbuilding
SEACOSD	The Jonathan Corporation
SupShip-Bath	The Baham Corporation

The NIDDESC working group executed a Plan of Action and Milestones (POA&M) approved by the NIDDESC steering group in August 1986 and updated in September 1987. By May 1989, the working group had substantially completed this POA&M at approximately 65% of the projected cost. While there were literally hundreds of interim products, the salient accomplishments under this POA&M were:

- * Establishing an approach to the transfer of the ship definition data,
- * Establishing marine-industry-wide agreement on the structural and piping information to be transferred, and

- * Influencing national and international standards development efforts to support marine industry needs.

In May, 1989, the steering group approved a second POA&M to guide the next phase of NIDDESC efforts. The working group efforts continue under this POA&M.

OVERVIEW OF NIDDESC APPROACH

In breaking down the digital data transfer problem into achievable pieces, NIDDESC has been guided by a few fundamental principles concerning digital data transfer. The first principle is that all digital data transfer projects require the completion of four steps before an assured data transfer capability exists. The second principle is that all transferred ship information falls into four categories.

Development of an Assured Data Transfer Process Capability

The development of an assured data transfer capability involving any type of information, exchange technique, or media can be divided into four steps. Specifically, they are:

Step 1. Identify Data for Transfer. NIDDESC is applying information modeling technology to obtain explicit agreement on the information to be transferred. Information modeling allows a precise statement of complex entities and relationships between data types with minimal ambiguity. The resulting model is in a form understandable by computer specialists, engineers, and managers. This model is the basis for the data transfer process. This step is not expensive, but takes time.

Step 2. Define Data Format. Once the subject data is determined, a data transfer format can then be defined. The DoD CALS initiative has emphasized the development of computer-based design, construction, and maintenance processes through national standards and DoD applications of these standards. NIDDESC is committed to this approach. A data transfer capability built on these standards can achieve significant economies based on commercially developed and supported software. Like step 1, this step is not expensive, but also takes time. NIDDESC has a number of tasks, described later, aimed at assuring that national and DoD standards support the marine industry.

Step 3. Develop or Acquire Translators. This step requires a substantial investment of resources and time. It is principally a software development effort that can only be undertaken when the requirements (i.e. data to be transferred) and the design (i.e. format of transfer) are completed. NIDDESC is not involved in the development or acquisition of digital data translators. In this area, NIDDESC is looking to the development of commercial translators based on CALS standards. This approach has been confirmed with the development of the Initial Graphics Exchange Standard (IGES). With each successive release of IGES, commercial products have become available implementing portions of the new standard.

where specific ship projects have economically pressing needs for data exchange capabilities which are beyond the scope of commercial products, NIDDESC can facilitate the development of specific software by having completed steps 1 and 2.

Step 4. Test and Validate Transfer Techniques. Testing and validation brings the data transfer capability to a production status. This step may require substantial resources and time. Extensive testing and validation is required prior to contractual data transfers. Due to resource constraints and the project-specific nature of test and validation efforts, NIDDESC is minimally involved in this area.

Ship Product Model Information Categories

Ship technical information falls into four broad categories as illustrated in Figure 1. These categories have different characteristics and uses.

The first category is *Requirements* information. The ship is designed, acquired, and maintained to fulfill some set of *functional and mission requirements*. These guide the initial ship *Definition* which is analyzed for its ability to fulfill these requirements. During the design stages, the ship *Definition* becomes more explicit and *procedural specifications* are developed to guide further design efforts. Ship requirements data must be accessible not only in design and construction stages, but also in service life stage to determine suitability of alternate components or configurations during maintenance and modernization efforts.

The process of developing the *Associated Technical Products* may highlight areas where the ship *Definition* needs modification. Alternately *Requirements* frequently change during the 7 to 15 year duration of the design and construction stages. All of the *Associated Technical Products* have the characteristic that a change in ship *Definition* invalidates them to some extent and requires them to be updated or regenerated.

During the design stages many *analysis models* and *analysis results* are created based on the developing ship *Definition*. *Analysis results* are evaluated against *functional and mission requirements* and provide the basis for ship *Definition* changes and *Requirements* for successive stages.

As the production planning and fabrication stages begin, *fabrication and assembly instructions* are developed and *purchase orders* are generated. *Test plans and instructions* are developed to verify that *Requirements* have been satisfied. *Operating, maintenance and training plans* and *support requirements* generally are developed by the shipbuilder as part of an integrated logistics support package.

Configuration Accounting information is needed to support various configuration management and change control processes applied to the ship *Definition*, the *Associated Technical Products*, and to the *Requirements*. This information is comprised of approval status: hull applicability and product structure information. This latter is most

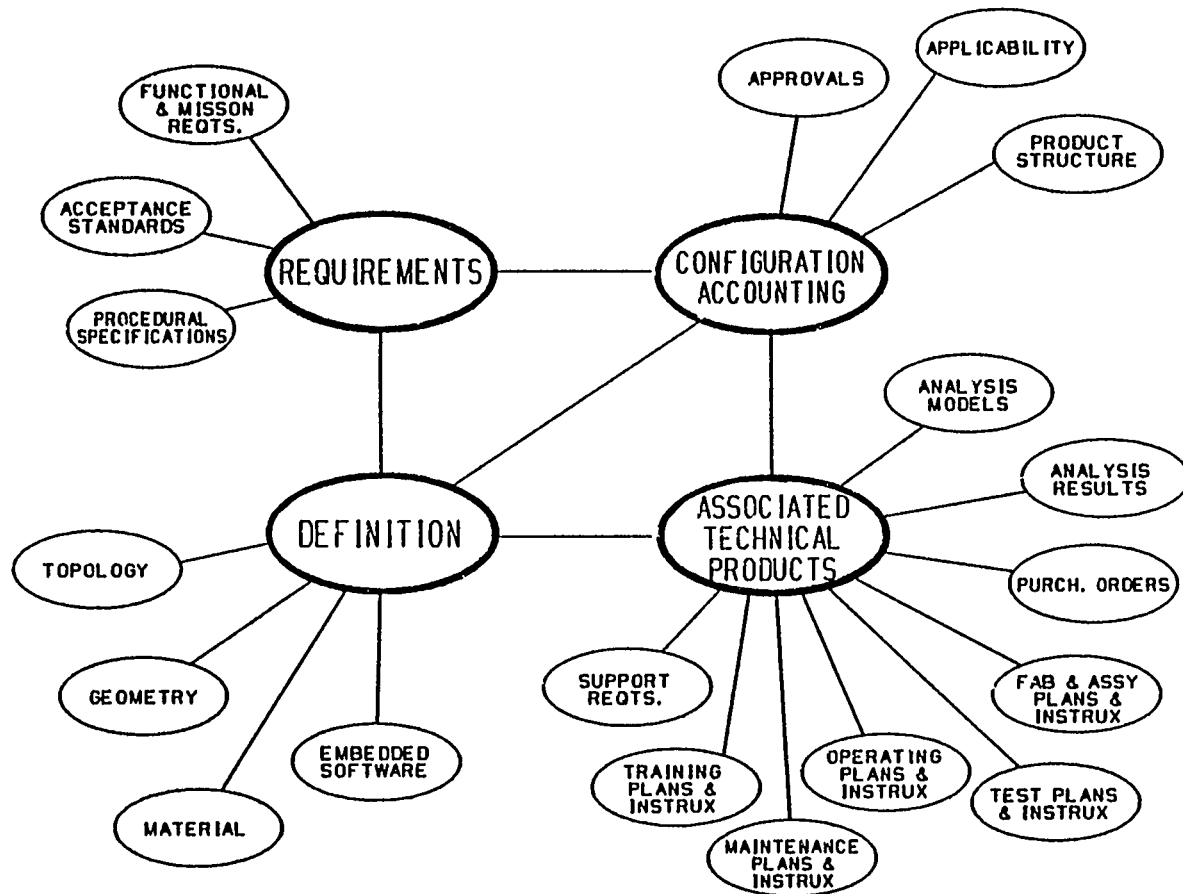


Figure 1 - Information Model Categories

frequently system-oriented ESWBS numbers, but at various stages can be compartment-oriented and/or assembly-oriented numbering systems.

Definition information is the representation of the ship that we want to design, build, operate, or maintain. Definition includes geometry (shape), topology (what pieces are connected to what), and material (what it's made of) data. Because combatant ships these days resemble floating computers which behave differently with different programming, embedded software is included.

All these categories of information are of prime importance to complete one task or another. Analysis reveals, however, that almost every task requires Definition information. This lead NIDDESC to focus on Definition data as the key element. The additional realization that the ship is constantly changing has also forced NIDDESC to include a minimal amount of Configuration Accounting information in their initial scope.

All of these categories of information are developed and many are communicated today via traditional media including drawings and documents. It is clear that the marine industry is in the process of a media-shift from paper-based to computer-based procedures. What is not so clear is that there are many degrees of computerization.

The simplest degree of computerization is "Image Capture." At this level the computer can display a video image of the paper product which can be reproduced or replaced relatively conveniently. Otherwise it has few advantages and some disadvantages compared to traditional media.

The next degree of computerization is the "2-D CAD Drawing." In addition to the advantages of "Image Capture" this degree allows ad hoc changes of scale and content and portrayal of alternate configurations. A trained user is still required to understand the 3-D product being displayed, and even trained viewers frequently develop different mental images based on the same set of drawings.

The next degree of computerization is the "3-D CAD Model." In addition to the advantages of the "2-D CAD Drawing" this degree allows ad hoc changes of the viewpoint and assures that all views represent the same 3-D product. This makes it easier for any user to form a correct mental image of the product and makes interference detection possible.

The next degree of computerization is the "Builder's Definition." In addition to the advantages of the "3-D CAD Model" this degree allows computer checking of component compatibility (no flanged joints to threaded connectors) and association of CAD models to material control systems, weight control systems, etc.

NIDDESC has chosen to operate at the builder's definition degree of computerization. This is the degree that leading builders are utilizing in their detail design and construction systems and which is of the most potential economic benefit for lead-builder follow-builder data transfers. Additionally this is the degree of computerization which the Navy will be able to capture as the basis for

service life support and modernization design. Finally, this degree of computerization can be decomposed to a lower degree easily, whereas the opposite movement is difficult if not impossible.

Implementation of NIDDESC Objectives

NIDDKSC's basic objective is to develop an industry-wide agreement regarding the data to be transferred. Once the data set for transfer has been defined, it is possible to define the format for transfer, develop the transfer software and test the results in a manufacturing environment. The progressive nature of Digital Data Transfer (DDT) implementation can be depicted in three intervals of time:

1. Near-Term Implementation (1 Year),
2. Mid-Range Implementation (2-5 Years), and
3. Long-Range Implementation (5+ Years).

NIDDESC is pursuing data format definition tasks designed to bring results in each time frame. In this way the NIDDESC program can support current ship design efforts and lay the groundwork for future procurements. Each of these time frames requires a unique approach as the CAD systems, data transfer standards and ship construction projects change. An overview of the NIDDESC approach is shown in Table II.

Table II. Overview of NIDDESC Approach

- I. Basic Objective - Identify Data for Transfer
 - A. Analyze Data Flows
 - B. Electrical Systems Data Model
 - C. Catalogs for Distribution Systems
 - D. Combat Systems
 - E. Outfitting & Furnishings
- II. Near-Term (1 Year) Implementation
 - A. Recommended Practices Manual
 - B. MIL-D-28000 Application Protocol for 3-D Pipe
- III. Mid-Range (2-5 Year) Implementation
 - A. IGES Implementation Based on HVAC Model
 - B. IGES Implementation Based on Structural Model
- IV. Long-Range (5+ Year) Implementation
 - A. PDES Inputs for Structure
 - B. PDES Inputs for Distribution Systems
 - C. PDES Logistics Models/Information

The Development of Basic Agreement Tasks will identify the data for transfer. These include the analysis of data flows, ship product models and catalogs for these models.

The Near-Term Implementation Tasks are designed to give nearly immediate enhancements in the ability to transfer CAD data. These tasks make use of current CAD platforms and IGES Application Protocols. Also included is the development of a Recommended Practices Manual.

The Mid-Range Implementation time frame of 2 to 5 years dictates enhancements to present platforms and CAD software. These tasks focus on incremental enhancements to IGES.

The Long-Range Implementation Tasks are designed to take advantage of the next generation of CAD systems. These CAD systems will utilize The Product Definition Exchange Standard (PDES). PDES will include the definition of data at the engineering object level.

BASIC OBJECTIVE - IDENTIFY DATA FOR TRANSFER

The basic objective of the NIDDESC project is the development of an industry-wide agreement regarding the information to be transferred. Information modeling techniques are used by software developers to define data and a framework for understanding that data.

Information Modeling Techniques

At this point, a few words on information modeling techniques will help to provide a context for the discussion that follows. An information model is simply a blueprint for understanding information. It provides a means for unambiguous communication between individuals. An information model defines a common context for the interpretation of information. The modeling process is independent of computer technology.

NIDDESC has developed information models of ship systems using the Nijssen Information Analysis Method (NIAM), (1). A NIAM diagram defines entities and their relationships. Entities can be objects or concepts. They are represented by circles. The second major element in NIAM diagrams are roles. Roles define the relationships between entities. They are represented by boxes that contain verb phrases. In NIAM diagrams the relationships between entities can be read as simple English sentences. This provides another means of representing the model which can be used for verification.

There are several types of constraints in NIAM diagrams that apply to entities and the roles between them. Constraints are the rules of behavior invoked when entering or retrieving data. They guarantee the consistency of the information. Constraints, in combination with entities and roles, provide a complete definition of the database. This definition allows individuals to communicate via the database. It can be used within one computer or as the basis of transferring information between different computers.

A complete information model includes diagrams, English statements derived from the diagrams and a dictionary definition for every entity.

NEAR-TERM (1 YEAR) IMPLEMENTATION

One thrust of the NIDDESC implementation effort is the development of digital data transfer standards for CAD systems equipped with IGES translators. These systems provide real and immediate capabilities within present limitations. In addition, the development of these near-term implementations provides test cases for emerging national standards.

Recommended Practices Manual

This document presents recommended practices for digital data transfer among various government

agencies, ship yards and design agents. Included in the scope is transfer between NAVSEA headquarters, Lead Builder, Follow Builders and Planning Yards. The entire ship life cycle is covered in this analysis; including design, construction, maintenance and overhaul of Navy ships. The manual is based on experience gained from current ship acquisition projects including DDG51 and SEAWOLF.

The manual is divided into two parts. The first part includes a general Introduction of the management of digital design information throughout the ship life cycle. The second part provides specific solutions on the types of data and the transfer mechanisms to be employed. Alternative solutions are provided that are time dependent based on anticipated Improvements in hardware and software capabilities and the implementation of national and international standards. The manual is coordinated with current published or developing standards such as MIL-D-28000. The manual also includes draft ship specifications, Contract Data Requirements List, and contractual inputs for inclusion in future contracts.

IGES Application Protocols

The IGES standard (2) was developed to provide the means of transferring graphic data from one CAD system to another using a universal data file format. The IGES standard is comprised of entities that represent elements commonly found in CAD systems. To date, none of the major CAD systems vendors have provided a full implementation of the IGES standard. However, each has implemented a portion of the standard using the entities that most closely represent the capabilities of their respective systems.

In order to use these IGES translators successfully, it is necessary to limit the product modeling to the subset of entities available on the target CAD systems. Once this subset is defined, it is necessary to prescribe a relationship between the CAD system entities and the product elements that they define. Finally, a test program is necessary wherein the elements of the CAD model are carefully tested with data that is representative of the design data. It is only after this process is complete that the successful transfer of CAD data with IGES entities can be achieved.

The procedure described is often known as an IGES Application Protocol (AP). The development of AP's can require significant resources. If organizations were to develop these procedures independently, there would be a major duplication of effort. In addition, the resulting AP's would be unique. The goal of universal data transfer offered by the IGES standard would be lost. The National Institute of Standards and Technology (NIST) has recognized the need for standard AP's and has developed a guide for their development (3). NIST is working with members of the IGES Organization to develop AP's. As they are developed, AP's will be submitted for inclusion in MIL-D-28000. AP's identify the information requirements of a particular engineering discipline (such as 3-Dimensional Piping) using the

terminology and practices particular to the discipline. AP's include the following elements.

1. Information Models. The first step in the development of an AP is the definition of the data comprising the product model. This model is independent of any CAD system implementation and can be validated by an expert from the application area. Once the model is defined the IGES entities are selected.

2. Format Specification. Along with the information models, it is necessary to develop a usage guide for the selected IGES entities that defines restrictions on the global and parameter data sections of the IGES file.

3. Test Cases. The final portion of the AP includes the protocol test cases. The test cases include test data and a test methodology including procedures and criteria for evaluating the test results.

The NIDDESC project is contributing to the development of Application Protocols in three technical areas, including:

- * 3-Dimensional Piping Model,
- * HVAC Model, and
- * Ship Structural Model.

3-Dimensional Piping Model

The 3-Dimensional Piping IGES Application Protocol (4) being developed by NIDDESC is based on the model developed under the SEAWOLF Digital Data Transfer Program. The SEAWOLF model has been generalized and expanded for this effort. This AP is geared to using IGES constructs and entities to pass enough information to capture the design and permit the fabrication of a piping system. No attempt has been made to pass either preliminary design concepts or life cycle and logistical information. The AP makes use of IGES Version 4.0 with the addition of version 5.0 attribute data. The AP enables the exchange of the following piping entities:

- * Pipes
- * Stave Damping Assemblies
- * Joints
- * Hangers
- * Catalog Parts
- * Components
- * Attachments
- * Product Structures
- * Piping Attributes

Figure 2 presents the NIAM diagram showing the piping parts relationships. The Piping Part entity is represented as a solid circle in the center of the diagram. Solid circles are used to define real world objects. In this case, Pipe, Piping Part, Geometry, etc. are all components of ship piping systems. These components are related in two major ways. The first type of relationship is the subtype relationship. This is shown by a line pointing from the subtype to the supertype such as the relationship between Pipe and Piping Part. All instances of subtype are automatically instances of the supertype and all properties of the supertype are inherited by the subtype. As entity relationships can be read in both directions, the

relationship between Piping Part and Pipe can be read as follows:

*A Pipe is a kind of Piping Part.
A Piping Part may be a Pipe.*

The second type of relationship between entities is the role relationship. This can be illustrated by the Product Structure and Piping Part relationship. A Product Structure is an aggregation of parts for a specific purpose or function. A product structure may be a System, Assembly, Drawing or Pipe Run. In NIAM diagrams, the role relationship is depicted by a rectangular box divided in half. This box contains verb phrases that describe the binary role relationships. In this case the roles can be described as follows:

*A Product Structure may associate any number of Piping Parts.
A Piping Part may be associated by any number of Product Structures.*

The role relationship is subject to various constraints that serve to further define the relationship. One such role restraint is simple uniqueness. This means that the role is unique. This constraint is shown by a double arrow by the role. Uniqueness is paraphrased "only one." A second constraint is simple totality. This means that the relationship between the object and the role must always occur. This constraint is shown by a "V" drawn on the line connecting the role and object. Totality is paraphrased "every." The relationship between Piping Part and Pipe Port demonstrates both the uniqueness and totality constraints. In one direction, no constraints apply:

A Piping Part has any number of Pipe Ports.

However, the converse relationship contains both uniqueness and totality constraints as follows:

Every Pipe Port is of only one Piping Part.

With the rules described above, the relationships of Piping part to the other entities of can be read as follows:

*A Pipe is a kind of Piping Part.
A Component is a kind of Piping Part.
A Piping Part may have any number of Pipe Ports.
Every Pipe port is of only one Piping Part.
Every Piping Part has only one Attribute Set.
Every Attribute Set is of only one Piping Part.
Every Piping Part has only one Geometry.
Every Geometry is of only one Piping Part.
A Piping Part may be attached by any number of Attachments.
Every Attachment attaches only one Piping Part.
A Piping Part may be associated by any number of Product Structures.
A Product Structure may associate any number of Piping Parts*

A NIAM diagram showing Pipe and IGES Relationships is given in Figure 3. Please note this figure was developed to define the Pipe/IGES relationships. Other relationships have not been included for the purpose of clarity.

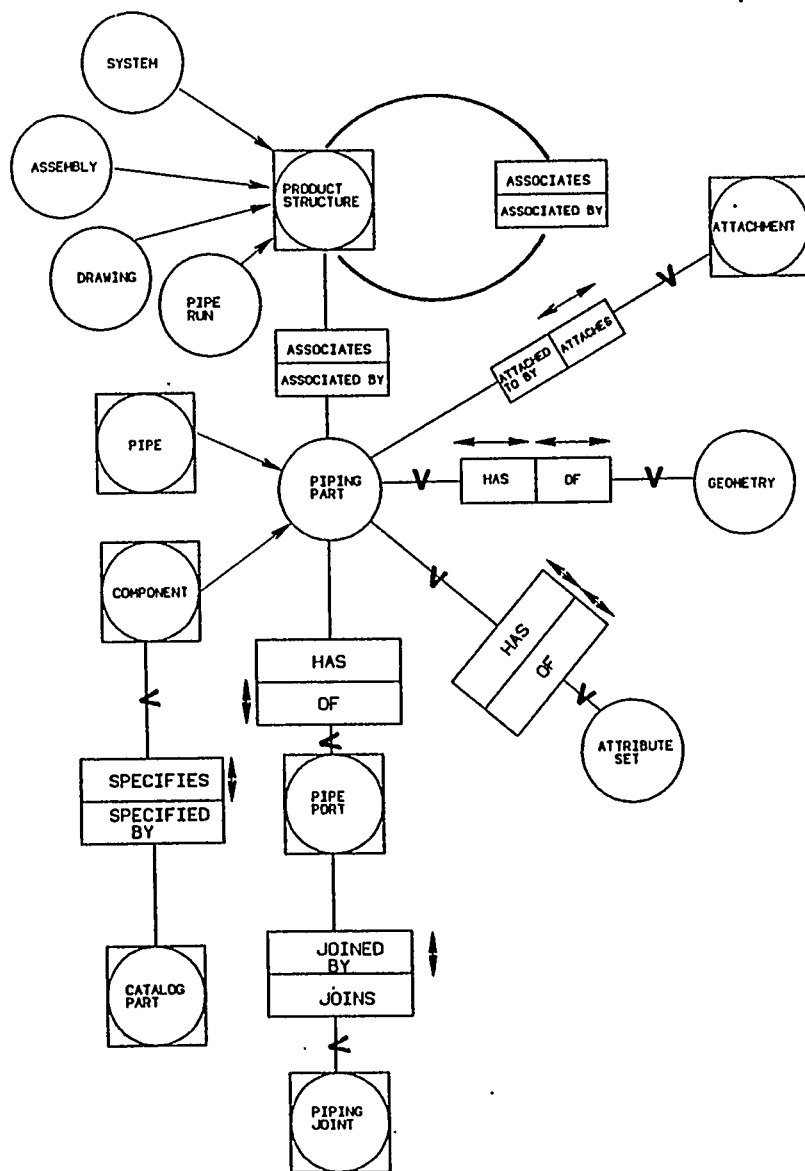


Figure 2 - NIAM Diagram of Piping Part Relationships
(From NIDDESC IGES Pipe Application Protocol)

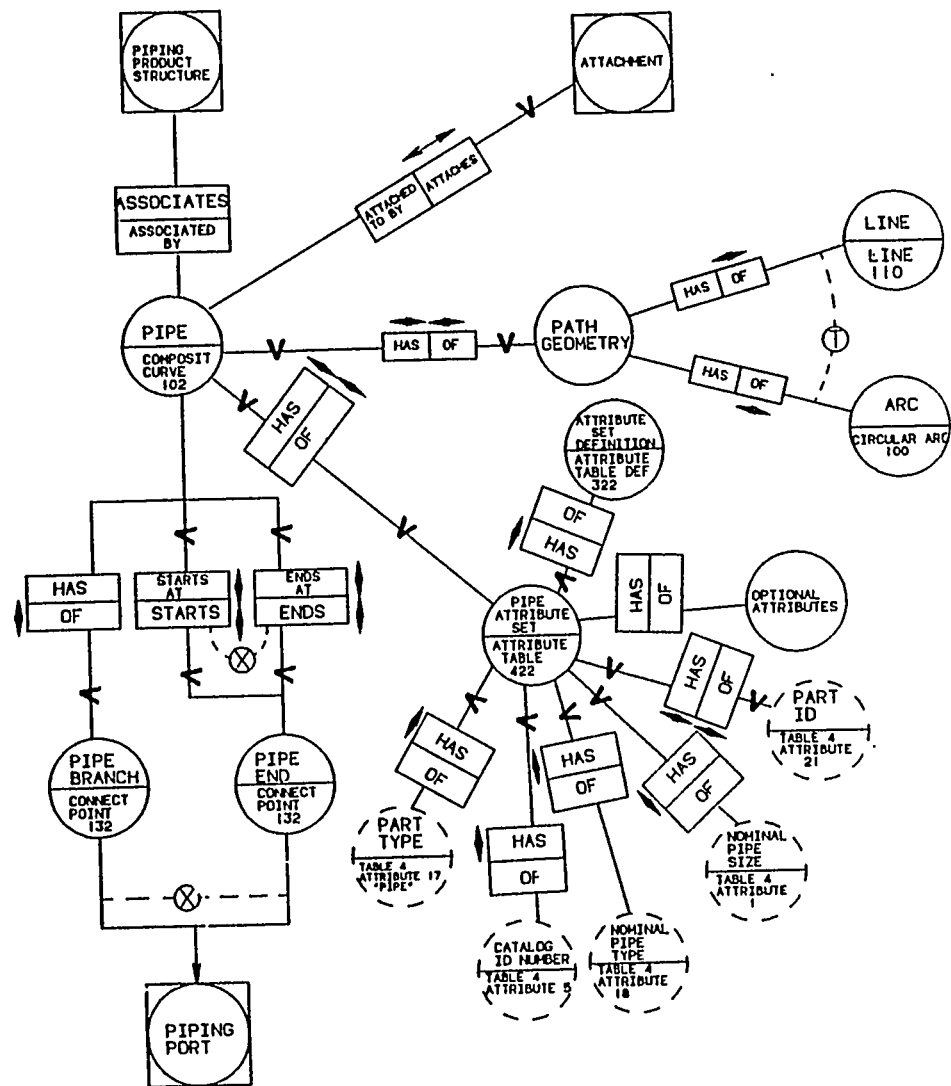


Figure 3 - NIAM Diagram of IGES Implementation for Pipe
(From NIDDESC IGES Pipe Application Protocol)

In Figure 3, the top half of the circle symbol defines the piping elements, the lower half of the symbol defines the IGES entity used to represent the piping element. IGES has no specific entity for pipe, therefore it is necessary to select from the available entities one which will represent pipe. In this case the Composite Curve (Entity 102) was chosen. The use of the Composite Curve Entity is not unique, it is also used to represent piping joints (such as tees and elbows) and pipe stave damping. As the Composite Curve is used to represent several piping elements, it is necessary to differentiate between the applications. This is done through the use of the Attribute Set as follows:

Every Pipe has only one Pipe Attribute Set.

Every Pipe Attribute Set has only one Part Type, only one Catalog ID Number, only one Nominal Pipe Type, only one Nominal Pipe Size, only one Part ID, and only one Attribute Set Definition.

A Pipe Attribute Set may have any number of Optional Attributes.

The Pipe Attribute Set is represented by the IGES Attribute Table (Entity 422, Form 0). The Attribute Set Definition is represented by Table 4 of the IGES Attribute Table Definition (Entity 322, Form 0). In IGES version 4.0, this list contains only 17 attributes. This AP makes use of attributes 18 through 27 which have been approved by the IGES committee and will be included in IGES version 5.0.

The Pipe geometric definitions, also shown in Figure 3, can be described as follows:

Every pipe has only one Path Geometry.

A Path Geometry has only Lines and/or Arcs.

Note the "T" between the Line and Arc objects. This is a subtype total constraint which connects all valid subtypes. From the above discussion, the centerline of a pipe is totally defined by any number of lines (IGES Entity 110) and/or circular arcs (IGES Entity 100).

Note the "X" between the near roles for the Pipe End. This is a role exclusion constraint which indicates that the roles are mutually exclusive. The treatment of pipe ends can be read as follows:

A Pipe may have one or more Pipe Branches.

Every Pipe starts at only one Pipe End.

Every Pipe ends at only one Pipe End.

Every Pipe End either starts a Pipe or ends a Pipe.

The complete AP (4) contains similar diagrams for Component Occurrence, Pipe Hanger, Stave Assembly, Joint, Attachment, Product Structure, Catalog Part, Catalog Part Geometry and External Reference.

HID-RANGE (2-5 YEAR) IMPLEMENTATION

The mid-range implementation time frame of 2 to 5 years dictates enhancements to presently available platforms and CAD software. During this time frame the majority of CAD system users will upgrade, but not completely replace, their present investment. This time frame allows for revisions of the IGCS standard. In order to take full advantage

of IGES standard development, NIDDESC has sent representatives to the quarterly IGES meetings. The goal of this activity is the development of extensions to IGES that will facilitate the transfer of ship product data. This effort has taken direct advantage of the SEAWOLF DDT program for ship 3-Dimensional pipe and the data transfer specification developed for the DDG51 DDT project. The results of this effort will be available for mid-range ship acquisition programs, CALS and other Navy CAD data transfer requirements.

NIDDESC plans to continue these mid-range implementation activities with the following efforts:

- * Participation in the IGES Organization,
- * IGES Changes for HVAC, and
- * IGES Changes for Ship Structure.

LONG-RANGE (5+ YEARS) IMPLEMENTATION

IGES is the data transfer standard presently in use in the CAD industry. It was developed to transfer graphical data entities between different CAD systems. In practice, designers employ these CAD entities to represent physical entities. The relationship between CAD entity and the physical entity is often inferred and does not reside within the computer database. Future CAD systems are being designed to resolve this problem. These CAD systems will possess databases that allow the definition of physical entities. For instance, Figure 3 shows the relationship between piping elements and the IGES entities that represent these elements. In future CAD systems this relationship will be an integral part of the system, transparent to the designer.

The Product Definition Exchange Standard (PDES) is being developed to take advantage of the ability of future CAD systems to define product models. PDES will provide for the transfer of this product data without loss of information or the introduction of ambiguities. To achieve this goal, PDES development requires a three layer architecture including applications layer, logical layer and physical layer. Information models required to communicate between these layers are being developed by experts in several engineering disciplines.

PDES version 1.0 (5) was published in the fall of 1988. It included mechanical piece parts, mechanical assemblies, electrical printed wiring board products, AEC models (including the ship structural model), FEM models and drafting applications. NIDDESC contributed the AEC ship structural model and has since begun the development of a distribution systems model. NIDDESC plans to continue the PDES development effort with the following tasks:

- * Participation in PDES Organization,
- * Reference Model for Ship Structural Systems,
- * Reference Model for Distribution Systems, and
- * Reference Model for Ship Logistics Data.

PDES Ship Structural Model

The NIDDESC Reference Model for Ship Structural Systems (6), was endorsed by the PDES Architecture, Engineering and Construction Committee in October 1988. The goal of this

document was the development of a ship structure information model that allows the transfer of the majority of the ship structure without manual intervention or interpretation of the results. This model has been incorporated into the first draft of the PDES standard, and as such is being reviewed and revised by the members of the PDES Organization. The Ship Structural Systems model defines the ship structural product at the completion of detailed design and lofting. Nesting data has been excluded as it is typically unique to individual ship yards. The ship product model includes the following geometric, topological and property information:

- * Molded Hull Lines;
- * Stiffened Surfaces (shell, bulkheads, decks, etc);
- * Cutouts, Lightening Holes and Penetrations;
- * Weld Data and Bevels;
- * Stiffener Data;
- * Material Definition (thickness, type, material);
- * Brackets, Collar Plates;
- * Stanchions;
- * Units/Assemblies;
- * Foundations; and
- * Rudder.

Definitions. The definition of the ship structural product model is contained in a series of NIAM diagrams showing the relationships between ship structural elements. The relationship between hull, assembly and subassembly is represented in the NIAM diagram shown in Figure 4. The elements shown have the following definitions:

- * Hull: Collection of Systems which comprise a ship.
- * System: Functionally related group of elements.
- * Structural System: Collection of structural parts used to divide and support other Systems.
- * Unit Assembly: Collection of parts and/or Sub-Assemblies in a logical or physical grouping.
- * Sub-Assembly: Collection of parts and/or other Sub-Assemblies in a logical or physical grouping.
- * Part: Unique structural element or component consumed during the production process.
- * Material: Substance making up a part including description of material and properties.
- * Path Segment: Bounded portion of a molded curve beginning and ending at nodes.

Relationships. These elements have the following principal relationships as shown in the figure:

- Every hull is made up of one or more Systems.*
- A Structural System is a kind of System.*
- Every Structural System is made up of one or more Unit Assemblies.*
- A Sub-Assembly is a kind of Unit Assembly.*
- A Sub-Assembly may be made up of Sub-Assemblies and/or Parts.*
- Every Part must be of exactly one Sub-Assembly.*
- Every Part must be either a Plate Part, Shape Part or Library Part.*

Every Part must be Identified by only one Part ID, created at only one Date/Time and made of only one Material.

A Material may be used for any number of Parts.

In this network, it can be seen that the structure of the ship hull is comprised of plate, shape and library parts. The model defines the relationships of each of these parts. For the purpose of brevity, the following discussion will be limited to shape parts. The complete model defines relationships of plate and library parts to a similar level of detail.

Figure 5 presents a NIAM diagram showing structural shape relationships. Structural shapes attach to a surface or plate along a straight or curved line. They have standard or non-standard cross sections. They may be twisted. They are intercostal or continuous. They are bounded by surfaces, plates or other shapes. Shapes have end cuts which can take on a wide variety of configurations. The following relationships can be seen from the figure:

Every Shape Part must start with only one End Cut.

Every Shape Part must end with only one End cut.

A Shape Part is defined by any number of Path Segments.

A Shape Part has any number of Shape part Edges.

Every Shape part is oriented by one or more Shape Orientations.

Every Shape Part is Identified by only one Shape Reference Point.

Every Shape part starts with only one Shape Clearance and ends with only one Shape Clearance.

Every Shape Part is offset by only one Shape Surface Offset.

Every Shape Part is identified with only one Cross Section.

A Shape Part is marked by any number of N/C Marks.

A Shape Part is joined by any number of Nodal Joints.

Every Shape Part is identified with only one Shape Part Type.

The complete model (6) contains descriptions of ship geometry and topology, parts (including plate, shape and library), joints and openings.

PDES Distribution Systems Model

In addition to the Ship Structural Model, NIDDESC is developing a Distribution Systems Model for the PDES standard. Like the Ship Structural Model, this is being developed in conjunction with the PDES AEC Committee. The Distribution Systems Model defines engineering systems whose function is to distribute fluids or energy including, 3-dimensional piping, electrical and HVAC systems. The developers of the model have a primary orientation to shipboard systems, however, the content and structure of the information defining these products are transferable across industries. In this way the marine community, through NIDDESC, is making a contribution toward the general goal of CAD integration through the development of international standards. The model is focused on the definition of elements which

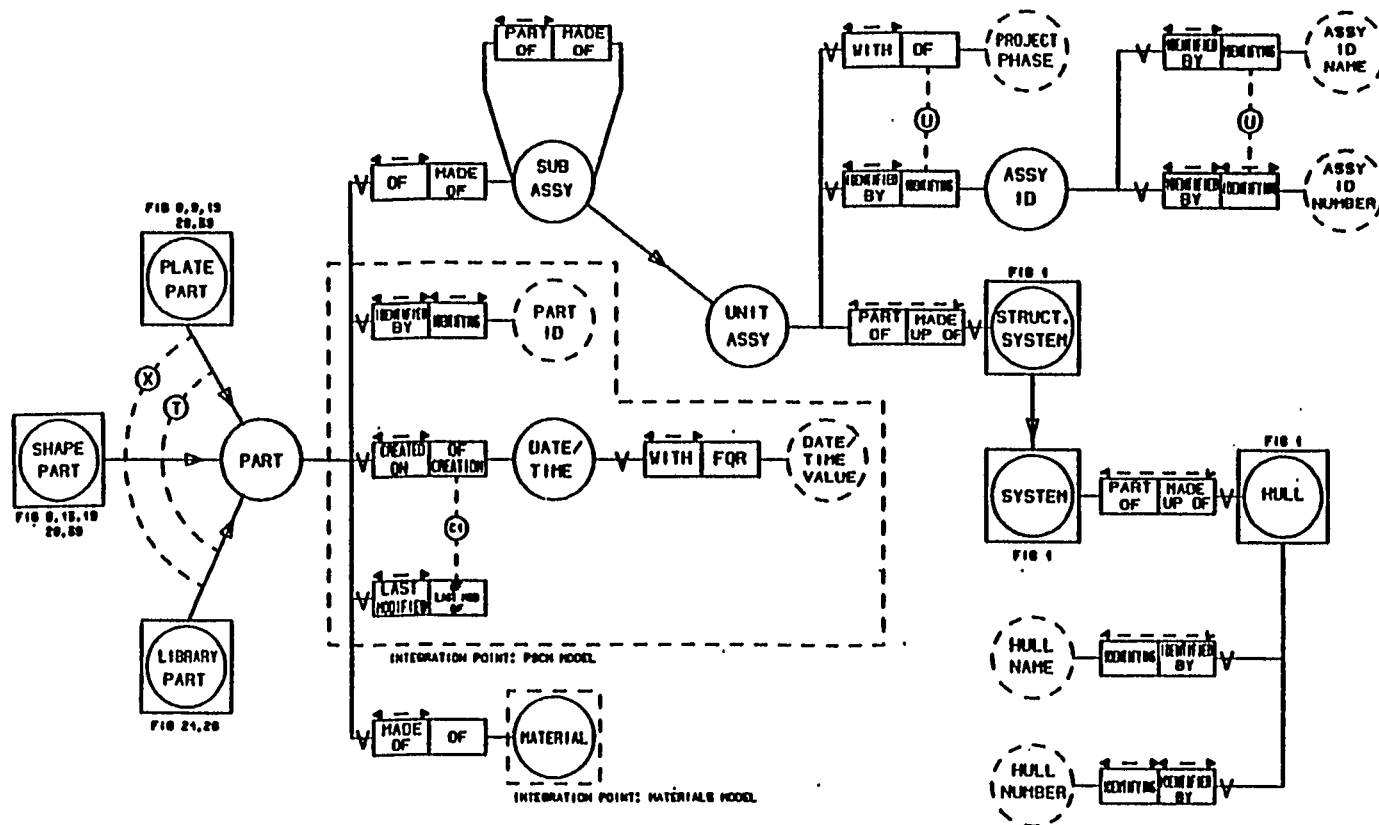


Figure 4 - NIAM Diagram of Hull/Assembly/Part Relationships
(From NIDDESC Ship Structural Model)

Figure 5 - NIAM Diagram of Structural Shape Relationships
(From NIDDESC Ship Structural Model)

comprise the distribution system including shape, topology and geometry. The life cycle focus is on the detailed design phase and the development of production data.

Many organizations are contributing to this effort by reviewing and commenting on the contents of this model. As a result it is being continually revised. The figures that follow represent the state of the model as it was developed in April 1989. This model is scheduled to be submitted to the PDES organization in October 1989. In the following discussion a general overview of the model will be presented. The complete model, in its latest form, can be found in Reference [7].

Definitions. Figure 6 shows the hierarchy of systems and parts in the Distribution System Model. In this diagram all part classes are subtypes of the System Part. The concept of inheritance is used so that attributes and other detailed information are conveyed to subtypes from the parent supertype. For instance, the Piping System Part must have one or more interface ports because it is a subtype of the Distribution System Part. The following definitions apply:

- *Distribution System Parts: Parts of an engineering system that distributes fluids or energy within the ship.
- * Devices: A part of several systems that needs not have interface ports. Devices tend to be more complex than Distribution System Parts. Devices may occur in more than one system.
- * Instrument A Device used for monitoring and/or control within the system.
- * Equipment A complex Device that, can belong to more than one system (e.g. pump, compressor or heat exchanger).

Relationships. The principal relationships shown in the figure can be stated as follows:

An Engineering System Part is a kind of System Part,

Every Engineering System Part must be either a Mechanical System Part, a Distribution System Part, or a Device.

Every Distribution System Part connects at one or more Interface Ports.

Every Distribution System Part must be either a Piping System Part, an HVAC System Part or an Electrical System Part.

Every Device must be either an Instrument or Equipment.

A Device may connect at any number of Interface Ports.

In the complete model, Piping, HVAC and Electrical Parts are further broken down into their respective part types. Figure 7 shows the Part/Catalog Relationships. Catalogs of parts are used extensively in describing ship systems. This figure is a generalization of the concepts which will be applied to all specific parts. Important concepts here are the relationships between Catalog Reference Part and Specific Part and the different Attribute Sets.

In short, a Part can be explicitly defined or referenced from a catalog of standard parts. If a Part is explicitly defined, then it has an Explicit

Part Attribute Set which contains, among other things, explicit part geometry. If a part is referenced from a standard parts catalog, then it is described by a Catalog Reference Part Attribute Set.

CONCLUSION

NIDDESC is an unqualified success. Three years ago the Navy and the marine industry were non-players in the digital data exchange standards world and their needs were being ignored. For example, draft versions of PDES at that time did not support the concept of a volume bounded by surfaces such as a ship compartment. Today, through NIDDESC, the Navy and the marine industry is an acknowledged leader in digital data exchange.

- * The NIDDESC Structural Model is part of the PDES First Working Draft and Its international equivalent ISO/STEP.
- * The NIDDESC Distribution Systems model is well on the way to incorporation in PDES.
- * The NIDDESC 3-D Piping Application Protocol has been found to support the needs of the process plant industry as well as the marine industry. It will be incorporated in MIL-D-28000 during 1989.
- * Many change requests originated by NIDDESC participants have been incorporated in IGES Version 4.0 or are being incorporated in IGES Version 5.0.
- * NIDDESC has established a track record of producing top-quality products on time and schedules promised.

There are many reasons for this transformation:

- * The technical qualifications and can-do attitude of the participants.
- * The teamwork displayed by NIDDESC members from different companies and government activities while working toward common goals. Their cooperation has been in the finest traditions of NSRP and REAPS cooperative efforts.
- * The establishment of formal POA&Ms to structure and focus NIDDESC activities.
- * Corporate willingness to absorb part of the cost of NIDDESC operation and corporate tolerance for what was frequently an uncertain funding situation.
- * Navy sponsors' willingness to support a project aimed at a general benefit.
- * The utilization of information modeling to obtain explicit and lasting agreement on the information to be transferred.

The authors are pleased and gratified to be associated with NIDDESC. We have the feeling that at the end of our careers, we will look back and say, "NIDDESC was an effort that really made a difference. "

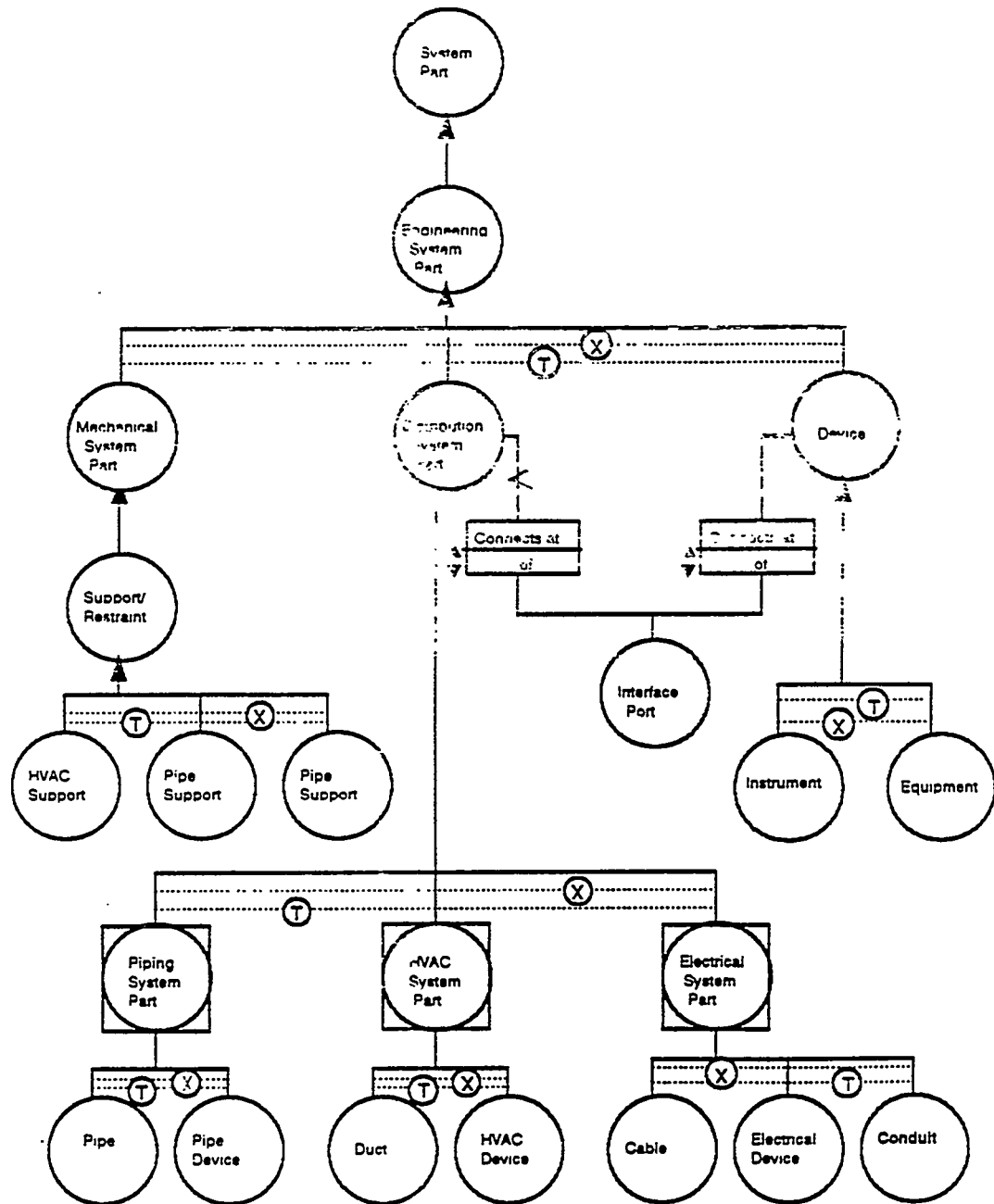


Figure 6 - NIAM Diagram of Part Hierarchy
(From NIDDESC PDES Distribution Systems Model)

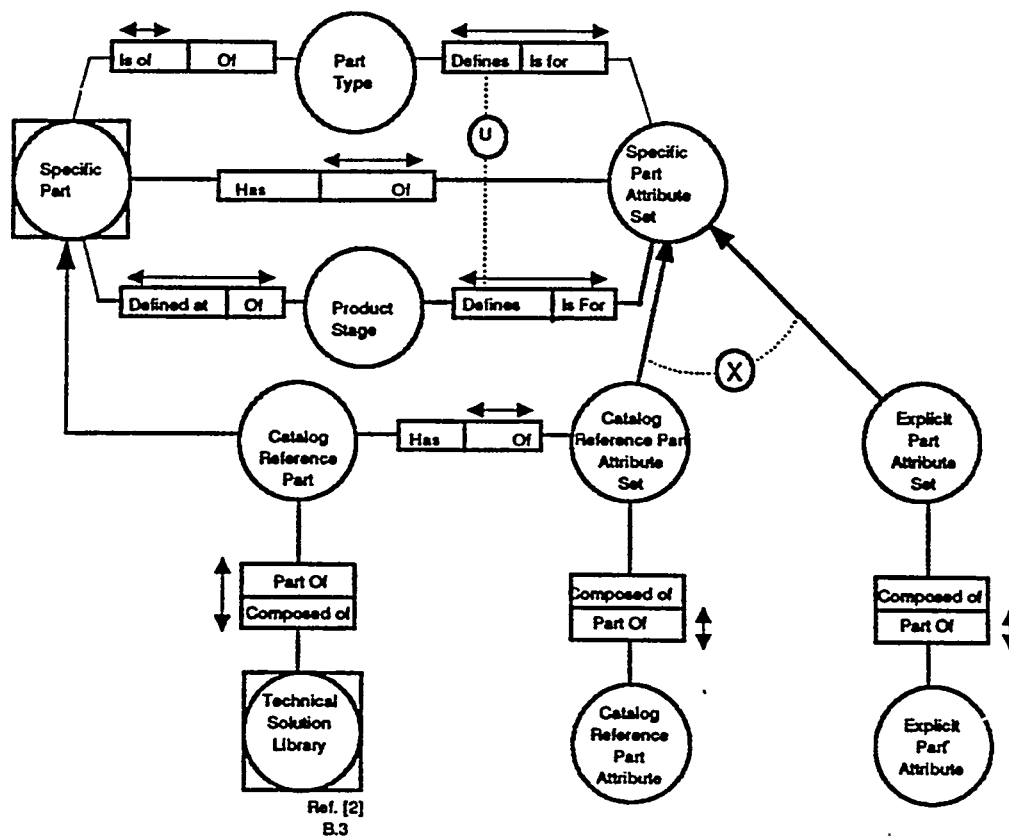


Figure 7 - NIAM Diagram of Part/Catalog Relationship
(From NIDDESC PDES Distribution Systems Model)

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No. 14

Liability for Hazardous Wastes Produced During the Course of Ship Repair

John L. Wittenborn, Visitor and William M. Guerry, Visitor,
Collier, Shannon, Rill & Scott, Washington, D.C.

ABSTRACT

Many common ship repair tasks result in the production of quantities of various hazardous wastes. These wastes, regardless of volume, present difficult burdens for shipyards and the U.S. Navy. Under federal environmental laws, the responsibility for handling hazardous wastes and the liability for their ultimate disposal rests with the person or persons who create the wastes and who arrange for their disposal. Often times, however, the responsibility and liability for handling and disposing of these wastes is unclear. This is especially true when naval ships are repaired in contractor facilities and wastes are produced by the activities of ships' force, contractor personnel or some combination of the two. Further complicating the web of liability is the divergent source of the wastes. Some wastes are produced as a direct result of required maintenance work on ship systems. Other wastes may be produced in the yard by activities which are largely discretionary with the contractor. Ultimately, these wastes from all sources must be identified, packaged, stored, treated, transported and disposed. Potential future liability may arise at each step in this process.

This article reviews briefly the structure and function of two principal federal hazardous waste statutes and explains how their myriad complex responsibilities and

liabilities are applied in the context of a typical ship repair. 1 /

SCOPE OF THE PROBLEM

Numerous hazardous wastes may and often are produced during the course of ship repair work. These can include (1) solvents used for engine repair, metal parts cleaning or painting; (2) acids or caustics used for boiler cleaning or line flushing; (3) spent abrasive blast containing quantities of toxic pigments; (4) sludges from fuel tanks or bilges; and (5) coolants or anticorrosive agents used in diesel engines or hydraulic systems. This list is far from exclusive. SUPSHIP Portsmouth has identified 43 kinds of hazardous waste typically produced during ship repair work. 2 / of course, not all of these wastes will "be produced in every ship repair. However, the production of any hazardous waste automatically triggers the application of several federal and state statutory and regulatory requirements, violations of which can lead to sizeable, civil and even criminal penalties. In addition, releases of such wastes, through spillage, in transportation

1 / Most states also have enacted statutes which will prescribe duties and liability for parties involved in hazardous waste handling and disposal. Readers are cautioned to consider the application of such laws in ascertaining their responsibility for hazardous wastes.

2 / Proposed Revised NAVSEA Standard Work Item No. 077-01, submitted to the General Committee of the NAVSEA Standard Specification for Ship Repair and Alteration Committee (SSRAC), June 12, 1989.

accidents, or at the disposal site even years after ultimate disposal, can lead to cleanup liability.

The principal federal statute which establishes the duties for hazardous waste handling and disposal is the Resource Conservation and Recovery Act (RCRA). ^{3/} The statute which creates liability for releases of such wastes into the environment is the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). ^{4/} These statutes apply to the U.S. Navy as well as to private shipyards. ^{5/}

RESOURCE CONSERVATION AND RECOVERY ACT

Enacted in 1976 as an amendment to the Solid Waste Disposal Act, RCRA was Congress' first attempt to regulate in a comprehensive fashion the handling and disposal of hazardous wastes. The Act is now well known for its "cradle to grave" regulatory program which requires detailed record keeping and careful tracking of hazardous wastes from the moment of production to the point of ultimate disposal. The key to making this system work lies with the person who produces the waste -- the generator.

Who is the Generator?

Although section 3002 of RCRA sets forth in general terms the duties of hazardous waste generator, but; the term itself and the details of those responsibilities are set forth in the U.S. Environmental Protection Agency's (EPA's) implementing regulations. Those regulations define the term "generator" as "any person, by site, whose act or

^{3/} 42 U.S.C. §6901 et seq. (1982).

^{4/} 42 U.S.C. §9601 et seq. (1982).

^{5/} Under both RCRA and CERCLA, Congress has enacted comprehensive federal facility provisions which, in general terms, waive sovereign immunity defenses for all substantive and procedural requirements under the law. Thus, federal agencies and employees are liable to the same extent for violations of the hazardous waste laws as any other person, including liability for cleanup costs under CERCLA.

process produces hazardous waste identified or listed in Part 61 of this chapter or whose act first causes hazardous waste to become subject to regulation." ^{6/} By referring explicitly to the site of generation, the definition requires a company with multiple facilities evaluate and comply with the generator requirements individually for each such facility. However, the duties of a generator apply to the person or persons who produce the waste rather than simply the facility at which the waste is produced. When multiple persons are involved in the production of a hazardous waste, EPA interprets the definition broadly to apply the generator duties and liabilities jointly to all of the generator parties.

Duties of the Generator

The first duty of any generator is to determine whether any of its wastes are hazardous wastes under the criteria prescribed by RCRA. To be a hazardous waste, a material must first be a "solid waste." EPA's current regulations define this term to include say "discarded material" that is not otherwise subject to a regulatory exclusion or a specific variance granted by EPA. ^{7/} "Discarded material" is in turn defined as any material that is abandoned, recycled or "inherently waste-like". A material is abandoned if it is disposed of, burned or incinerated, or accumulated, stored or treated prior to or in lieu of abandonment. A material can be a solid waste if it is recycled in a manner constituting disposal, burned for energy recovery, reclaimed, or speculatively accumulated. Materials are not solid wastes when recycled in a manner involving direct use or reuse as ingredients feedstocks in a production process or as an effective substitute for a commercial product, or which are recycled in a closed loop production process.

Once a material is found to be a solid waste, it must be determined whether it is also a hazardous waste. Unless excluded or exempted under EPA's regulations, a solid

^{6/} 40 C.F.R. §260.10 (1988).

^{7/} 40 C.F.R. §261.2(a), 40 Fed. Reg. 664 (Jan. 4, 1985).

waste will also be a "hazardous waste" if it is either (1) specifically listed by EPA or (2) it exhibits any of the four characteristics of a hazardous waste set forth in EPA's regulations and discussed below. By regulation, EPA has specifically excluded certain wastes from the definition "hazardous wastes." 8 / In addition, EPA has provided other limited regulatory exemptions for particular circumstances. For example, hazardous sludges which are generated in a product or raw material storage tank, transport vessel, pipeline or manufacturing process unit are exempt from the definition of "hazardous waste." 9/

Pursuant to statutory authority, EPA has established by regulation three lists of hazardous wastes: (1) hazardous waste from nonspecific sources (F-listed wastes); (2) hazardous wastes from specific sources (K-listed wastes); and (3) discarded commercial chemical products, off specification products, containers and spill residues thereof (U- or P-listed wastes). In addition to these specifically listed wastes, wastes which meet one of four hazardous characteristics: ignitability, corrosivity, reactivity, or toxicity, are also covered by RCRA. Specific definitions of each of these characteristics are contained in EPA's regulations at 40 C.F.R. 55261.21, .22, .23, and .24. Finally, a material will be subject to regulation under RCRA if it is a combination or mixture of a listed hazardous waste and any other solid waste.

Once the generator has determined that his waste is a hazardous waste, he must obtain an EPA identification number before the waste can be transported, treated, stored or disposed. Moreover, persons who receive wastes from the generator for shipping, treatment, storage or disposal must have obtained EPA identification

8 / The list of exclusions includes house household wastes, utility wastes from coal combustion, waste from the extraction and processing of ores, certain chromium-bearing wastes, etc. 40 C.F.R. §261.4.

21 40 C.F.R. 5261.4(c).

numbers. 10 / The generator also has the responsibility of preparing the Uniform Hazardous Waste Manifest, a control and transport document that accompanies the hazardous waste at all times. Before shipment, the generator must insure that the waste is properly described as required by Department of Transportation (DOT) regulations, and properly packaged and labeled for shipment. Next, the generator must ensure that the name and EPA identification numbers of each authorized transporter and the treatment, storage and disposal facility are listed on the Manifest. Finally, the generator must ensure that a return copy of the Manifest is received indicating that the waste was accepted by the designated treatment, storage or disposed (TSD) facility and keep a copy of the final signed Manifest for a period of three years.

As amended in 1984, RCRA now requires the generator to certify on the Manifest that he has in place a program to reduce the volume and toxicity of such wastes to the degree determined by him to be economically practicable and that the proposed treatment or disposal method will effectively minimize the present and future threat to human health and the environment. For wastes which will be disposed of on the land, the generator must also certify that such wastes meet the applicable treatment standard which will allow land disposal to occur.

Before shipping wastes off-site, the regulations allow the generator to accumulate up to 55 gallons of hazardous wastes at the point of generation, as long as the containers are properly marked. In addition, the generator is allowed to store hazardous wastes on its site prior to shipment for a period of up to 90 days, without first obtaining a permit and meeting all of the requirements for permitted storage facilities.

Obviously, the proper identification of the generator is crucial in the overall RCRA hazardous waste regulatory scheme. Not only do the duties and responsibilities follow the identification of the generator, but, certain functions, such as on site storage for up to 90 days, are only allowed to the generator. The

10 / 40 C.F.R. 262.12(c).

penalties which accompany failure to properly perform these generator duties can be substantial. For violations of the regulations, including on-site storage beyond 90 days, RCRA provides for civil penalties of up to \$25,000 per day. For knowing or willful violations, criminal penalties, including fines and imprisonment, are available. When more than one party is considered to be a generator, these penalties can be applied to all "co-generators" of the wastes. Because many of the wastes produced during ship repair are co-generated, the allocation of the duties and liability under RCRA is of great importance.

CERCLA

While RCRA establishes a cradle-to-grave regulator program for present hazardous waste activities, the Comprehensive Environmental Response, Compensation and Liability Act (usually referred to as "CERCLA" or "Superfund") establishes a comprehensive response program for threats to environment caused by both present and Past hazardous waste activities.

CERCLA broadly authorizes EPA to undertake short-term "removal" and/or long-term "remedial" action in response to a "release" (spilling, leaking, pumping, etc.) or a "substantial" of a release" of any (1) hazardous substance; or (2) pollutant or contaminant under circumstances where the pollutant or contaminant "may" present an imminent and substantial danger. A typical "removal action" would be a response to a tank truck spill in which EPA siphons all spilled materials and hauls away a few inches of contaminated soil. Removal action costs can run from a few thousand to two million dollars, and in certain cases, even more. ^{11/} A typical "remedial action" would involve a more thorough cleanup of a Waste disposal site such as a landfill which is contaminating the groundwater and which might require extensive construction activity,

including possibly a groundwater pumping and treating program. Remedial actions at Superfund sites can cost hundreds of millions of dollars. With elaborate planning, design, construction and operation activities.

To ensure that EPA (or a State) is reimbursed for Costs associated with a remedial or removal action, CERCLA authorizes EPA (or a State) to bring actions against "responsible parties", who are in varying degrees related to the site at which there is a release or a threatened release. The types of parties who may be liable for costs associated with a response action are specified in section 107(a) of CERCLA as follows:

- (1) Present and past "owners or operators" of the site at which there is a release or threatened release;
- (2) parties who transported wastes to the site at which there is a release or threatened release ("transporters"); and
- (3) parties (usually referred to "generators") who by contract, agreement or otherwise "arranged for" the wastes to be transported, disposed or treated.

Significantly, all of these "responsible parties" are strictly liable for costs associated with remedial or removal actions. This means that a party will still be liable even if he can demonstrate that he used all "due care and met all the legal requirements (such as selecting a properly licensed hauler to take the waste to a properly licensed landfill) unless he can establish one of three affirmative defenses set forth in section 107(b) of CERCLA. That section provides a defense to Superfund liability only for a party (defendant) who can demonstrate by a Preponderance of the evidence that the release or threat of a release was caused solely by: (i) an act of God; (ii) an act of war; or (iii) an act or omission of a third-party other than an employee or agent of the defendant and other than a third-party whose act or omission occurs in connection with a direct or

^{11/} By statute, removal actions are limited in scope to one year and \$2.0 million unless certain conditions are found and special authorization obtained by EPA CERCLA section 104(c)(1); 42 U.S.C. §9604(c) (1).

indirect contractual relationship with the defendant. to establish the "third-party" affirmative defense, the defendant must demonstrate by a Preponderance of the evidence that he: (i) exercised due care with respect to the hazardous substance concerned; and (ii) that he took precautions against foreseeable acts or omissions of any such third persons. Courts have very narrowly construed these three affirmative defenses to Superfund liability and generally only allow a third-party defense when there is no contractual relationship between the third-party and the defendant. U.S. v. Monsanto, 858 F.2d 160, 169 (8th Cir. 1988). ¹²

Under CERCLA, a responsible party may be held liable in the first instance for the entire cost of cleaning up a site instead of being liable only for the "share" of the release for which he is actually responsible. A responsible party in turn can bring a contribution claim under section 113(f) against any other person "who is liable or potentially liable under section 107." In resolving contribution claims, a court may allocate response costs among liable parties using such equitable factors as the court determines appropriate. often EPA will pursue only a single responsible party or a small group of responsible parties for the total costs associated with a removal or remedial action. These responsible parties must then try to recoup the costs of EPA's cleanup by pursuing independent contribution claims against other responsible parties.

RCRA/CERCLA OVERLAP

Although CERCLA liability is distinct from RCRA duties, the two programs can and often do overlap. Frequently, to identify CERCLA responsible parties for a release

¹² / In 1986, Congress clarified the "contractual relationship" concept as it applies to landowners. Now, a party who acquires by deed or contract, a facility upon which hazardous substances have been placed or disposed may still be an "innocent landowner" if he took reasonable precautions prior to the purchase to determine whether the site was contaminated. See CERCLA section 101(35)(A); 42 U.S.C. §9611(35)(A).

requiring remedial action, EPA will use information on the RCRA Uniform Hazardous Waste Manifest forms to find the generators and transporters of the waste. Thus, the EPA generator number on the RCRA hazardous waste manifest becomes the fingerprint that EPA will use to identify future responsible parties under CERCLA.

APPLICATION To SHIP REPAIR OPERATIONS

RCRA Compliance

In the context of a typical ship repair operation, both the Navy and the contractor are likely to be considered generators of hazardous wastes. The contractor would clearly be the generator for those wastes which his personnel create through the use of materials, such as hazardous solvents, which are discretionary with the contractor. In addition, the contractor would be liable as a generator for wastes which first become subject to regulation because of the acts of his employees. Similarly, the U.S. Navy would be the generator for wastes produced exclusively by the ships' force either on the ship or in the contractor's facility. In such cases, it is the Navy's own operations which first cause these wastes to become subject to RCRA regulation. Thus, the Navy is clearly the "person" whose act first produces the hazardous waste. ¹³ Moreover, the Navy, and not the contractor, produces, owns and possesses the material on its ships; therefore, only the Navy could have the intent to "discard" its own hazardous materials and thereby first cause them to become subject to RCRA regulations. A shipyard contractor which simply removes, handles or disposes of hazardous waste produced by the Navy is not a RCRA generator of those wastes because the contractor neither produces the hazardous wastes nor first causes them to become subject to regulation.

¹³ / 40 C.F.R. §260.10 defines "person" to mean an individual, trust, firm, joint stock company, federal agency, corporation (including government corporation), partnership, association, state, municipality, commission, political subdivision of a state, or any interstate body. (Emphasis added).

There is a category of waste however, for which both the Navy and the contractor would be considered co-generators. Co-generated wastes include comingled wastes such as bilge water which was contaminated by actions of both the Navy and the contractor, or materials such as diesel engine coolant fluid which becomes a hazardous waste when removed from the ship's systems pursuant to necessary repair work. For these wastes, both the Navy and the contractor would share generator liability because their independent actions each contributed to the contamination, or because their actions in combination first caused the material to become subject to regulation -- the Navy by ordering the repair and the contractor by performing the repair and removing the fluid.

Under EPA's policy, the Navy and the contractor are co-generators of these wastes and are equally liable for their proper disposition. The question of who must perform the duties of the generator is one to be resolved by contract between the Navy and the shipyard and not by EPA's regulations. Regardless of who performs the generator duties, EPA will look to either party or both parties if the requirements of the regulations are not performed or not performed properly. Thus, both the Navy and the shipyard must ensure that RCRA compliance is scrupulously maintained.

Once the RCRA issues are resolved and wastes have been properly identified, packaged and shipped for disposal, potential liability does not end. In some cases, despite the best intentions of both parties and despite adherence to the RCRA requirements, hazardous waste problems will still arise if wastes are accidentally spilled or even if wastes are released into the environment years after proper disposal. In either of these cases, the private shipyard and the Navy may be faced with cleanup liability under CERCLA.

CERCLA Liability

As described above, CERCLA liability may arise whenever EPA, a State or another private party undertakes a removal or remedial action in response to a release or threatened release of hazardous substances. In the context of ship repair, this release or threatened

release may apply to wastes generated during the course of ship repair which are released from: (a) a Navy ship docked at a private shipyard facility; (b) a private shipyard facility; and (c) a treatment, storage or disposal facility or during transportation.

Section 107(a) of CERCLA imposes liability on "the owner and operator of a vessel or a facility" from which there is a release or threatened release of hazardous substances. Thus, if there is a release from a Navy vessel which is docked at a private shipyard facility, the Navy, as the owner or operator of the "vessel" from which there was a release, would certainly be a responsible party. 14/

The shipyard contractor would also be considered a responsible party if the contractor "operated" or "controlled" repair procedures on the Navy vessel that caused or contributed to the release of the hazardous substances. Even if the shipyard contractor did not directly contribute to the release on the Navy vessel, the contractor might still be considered a responsible party because CERCLA defines "facility" broadly to include any place where hazardous substances have "come to be located." Therefore, as the owner and operator of the shipyard facility at which the release occurred, the contractor could be a responsible party for releases from the ship even if he did not contribute to or cause that release. 15\

The contractor could also claim that he was not liable for the

14 / Section 120 of CERCLA expressly provides that "each department, agency and instrumentality of the United States . . . shall be subject to, and comply with, this Act in the same manner and to the same extent, both procedurally and substantively, as any nongovernmental entity, including liability under section 107 of this Act. Thus, the Navy would not have a "sovereign immunity" defense to CERCLA liability.

15 / In such a case, the contractor could also argue that a release from the Navy "vessel" is not a release from his "facility" since these two terms are given equal and separate status under section 107(a).

release because the release was due to an unforeseeable act or omission of a third party (the Navy). However, in order to make a successful "third-party" defense, the shipyard contractor would have to demonstrate that the release from the Navy vessel did not occur "in connection with" the contract between the shipyard and the Navy and that the shipyard exercised due care and took precautions against the Navy's foreseeable acts or omissions causing the release.

If a release of hazardous wastes generated during the course of ship repair on a Navy vessel occurs on shore at the shipyard facility the shipyard contractor would clearly be a responsible party as the owner and operator of the facility. The Navy would also be considered a responsible party if it could be determined that the Navy had "arranged for" the treatment, transportation, or disposal of the hazardous wastes released.

Courts have broadly interpreted the "arranged for" language in section 107(a) as imparting liability to any party with the authority to control the handling and disposal of hazardous substances, even if that party did not actually exercise its authority or did not own or possess those substances. United States v. Northeastern Pharmaceutical and Chemical Company, 810 F.2d 726 (8th Cir. 1987). Under common law theories, if a shipyard contractor was handling hazardous substances generated during the course of ship repair work pursuant to a contract or agreement with the Navy, a court could construe the Navy as having the authority to control the handling and disposal of those substances. In such a case, the Navy would be held to be a CERCLA responsible party over the wastes even though it was not the RCRA generator of those wastes.

The full reach of CERCLA liability is illustrated by a recent case in which pesticide manufacturers were held liable under section 107(a)'s "arranged for" language for releases which occurred at the facility of a pesticide formulator that processed the manufacturers' pesticides to produce a commercial product. The court found that the manufacturers contracted with the formulator to mix its materials for eventual sale knowing that in the process certain

hazardous wastes were likely to be produced. Because the formulator produced the waste for the manufacturers' "benefit and at their direction," the court found a sufficient degree of control to hold the manufacturers liable under CERCLA for the cleanup of those releases. U.S. v. Aceto Agricultural Chemicals Corp., Nos. 88-1580 to 1583 (8th Cir. April 25, 1989). Because of the contractual relationship between the Navy and the shipyard, liability for releases of wastes which are derived directly from ship systems or which are otherwise under the control of the Navy will likely be attributable to the Navy as well as the contractor even if the release is actually caused by the contractor.

When a release of hazardous substances generated during the course of ship repair operations occurs off-site either (i) on the highway during the transportation of the wastes or (ii) at a treatment, storage or disposal facility, the owner or operator of the transportation vehicle, or of the treatment, storage or disposal facility, would clearly be a responsible party. In addition, the shipyard contractor and/or the Navy would also be a responsible party for those wastes which it had arranged by contract, agreement, or otherwise to be transported, treated or disposed. Once again, the liability of the shipyard contractor and/or the Navy would depend on the authority or control those parties exercised or could have exercised in the selection of the transporter, or the treatment, storage or disposal facility.

Neither the shipyard contractor nor the Navy could escape CERCLA liability by arguing that they did not select or even know about the site at which their wastes were disposed. Courts have consistently interpreted CERCLA as imposing strict liability on the party who arranges for the disposal or treatment of hazardous wastes regardless of whether that party selects the site at which the wastes are subsequently dumped. United States v. Ward, 618 F. Supp. 884, 895 (D.C.N.C. 1985). The courts recognize that a less stringent interpretation "would allow generators to escape liability under CERCLA by closing their eyes to the method in which their hazardous wastes were disposed of." *Id.*

Under these broad constructions, even though the shipyard contractor, as agent of the Navy, makes the actual transportation and disposal arrangements, the Navy cannot escape the potential liability which may accrue if those wastes are subsequently released into the environment. The allocation of this liability between the contractor and the Navy may be resolved by contract between the two parties or will be decided by the court using "equitable factors" in a subsequent action for contribution.

CONCLUSION

The web of liability and responsibility under RCRA and CERCLA is both broad and complex. The reach of these statutes is deliberately far, with the intent of maximizing the number of parties to whom EPA can look for enforcement and liability. However, the statutes are not clear with regard to the allocation of responsibility and liability among the various parties within EPA's web. In the context of hazardous wastes produced during ship repair activity in private shipyards, these legal responsibilities must be clearly resolved by contract to insure that all requirements of the law are met in a full and fair manner. Although such contractual provisions will not affect either party's liability to EPA or a State under RCRA or CERCLA, they will enable the parties to fairly allocate between themselves both the duties and costs associated with the handling, treatment, and proper disposal of these wastes.



A Study of the Causes of Man-Hour Variance of Naval Shipyard Work Standards

Howard M. Bunch, Member, UMTRI, University of Michigan, Ann Arbor, MI

Abstract:

This paper is a presentation of the results of a study conducted at a U.S. Navy shipyard during 1987 concerning the relationship between engineering standards and the variances that were occurring in production budget and charged manhours. The 10 engineering standards having the greatest manhour variances were examined. These standards, as a group, accounted for about 62 percent of the manhour variance that was reported during the first nine months of 1987. The study indicated that, with one exception, all of the standards were "generic" in their application, i.e., they can be applied over a wide range of job orders. The study also concluded that engineered standards are only partially responsible for the production variance.

Introduction

In 1985-86 there was an intensive management analysis of U.S. Navy shipyard operations with the objective of making specific recommendations that would strengthen the operations of these activities. The report indicated that inflated return costs lead to misuse of shipyard resources and increased costs. A sample of 38 key operations showed an average variance of 41 percent over the standards. One of the specific elements identified as a contributor to this problem was "estimates derivation".⁴

In 1987 the author, while on temporary assignment at Philadelphia Naval Shipyard, was asked to investigate the role of engineered (or pre-determined) time standards as a contributor to the workload variances that were occurring at that yard. The request was partially the result of the criticisms levied by the Navy shipyard operations evaluation, cited above; however, Philadelphia Naval Shipyard's management had independently arrived at a desire to investigate the link-up between cost variance and engineered standards, especially as it might affect their planned implementation of zone-logic construction concepts.⁶

This paper is a summary presentation of the investigation that occurred, and includes the conclusions and recommendations that were a part of the report. Finally, there is an update of what has actually occurred relative to the recommendations in the 18 months since the investigation was completed.

Engineered standards

At Philadelphia Naval Shipyard the engineered standards are developed from the "Allowed" or "Standard time (T), which is the combination of "Work-Factor" time (W), plus an allowance factor for personal, unavoidable delay, and fatigue (A):

$$T = W.A \quad (1)$$

"'Work-Factor' time represents the output attainment capability of averaged experienced operators, working with good skill and good effort and without interruptions or delays; it is the common denominator and index of output capability (expected attainment) for the world population of average experience operators." ⁷

"Personal, fatigue and delay allowances is the time allowed a worker to compensate for attending to personal needs, for fatigue, and for delay occurring due to conditions beyond his control. This time is additive to the normal time required to accomplish a job. The inclusion of this allowance is common practice in the development of a labor standard. . . ."⁸ The allowance factor will typically have a range of 1.02 to 1.30.

The standard time (T) is further adjusted to allow for non-productive or standby time. This final calculation is performed by the planner and estimator, and results in the "Standard Manhour Allowance" (SMH), or sometimes called the "Planning Standard" (PS). At Philadelphia Naval Shipyard the term is called "Engineered Standard"; this expression was the one used in this paper. Thus the Engineered Standard (ES) is the time actually assigned to a particular task, and includes the standard time (T), plus allowances for non-process (or non-productive) time (NT):

$$ES = T.NT \quad (2)$$

The Study Approach

The study plan was comprised of three phases:

1. analysis of the yard's use of engineered standards during 1987, isolating those that had the largest occurrence of manhour variance (both overall and by production group);

2. development of a cause-effect diagram that described the factors that can cause production variance to occur; and evaluating the effect of engineered standards on the over-all work variance, and

3. suggestion of an action plan for reducing production variance attributed to engineered standards.

Analysis of Engineered Standards

As shown in Table 1, a total of 2,173,988 manhours was budgeted for assigned work on 22,334 key operations during the study period; there was, however, a total of 2,846,717 manhours expended to accomplish the assigned tasks. The difference (or variance) between the two amounts is 672,729 manhours, or a performance factor of 1.31.9

The key operations were then linked to the engineered standards used to develop the budgets for each key operation; the standards were next arrayed on the basis of the amount of variance occurring on key operations associated with each standard. The Top 10 standards, in terms of amount of variance, are shown in descending order in Table 1. Six standards accounted for over 50 percent of the variance; yet they were involved in only 26 percent of the key operations (5,882 versus 22,334). The average key operation was budgeted at 153 manhours, but required 210 manhours to complete. The resulting performance factor was 1.38.

Table 1 continues the listing through the "Top 10"; the group accounted for nearly 62 percent of the total reported variance, even though it accounted for only 38 percent of the total key operations (8437 versus 22334). The average key operation for the group was budgeted at 129 manhours, but required 178 manhours: the performance factor was 1.38. It should be noted, also, that the "Top 10" standards were with one exception, generic in nature, i.e., they were designed to provide guidance for a broad functional work activity. e.g., structural welding.

---ENGINEERED STANDARD---		# of Line Items	-----MANHOURS-----			Percent of Total Variance		Performance Factor	Manhours Budget/#Items	Manhours Actual/#Items
Number	Name		Allowed	Expended	Variance	Line	Cumulative			
056-801	Piping--Remover, Fabricate, Class P1, P2, P3	1,868	426,794	536,765	109,971	16.35%	16.35%	1.26	228.48	287.35
100-303	Structural Field Installation Aluminum and Steel	671	79,836	163,737	83,901	12.47%	28.82%	2.05	118.98	244.02
026-903	Welding, Structural/Production	894	100,263	155,217	54,954	8.17%	36.99%	1.55	112.15	173.62
304-301	Electrical Electronic & Fire Control Cable & Equipment Installation	1,943	188,043	221,616	33,573	4.99%	41.98%	1.18	96.78	114.06
505-349	Welding, Pipe Class P1 & P2 (Field)	492	68,648	98,174	29,526	4.39%	46.37%	1.43	139.53	199.54
587-914	Catapult Launching Engine Components, Shipboard RPR	14	35,657	61,192	25,535	3.80%	50.16%	1.72	2546.93	4370.86
0038-306	Valves, GTV, LD&HI, Press & Welded-In, Insp Rpr & Test	147	22,612	46,701	24,089	3.58%	53.74%	2.07	153.82	317.69
0100-305	Structural Foundation, AI & Steel Assemble & Install	678	39,050	61,590	22,540	3.35%	57.09%	1.58	57.60	90.84
0100-306	Access Opening, Remove and Install	688	46,596	62,325	15,729	2.34%	59.43%	1.34	67.73	90.59
0804-352	Rigger Service Surface Craft	1,042	77,131	91,206	14,075	2.09%	61.52%	1.18	74.02	87.53
---Total, "Top 6"---		5,882	889,241	1,236,701	337,460	50.16%	50.16%	1.38	152.88	210.25
---Total, "Top 10"---		8,437	1,084,630	1,498,523	413,893	61.52%	61.52%	1.38	128.56	177.61
---All Standards Beyond "Top 10"---		13,897	1,089,358	1,348,194	258,836	38.48%	100.00%	1.24	78.39	97.01
---GRAND TOTALS---		22,334	2,173,988	2,846,717	672,729	100.00%		1.31	97.34	127.46

TABLE 1. THE "TOP 10" ENGINEERED STANDARDS HAVING THE GREATEST MANHOUR VARIANCE AT PHILADELPHIA NAVAL SHIPYARD-NINE MONTHS OF 1977.

The exception was standard #587-914, dealing with catapult launching equipment repair. But, even in this case the key operation budgets were so large (approximately 2500 manhours) that it too could be considered as a generic standard.

The rest of the engineered standards beyond the "Top 10" accounted for about 38 percent of the total reported variance. The performance factor for this group was 1.24, and the average work order was budgeted at 76 manhours, but required 97 manhours.

The relationships between key operation size and the performance factors for the engineered standards are shown in Figures 1 and 2. A least-squares fit of the data for nine of the top ten standards¹⁰ indicates a slight upward movement in the performance factor for those engineered standards with larger budgeted manhours per work order, depicted in Figure 1. The wide scatter in the data (confirmed by $R = .12$) suggests, however, that budgeted manhours is not the major variable affecting the performance factor. Or, at least, there is a weak linear relationship between the two variables.

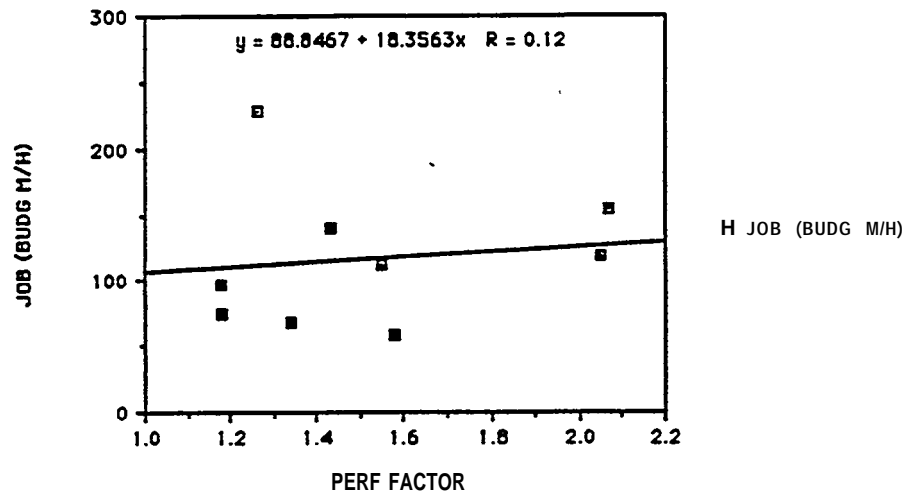


FIGURE 1 KEY OPERATIONS AVERAGE JOB BUDGET MANHOURS FOR VARIOUS ENGINEERED STANDARDS. PHILADELPHIA NAVAL SHIPYARD-NINE MONTHS OF 1977.

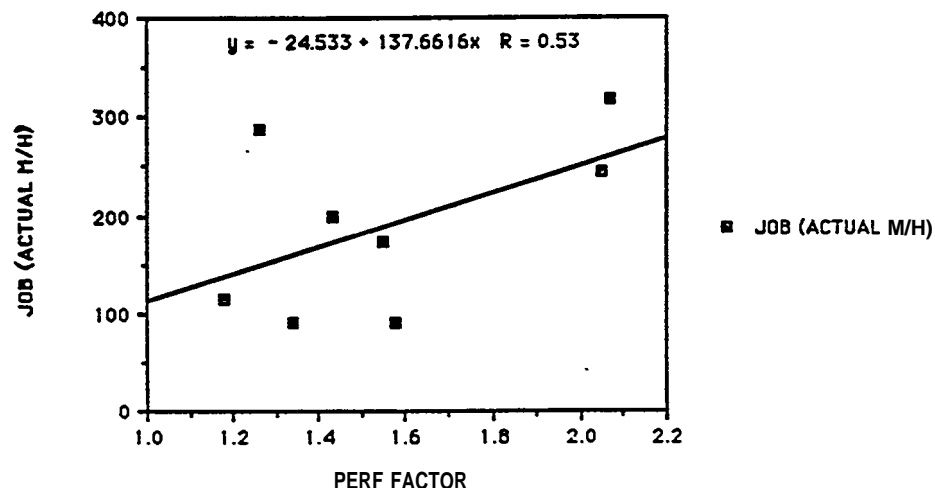


FIGURE II. KEY OPERATIONS AVERAGE APPLIED MANHOURS FOR VARIOUS ENGINEERED STANDARDS. PHILADELPHIA NAVAL SHIPYARD-NINE MONTHS OF 1977.

Figure 2 plots the relationship between the performance factor and the actual manhours required to complete the key operation. In this case, there is a significant increase in the performance factor as the amount of manhours required to complete the job increases. Too, the strength of the relationship increases, as evidenced by the higher "R" statistic.

There were three conclusions from this portion of the analysis:

1. Engineered Standards that produce larger manhour allocations for a work assignment tend to result in larger performance factors.

2. A common characteristic of those standard producing the greatest manhour variance (i.e., the "Top 10") was that they were generic in scope, i.e., the standards consisted of general descriptions of tasks and associated manhours, and the planner was required to construct the specific work assignment budget by referring to the general data tables in the standard; and

3. Consistent with the situation in many cause-effect analyses, a significant amount of the total production manhour variance could be linked to a few engineered standards. (This was an example of the "significant few versus the the trivial many" phenomena.)

The study was expanded to examine the relationship between the performance factors of specific production unit key operations and their link-up with engineered standards.

Figure III presents the key operations performance factors during the study period for each of the production units; the range was from a low of 1.10 (for the production services group) to a high of 1.58 (for the mechanical machinery group). The figure shows that the production groups can be divided into two classifications: those groups whose performance factor is below the average (the Production Services Group, Pipe Boiler Group, and the Electrical Group), and the groups whose performance is above the average (Mechanical Machinery Group and the Structural Group).

An attempt was then made to see if there was any clear link-up between the below- and above-average clusters, and their involvement in the "top-10" standards. To do this, an examination was made of standards most associated with high variances in each of the production shops of each group. The "Top 5" standards in each shop were examined. Table 2 shows the results of this analysis, with the groups with above-average performance factor (as shown in Table 1) being displayed above the dashed line. The analysis gave mixed results. The data indicated that the

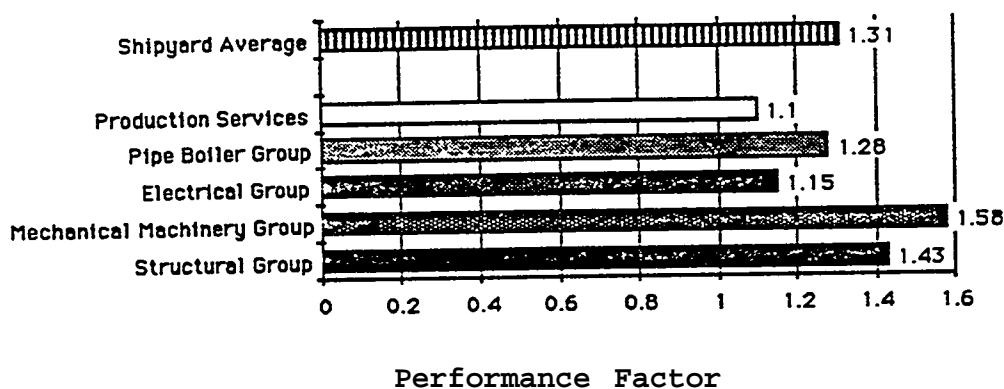


FIGURE III. PRODUCTION PERFORMANCE FACTOR FOR PRODUCTION GROUPS.

---Production Shop---	-----Top 10 Standards-----				-----Total, All Standards-----				Part Factor w/o Top 10
	Budget	Actual	Variance	Performance Factor	Budget	Actual	Variance	Performance Factor	
	-----Manhours-----				-----Manhours-----				
Structural Group	325983	532952	206969	1.63	698349	996557	298208	1.43	1.25
Mechanical/Machinery Group	57902	107422	49520	1.86	248355	392753	144398	1.58	1.50
Electrical Group	164611	189155	24544	1.15	243168	278695	35527	1.15	1.14
Pipe/Boiler Group	414168	534134	119966	1.29	521510	671466	149956	1.29	1.28
Production Services Group	82826	97535	14709	1.18	462604	507238	44634	1.10	1.08
Totals, All Groups	1045490	1461198	415708	1.40	2173986	2846709	672723	1.31	1.23

Source: PHSY

TABLE 2. RELATIONSHIP OF 'TOP 10 STANDARDS UPON PRODUCTION GROUP PERFORMANCE.

Structural Group's greatest amount of variance was associated with those standards in the shipyard's "Top 10". The other above-average production group, Mechanical and Machinery Group, did not have the same association. Only about 23 percent of its variance was associated with the "Top 10".

The same inconsistency occurred in the below-average groups. The Pipe and Boiler Group had an extremely strong link-up with the "Top 10"; the Electrical Group had moderate link-up, and the Production Service Group had about 18 percent link-up.

Table 2 does reveal, however, how much the performance factor for the groups, and for the entire shipyard, would be reduced if the variance for the Top 10 standards were eliminated. For the entire shipyard the improvement factor would be reduced from 1.31 (indicated in Table 1) to 1.23 an improvement of eight points, or about a 415 thousand manhour reduction.

This portion of the analysis resulted in the following conclusions:

1. Eliminating the variance in the "Top 10" standards would result in significant reductions in manhour overruns;
2. While there are major differences in the performance factors for the production groups, the variances associated with the "Top 10" standards affect all of the production groups. However, the Structural Group would show the greatest improvement if the variance for the "Top 10" were eliminated.

Analysis of Cause-Effect Relationship for Production Variance

Cause-and-effect diagrams are drawn to illustrate the various causes affecting a result by sorting out and relating the causes. The cause-and-effect diagram, sometimes called an "Ishikawa diagram" after the Japanese professor that first used the concept, can be applied to any problem. It was applied to this problem because of the need to better understand all of the factors that can affect production variance.

Figure IV is a cause-and-effect diagram that shows some of the causes that can effect production variance. During preparation of the chart several interviews were held with production, planning, and industrial engineering personnel at Philadelphia Naval Shipyard.¹¹ The figure includes the comments of those interviewed as to the more significant reasons for production variance.

In making the chart the following steps were followed:

- Step 1: Decided upon the effect characteristic to be evaluated. In this case, the effect statement was: "the difference in allowed versus expended manhour budgets."
- Step 2: Wrote the effect characteristic on the right side of the chart. Then drew a broad arrow from the left side to the right side.
- Step 3: Wrote the main factors causing the effect, directing a branch effort for each factor to the main arrow. The causal factors were grouped into four main categories: equipment (machines and tools), procedures (processing actions), policies (management or organizational guidelines), and people (training, attitude, behavior).

step 4: Wrote in the detailed factors relating to the main factors. The subdivisions of the detailed "factors are shown as connecting twigs.

Step 5: Indicated with an asterisk the detailed factors that are in some way related to engineered standards.

Figure IV dramatically illustrates the variety of factors affecting production variance in the shipyard. Importantly, any one of the Factors could, in any specific situation, be the major cause for a project overrun (or production variance).

An asterisk (*) is attached to those causes that are related to engineered standards. Importantly, standards-related causes for production variance account for only a few of the total possibilities. On the Policies branch of the diagram, for example, "unclear instructions" can lead to an engineered standard that is incorrect, or might be improperly applied.

The other instances where cause-linkup occurs with an engineered standard are in the Procedures

branch of the diagram. The causes are "wrong assumptions," "not clear," "calculations incorrect," and "antiquated procedures." With respect to the last item, it was estimated in one interview that at least 40 percent of the standards are antiquated at any moment in time.¹² Additionally a percentage of the procedures are not covered by engineered standards: one estimate was that about 70-80 percent of the production manhour budgets are developed from engineered or estimated standards.^{13 14}

At the beginning of the interviews most interviewees expressed the opinion that engineered standards were major causes of production variance. When the interviewees were shown a cause-effect diagram, similar to that displayed in Figure IV, they then acknowledged that other causes were probably more significant, and that the standards-variance link-up was not as strong as originally surmised. One especially knowledgeable interviewee, a person who has been involved in several shipyard reviews of production variance, felt that "poor communication" among people was the greatest single contributor to production variance.

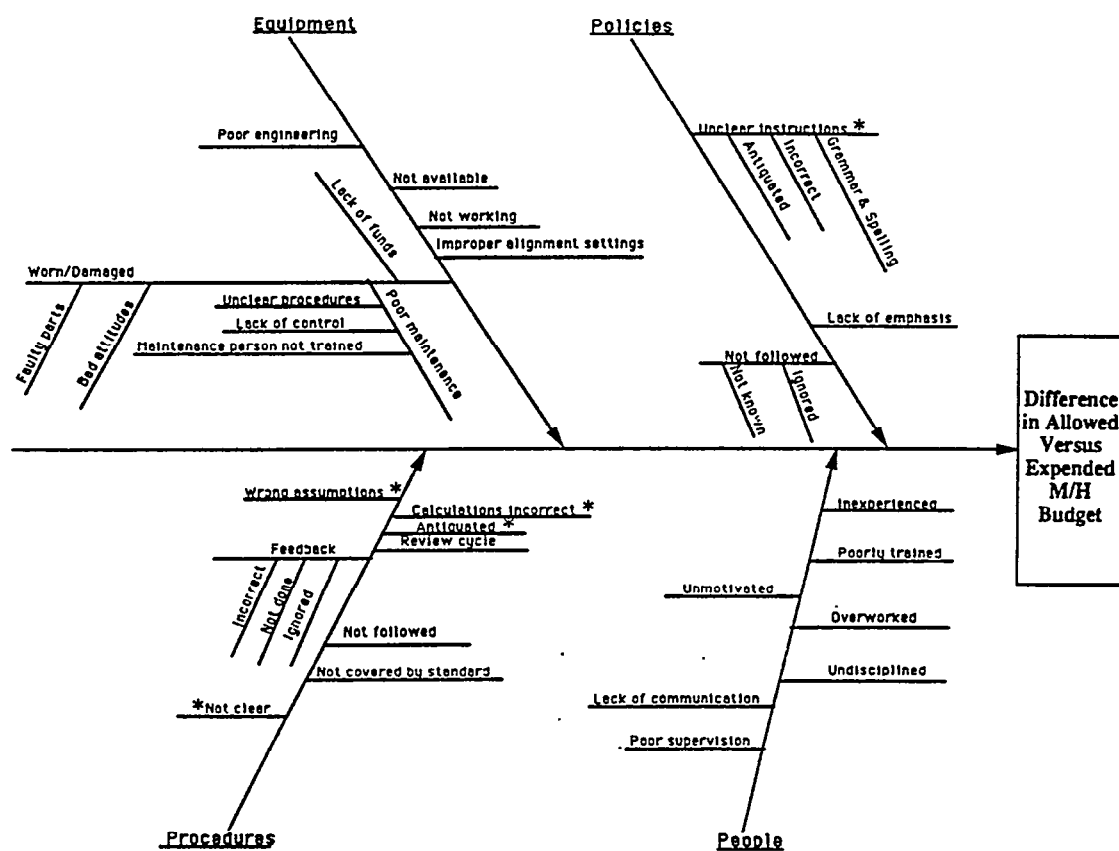


FIGURE IV. CAUSE-EFFECT DIAGRAM OF DIFFERENCES IN ALLOWED VERSUS EXPENDED PRODUCTION MANHOURS AT PHILADELPHIA NAVAL SHIPYARD.

The conclusions of this phase of the analysis were:

1. The causes for production manhour variance are numerous, and those related to engineered standards are in the minority.
2. Antiquation is the major deficiency of engineered standards relative to production variance. About 40 percent of the standards are antiquated relative to current practice, at any specific point in time.
3. Causes linked to engineered standards are not as significant a factor in production variance as is generally surmised by some shipyard management.

Action Plan for Reducing Production Variance Attributed to Engineered Standards

It was decided to focus attention on reducing the variance associated with the "Top 10" standards, listed in Table 1, shown earlier.

The decision was made by Philadelphia Shipyard management to adjust their priorities of updating specific engineered standards; the standards listed in the "Top 10" were moved up in the time schedule for reconsideration. Table 3 describes the changes in priority that were made. The table also shows the status of those commitments for change as of June 1, 1989--some 22 months after the decision to proceed.

As a result of the investigation, and recommendations, the shipyard did take action to effect improvements in the relationship of engineered standards to production variance. While the study also highlighted the fact that engineered standards are not the major cause of production variance, the significance of the standards-variance relationship was sufficiently strong to warrant proceeding with an improvement effort. Importantly, the investigation gave guidance as to those standards which should be given the greatest priority in being reevaluated. 15

--ENGINEERED STANDARD--		PRIORITY ADJUSTMENTS MADE IN 1987	STATUS A/O JUNE, 1989
Number	Name		
056-801	Piping--Remover, Fabricate, Class P1, P2, P3	Was being reevaluated at time of study. Release was set for 12/87.	Superseded by #0056-349. New standard issued in 1/89
100-303	Structural Field Installation Aluminum and Steel	Moved up to #25 on priority list. Not on list previously. Scheduled to start work before 12/87	Superseded by 0100-349. New standard issued in 11/88.
026-903	Welding, Structural/Production	Was being reevaluated at time of study. Release was set for 9/87	Superseded by 0026-348. New standard issued in 12/88
304-301	Electrical Electronic & Fire Control Cable & Equipment Installation	Was being reevaluated at time of study. Release was set for 8/87	Revised and updated Change issued in 9/88
0505-349	Welding, Pipe Class P1 & P2 (Field)	Moved up to #6 on priority list. Previously had been #34 on list.	Revised and updated to 0505=349A Change issued in 1/88
587-914	Catapult Launching Engine Components, Shipboard RPR	Release projected for 10/87. Moved up in priority.	no change
0038-306	Valves, GTV, LC ⁺ H1, Press & Welded-In, Insp Rpr & Test	Moved up to #9 on priority list. Previously had been #13 on list.	Revised and updated to 0038-306A Change issued in 8/88
0100-305	Structural Foundation, AI & Steel Assemble & Install	Listed as #29 on priority list. No change in status.	Superseded by 0100-349 New standard issued in 2/89
0100-306	Access Opening, Remove and Install	Moved up to #12 on priority list. Previously had been #30 on list.	no change
0904-352	Rigger Service Surface Craft	Moved up to #10 on priority list. Previously had been #28 on list.	Superseded by 0904-349 New standard issued 2/89

TABLE 3. CHANGES MADE IN THE SCHEDULE FOR REEVALUATION OF THE "TOP 10" ENGINEERED STANDARDS AFTER BEING IDENTIFIED TO SHIPYARD MANAGEMENT.

As can be seen in examination of Table 3, several of the "Top 10" standards were evaluated and put into the shipyard's system in 1988. It is expected that it will be at least two years before sufficient data is available to determine whether production variance reductions have occurred as a result of these reevaluations. Current management is of the opinion, however, that reductions will occur. Additionally, the management is now consistently giving high priority for reevaluation to any standard that is shown to have links to those key operations that have high production variance.¹⁷

Acknowledgements

The author is grateful to the Philadelphia Naval Shipyard organization for its willingness to cooperate in the project, and for its continuing openness in responding to questions during the research effort. Without such cooperation the effort would have been impossible to accomplish.

It is important to note that the views and analyses expressed are the opinions of the author, and are not necessarily those of Philadelphia Naval Shipyard, or any of its personnel.

References

Captain Donald A. Stoufer; Kehoe, Joseph; and Purdy, William, "Management Analysis of the Navy Industrial Fund Program: Shipyard Review Report," Contract NO0600-84-C-4259, June, 1986.

2 "Variance" was defined as the difference between allocated (or budget) manhours and applied (or charged) manhours. The same definition applies in this paper.

3 Ibid pg. OPS-5

4 Ibid pg. OPS-5

5 "Engineered time standards" describes the time assigned to a particular task, which represents how long it will actually take to perform the work. It involves the use of time measurement procedure for determining a standard. The steps taken are (1) a systematic analysis of the actions for performing a given job, (2) measurements are made of the actions, and (3) computations are made to determine the total effect (or cost) of the actions upon the system.

6 Personal conversations during July and August, 1987. with Captain H. P. Willimon, Jr., USN, Planning Officer, Philadelphia Naval Shipyard...

7. Joseph H. Quick, "A Universal Standard for Work Measurement", Science Management Corporation, 1977.

8. Personal, Fatigue, and Delay Allowances Philadelphia Naval Shipyard Document, Undated.

⁹The performance factor is the quotient of actual manhours divided by budgeted manhours.

¹⁰Engineered Standard #587-914, "Catapult Launching Engine Components, Shipboard RPR," was omitted from this analysis because of its unique statistical profile. The sizes of work orders performed under this standard were approximately 15-30 times greater than for the remainder of the standards.

¹¹Interviews were held during the period August 1-12, 1987. Interviewed persons included W. Hemphill, Owen Moran, W. Stepler, J. Miller, and A. Cates, Code 380; N. Battista and D. Helker, Code 2030. All interviewed personnel were civilian employees of Philadelphia Naval Shipyard.

¹² Ibid

¹³ Ibid

¹⁴With the introduction of zone technology at Philadelphia Naval Shipyard, the percentage of manhours budgets derived from standards has diminished, and as of June, 1989 was running about 60 percent (Source: telephone conversation with Mr. T. O'Donnell, PNSY, July, 1989.)

¹⁵Telephone interview with Mr. T. O'Donnell, Head, Methods and Standards Branch, Production Engineering Division, PNSY, July, 1989.

¹⁶Ironically, reports were already being issued on a quarterly basis in the Philadelphia Naval Shipyard reporting system (PNSY Report #PCL05-A) that showed the relationships of production variance and engineered standards. For some reason, the reports were being overlooked by the shipyard's management as they made priority decisions concerning reevaluation of specific standards.

¹⁷Op.Cit. O'Donnell.



Results From Use of an Integrated Schedule for Drawing Development and Equipment Procurement

James R. Wilkins Jr., Member, Wilkins Enterprise Inc., Riva, MD

ABSTRACT

As part of an SP-4 project, a computer program was developed to produce integrated schedules for drawing development of drawings and equipment procurement. The program also can be used either to develop a schedule for the fabrication and assembly stages of the construction process or to receive data from an existing construction schedule. In either case, the construction data is used to ensure that drawings are produced and equipment is purchased in time to support production planning. The program uses a commonly available database program, is suitable for use on a minicomputer and will allow a network of terminals to be used to enter data and obtain reports.

This paper reports on the results of applying this scheduling program to a simulated shipbuilding program and highlights a number of significant results. The principal result was to clearly demonstrate that planning for the purchase of equipment must take into account the needs of the ship design process for data about the equipment being procured.

NOMENCLATURE

Because the program described herein was developed for application to modern, modular (zone-oriented) ship construction programs, and because the terminology used for such programs varies so greatly among shipyards, it is necessary to define each of the following terms. Readers should be able to make the mental transformation to the terminology used in their own shipyard or in other literature, given these definitions.

Unit The basic modular structural element used to construct a ship. With some exceptions, a unit is the first modular level at which outfitting is accomplished.

Outfitting - The installation of system elements into a unit or combination of units.

Block - A combination of several units, assembled together and outfitted prior to erection at the final building site.

Sub-Assembly - Combinations of parts which may be joined with other sub-assemblies or parts to construct units.

Machinery Package - A collection of equipment, foundations, piping, electrical fixtures, wiring, gauges, etc., which is constructed as an entity, pretested whenever possible, and loaded into a unit, a block or on-board the ship during erection. Effective design and use of these construction elements has greatly increased productivity as well as equipment operability and maintainability.

BACKGROUND

One of the major efforts in accomplishing a shipbuilding program is to buy the equipment used to build the ship. This procurement effort is controlled through a document usually identified as the Material Ordering Schedule (MOS). The principal elements of the MOS are a listing of every type of equipment which must be procured and the date by which each must be received in the shipyard in order to meet the construction schedule.

The length of time between the day on which an item is ordered and the day on which the vendor can have it delivered to the shipyard is known as the equipment's "lead time". When this duration has been determined, it is possible to compute the date by which the equipment must be ordered, or the Purchase Order Award Date (POA).

The POA date determined in the manner described above completely ignores the design process. But the equipment procurement process and the design process are inseparably linked. During the early stages of the design of each of the ship's systems, the designer must define the performance requirements of every piece of equipment in the system for which he or she is responsible. Thus information must be known before it can be provided to prospective vendors for preparation of their offers to the shipyard.

The design process, on the other hand, cannot be completed until after the equipment vendor provides

(a) Performance Data, describing the actual performance of the equipment being provided, and

(b) Configuration Data, providing the exact dimensions of the equipment.

Although the shipyards Request for Proposal (RFP) to the vendor will have defined minimum performance characteristics to be met by the equipment, the actual performance provided by the available equipment can be quite different. In such cases it is necessary for the system designer to review the design and, if necessary, make changes. Similarly, the configuration of the finally selected equipment may vary from that which was assumed during the earlier design stages.

Consequently, the design of systems cannot be considered complete until all of the detailed performance and configuration data have been received from the equipment vendor and the effect of any significant variations incorporated in the final drawings used to construct the ship.

Thus it will be seen that the POA cannot (should not, at least) take place before the equipment requirements are defined and the vendor has given adequate assurance that the performance and configuration requirements can and will be met. However, in the description, provided above, of how the required POA date is normally established, there was no consideration of the information needs of the design process.

The purpose of the task authorized by Panel SP-4 was to identify the information flow requirements that link the ship system design and equipment procurement processes, and to determine the interfaces between the two which control the scheduling of each. It was understood before starting the project that it should be possible to determine the lead time for equipment data and

the date by which that data would be required by the design process. With these data it would be possible to identify the POA date necessary to meet the design process's information needs.

Experience had made it clear that the POA date for equipment design information (software) is almost always earlier than the POA date determined from considerations of the hardware delivery. The goal of this study was to more specifically quantify the information flow interfaces, i.e. what data is required for the equipment ordering process from the design process, what information from the equipment procurement process is needed by the design process, and what are the points in each of these processes that the data must be known. It was recognized that, with this information, it would then be possible to develop integrated schedules for drawing development and for equipment procurement.

STUDY APPROACH

General

For the purposes of this study, the overall shipbuilding process was considered to be composed of three different, major processes - the design/drawing process, the equipment procurement process and the construction process. To conduct the study, it was useful to construct a process model of each, with all of their activities identified. Figure 1 illustrates the primary elements of the three process models that were used.

Design Process Model

The study identified three of the major elements of the overall design/drawing process to be involved in information interfaces with the other processes.

The first of these is the System Diagram Design Stage, during which system diagrams are developed. The second is the Composite Drawing Stage, during which all of the individual systems drawings are integrated into composites for various spaces in the ship. The third is the Construction Drawing Stage, when the Assembly/Installation and Part Fabrication Drawings are produced.

System Diagram Design Stage.

This stage was further broken down into four activities, which were identified as Phase One, Phase Two, Phase Three and the Calculation Phase. As illustrated in Figure 2, Phase One precedes the Calculation Phase, Phase Two follows the Calculation Phase, and Phase Three follows Phase Two.

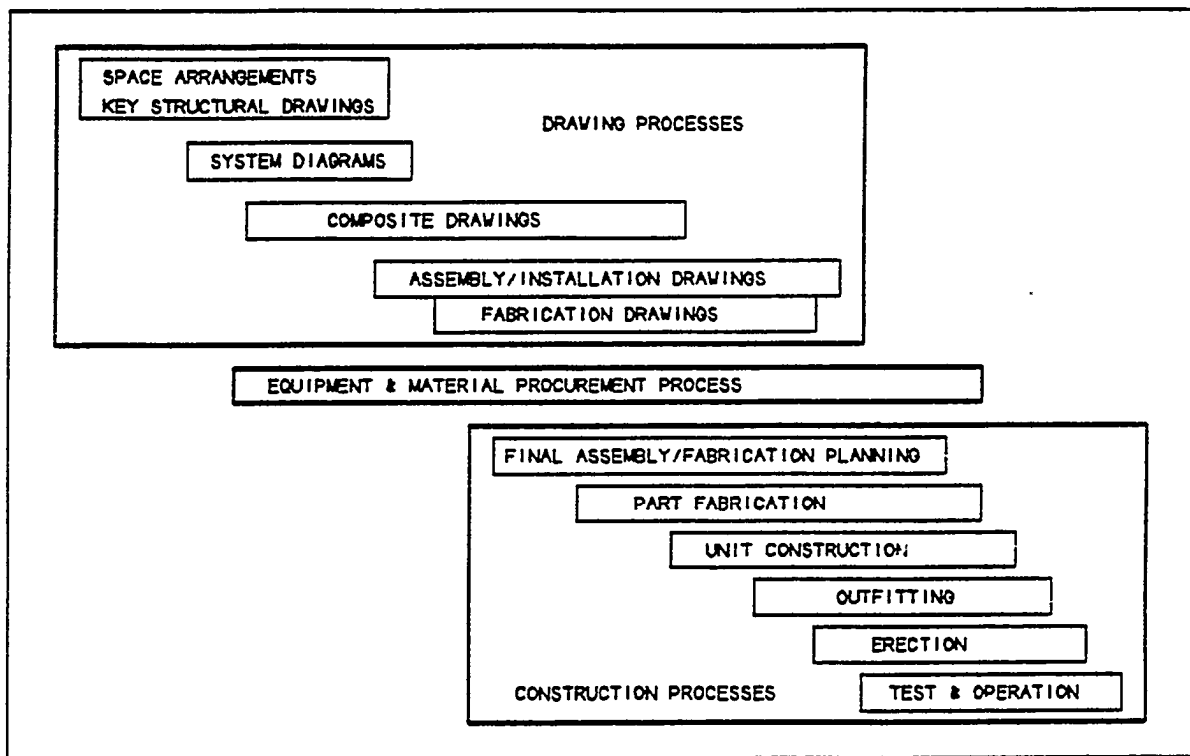


Figure 1. Shipbuilding Processes of Interest

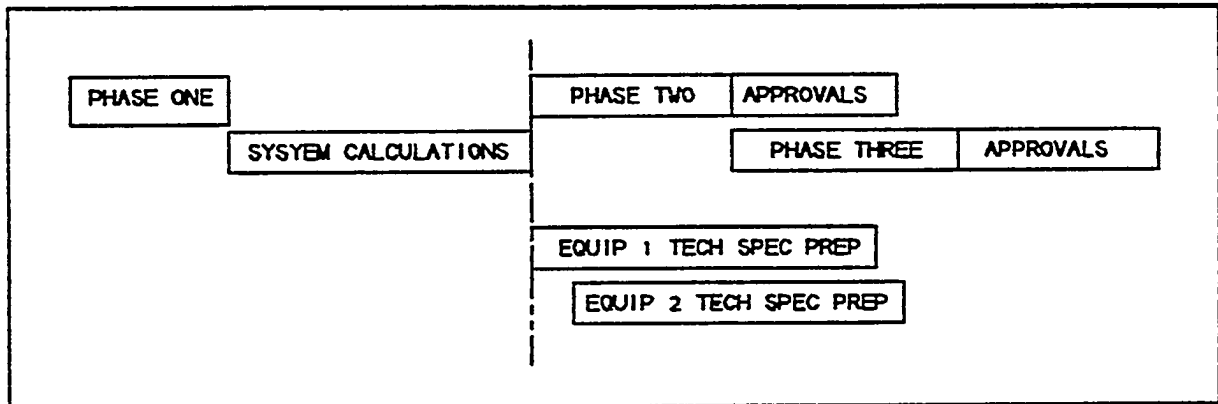


Figure 2. Diagram Process Activities

Phase One involves review of all ship specification documents which relate to the system being designed, plus the initial work which is prerequisite to being able to do the system design calculations. The System Calculation Phase covers all of the efforts which are required in order to determine the size of system components and the required performance characteristics of every equipment required by the system.

During Phase Two of the Diagram Stage, all of the major elements of the

system are placed on the drawing. These are normally shown in diagrammatic format, without dimensional details. It is becoming common for the backgrounds of system diagrams to provide at least an indication of compartmentation boundaries. At the end of Phase Two, the drawing is sufficiently complete for review by the owners and regulatory bodies, who need to assure themselves that their individual requirements have been satisfied by the shipyard's system design.

A Phase Three effort has been defined, because Diagrams are required to include tables which define the details of every piece of material and equipment which is used in the system, including manufacturer's names, model numbers, etc. These data are not required for design development, so can be added to the diagram after the rest of the diagram design process is complete.

Composite Drawing Stage. The Composite Drawing, often called an Interference Control Drawing, is a drawing showing the detailed layout of all systems in a ship or in a part of a ship. Composites in the past usually have been limited to coverage of specific areas in the ship, where there are many systems installed in limited volume, such as a machinery space, . For ship-building programs which apply modern, unit-oriented construction techniques, composites normally cover the entire ship. The use of computers for developing composites is now quite common in larger shipyards.

Because the composite includes all systems, it cannot be considered complete until the design of all individual ship systems are finished. For unit-oriented programs, it is essential that the composite drawing be carefully oriented to the unit breakdown of the ship construction process. In developing schedules, the schedule for completing of the composite for each unit must be considered.

Although the Assembly/Installation (A/I) drawings for a unit may be started before the unit's composite drawing is completely finished, the composite should be virtually complete to minimize the likelihood of having to waste manhours making changes to the A/I drawings to reflect last minute changes to the composite.

Construction Drawing Stage. As previously indicated, two types of drawing are produced during this stage. The Fabrication Drawings give production personnel all the information necessary for them to construct the parts which make up a system. These include the details for every piece of plate which is cut, every structural member which must later be welded to others, for every section of piping and fittings which must be fabricated, all ducting, wireways, etc., etc., etc. In the preferred modern construction practice, all parts related to a particular construction trade will be included in a drawing which relates to a single unit or block. Thus, for instance, all piping systems for one unit will be shown in one unit piping fabrication drawing package.

Similarly, a separate A/I drawing will be provided for each system-type in a unit or block. This drawing will show the dimensional details necessary to allow the production personnel to properly install all parts of the systems for which their trade is responsible in that part of the ship.

Actually, although the Fabrication Drawing is the first document to be used by the production personnel, it cannot be started until the Installation Drawing has been at least partially developed. The layout of a system on the Installation Drawing will determine where bends in a piping, ventilation or wireway system must be made, where support must be provided; etc.

On the other hand, the Installation Drawing cannot be considered complete until the Fabrication Drawing is complete, because fabrication considerations may make it necessary to make changes to the way the system is to be installed.

Equipment Procurement Process Model

General - The first steps in the equipment procurement process take place during the time that the shipyard is preparing its bid to build the ships in the prospective program. The contract design package provided by the owner will identify all major equipment requirements to the extent that they have been identified through the contract design stage. Each shipyard will contact equipment vendors for information concerning their equipment. The pricing and delivery information received as a result of these contacts will be used by the shipyard in its planning and cost estimating efforts for its proposal to the owner.

If an adequate Job of identifying its total ultimate requirements for data as well as hardware is done by the shipyard at this time, and if the shipyard receives good descriptions of the performance and configuration of the equipment as a result of this pre-award effort, the shipyards post-award design efforts will be simplified greatly.

Nevertheless, after award, the shipyard must recheck every element of the ship design, making its own determination of the performance requirements for each equipment.

Post-Award Activities - Final efforts for equipment procurement normally are delayed until the equipment's performance requirements have been finally established during the system calculation phase of the Drawing Process.

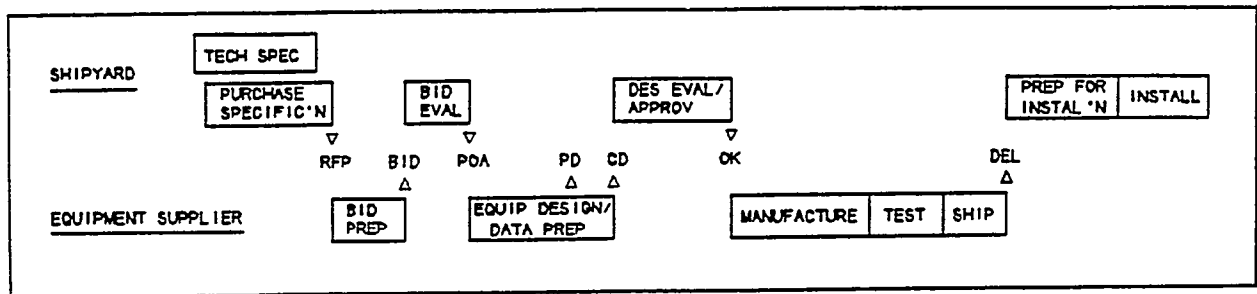


Figure 3. Equipment Process Activities

The first steps in the equipment procurement process include the preparation of the Equipment Technical Specifications, which define the performance requirements which must be met by the equipment being purchased. The preparation of the remaining portions of the RFP may go on in parallel with preparation of the Technical Specifications, since the two efforts are normally accomplished by two different organizations in the shipyard.

After the successful offeror has been selected, he must provide the shipyard with a number of different types of data in addition to delivering the hardware. For the purposes of establishing the interfaces between the drawing development and equipment procurement processes, it was found unnecessary to include Integrated Logistics Systems (ILS) data, although tracking the delivery of the several different ILS deliverables is, of course, vital to the ability to deliver a completed ship on time.

Figure 3 illustrates the post-award activities which were determined to be controlling in the development of schedules for the equipment procurement process and its interfaces with the other processes involved.

Interfaces

- Requirements. The first interface between the equipment procurement process and that of drawing development is the definition, by the shipyard designers, of the performance, configuration, data and any other requirements that the equipment vendor must satisfy. This information should be included in the RFP sent to all prospective vendors.

RFP Response. If the RFP as properly prepared, that is, if it asks for a complete description of the vendor's predictions of the equipment's performance characteristics and configuration, this information can be effectively used by the system designers. It not only will allow selection of the most desirable piece of equipment, but it also will allow the designer to

proceed confidently with the system design.

This information is easily provided when the equipment in question is already in production. However, if the requirement is for a piece of developmental hardware, the data provided by prospective vendors necessarily will be more suspect and will require validation after award.

Performance Data. The first data that is needed from the selected equipment vendor is his prediction of the equipment's performance characteristics. Phase Two of the System Design Stage cannot be considered complete until this information has been obtained for every piece of equipment in the system.

In the best case this performance data submittal can be a restatement of what was submitted with the vendor's proposal, and should be available within days after POA.

In the case of developmental equipment, the vendor should be able within a few weeks to provide the shipyard with the actual performance criteria that are being used in their design efforts, which may for some reason differ from the RFP requirements. Although the actual performance results for developmental equipment will not be definitely established until the production equipment has been built and tested, the design and construction of the ship must proceed on the assumption that the predicted performance (which must meet or exceed the required performance) will be obtained.

configuration Data. Information about the exact geometric details of an equipment is needed for the Composite Drawing Phase. As in the case of performance data, this data should be available from the vendor immediately except in the case of developmental hardware. Actual configuration data for developmental equipment will be available as soon as the final drawings for the equipment's fabrication are complete.

Approval for Manufacture. In the case of developmental equipment, it is not uncommon for the shipyard to insist that the vendor not start the actual production effort on the equipment without the shipyard's prior approval. The shipyard may be required to obtain the owner's approval before any manufacturing costs are accrued on the equipment. (411 such review and approval efforts must be considered in the planning and scheduling processes to preclude unexpected shipbuilding delays.

Difficulties in obtaining approval for manufacture may result in equipment design changes. If there are resulting performance changes, the system diagram may have to be revised. If there are configuration changes, the composite drawings for all units in which that equipment is installed may have to be changed. If equipment production is delayed, the entire shipbuilding sequence may be adversely affected.

Thus, good management of the manufacturing approval activity is essential to the productivity of the entire shipbuilding process.

Hardware Delivery. The final interface with the shipyard, as far as this study was concerned, is the delivery of the tested hardware. The need and availability of vendor data and personnel for the final on-board testing and operation of the equipment is recognized, but does not influence the drawing development or equipment procurement processes.

Construction Process Model

Construction Stages - In modern shipbuilding practice each unit goes through several stages of construction. Most units proceed through a sequence of stages which include

(A) Structural Fabrication, when structural pieces are cut out and built into structural subassemblies.

(B) Structural Assembly, when subassemblies are joined into the complete unit. Some outfitting of subassemblies may be accomplished during this stage. For instance, parts of various systems may be installed on a deck section before the deck section is joined to the rest of a unit.

(C) Pre-Paint Outfitting, when additional system parts are installed on the as-built unit before the unit is blasted and painted.

(D) Post-Paint Outfitting, when those items which could be damaged by blasting are installed.

(E) In addition~ machinery packages must be built. These go through most of the construction activities of the stages described above, but, for machinery package scheduling, the total effort may be considered a single stage. Machinery packages may be installed during any of the outfitting stages.

SCHEDULING CONSIDERATIONS

General

After evaluating the total information flow requirements that enmesh the three processes described above, it became clear that the completion date of the system calculations was a critical date for the entire process. But that date is controlled by any one of four other conditions. Figure 4 is a simplified illustration of how the various processes tie together.

System Path Condition

The first condition to be considered is that which would exist even if no equipment were required by a system, that is, if the entire system could be assembled using stock material that already existed in the shipyard storage facilities. This case is indicated in Figure 4 by the path A-A1-B-C.

This path illustrates that the System Diagram Phase Two must be completed before the composite drawing for any unit in which the system is located can be completed. Conversely, it shows that the earliest required UCD completion date (point C, which hereafter will be referred to as the System C-Date) will establish the required completion date for the Phase Two effort (point B), which in turn will establish A1. A1 is one possible required completion date for the System Calculation (point A).

It should be noted that the technique for determining the system C-Date is itself quite involved, and will not be discussed further herein. A full description is provided in Reference 1.

Equipment Related Paths

General. Once a piece of equipment is required, three other potentially controlling paths exist. Note that when more than one type of equipment must be procured for a system, all three paths must be investigated for every type.

Performance Data Path. As noted earlier, equipment performance data (PD) is required in order to complete the Phase Two Diagram effort. Thus the time frame between the finish of system calculations and the receipt of the PD

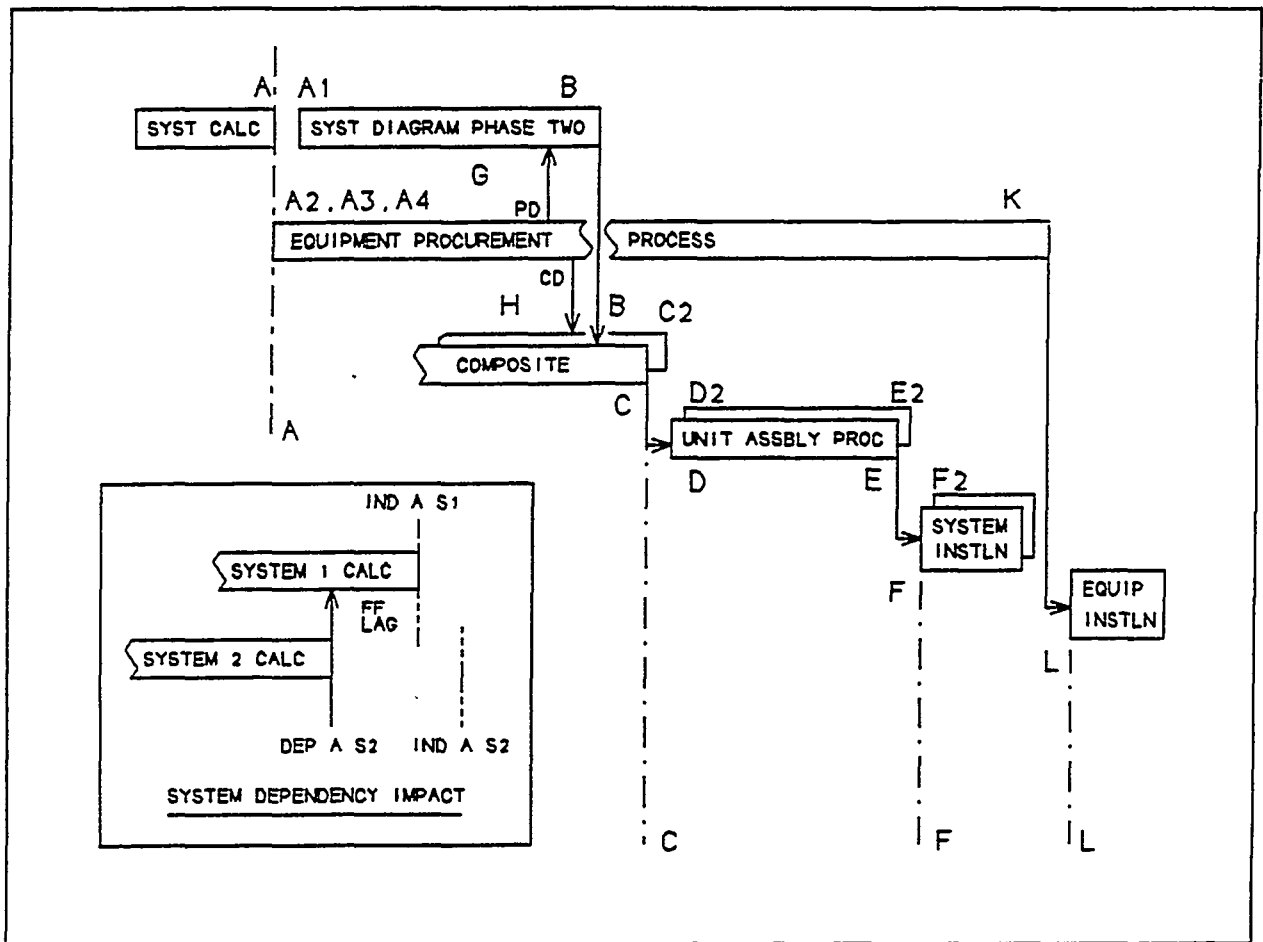


Figure 4. Schedule Control Activity Network

for the last piece of equipment in the system determines A2 for the given system's C-Date. This path, then, is A-A2-G-B-C.

Configuration Data Path. The configuration data (CD) from the vendor is used to confirm the composite drawing(s) for the unit(s) in which the equipment(s) are located. Some of a system's equipment will be located in different units than other equipment. Thus a calculation must be made for every equipment and every related unit to determine which combination creates the earliest A3, for path A-A3-H-C2.

Hardware Path. The date, L, on which each item of equipment is scheduled to be installed in a unit, in a block or on-board must be determined, and the lead time from start of writing the Technical Specification to installation must be defined. Then, working backwards along the path A-A4-K-L, another A-Date is determined.

Independent System A-Date

The earliest of all of the A-Dates determined as described above will define the System's Independent A-Date. That is the date by which the System Calculations would have to be completed if the system had no interfaces with any other systems.

Dependent System A-Date

Most systems, however, are not independent. Those which provide services to others must receive information about the requirements of the served system before their own characteristics can be definitized. The served system is then the dependent system from this point of view.

As depicted in the inset in Figure 4, if System 1 requires information from System 2, then System 2's calculations must be completed in time for System 1's calculations to be finished.

This may require System 2's calculations to complete earlier than if system 2 were an independent system.

The Dependent System A-Date is the final, controlling date for the system design effort.

COMPUTER PROGRAM

General

Having developed an information flow logic that was supposed to support development of integrated schedules, the next logical step was to use that information and develop the integrated schedules. To do so, two types of computer application programs were considered, a networking program and a relational data base program. Both types of program are available from several sources. Furthermore, applications of both types suitable for micro-computers, or PC'S, are available, as well as applications for mini- and main-frame computers. Because of the presumed greater accessibility of PC'S, and thus greater potential utility of a program which could be run on them, PC applications were examined first. Of the programs investigated, the database program was found to be simpler to use. Thus, the integrated scheduling program was developed on that system. The PC application was found to be fully capable of meeting the system requirements.

No attempt was made to try other available database programs or to utilize programs for larger computers. The information provided by the study effort serves only to demonstrate that one workable solution exists and to provide the information necessary for successful implementation of that solution. Any shipyard having an installed relational database system should be able to develop its own scheduling programs using the data provided in Reference 1.

Data Base

General. The relational database application program that has been used for this project is R:BASE FOR DOS, a product of MICRORIM. The basic elements of this program are Tables, Forms, Reports and the specific Application program that controls the operation of the system.

Tables. The Tables are used to store data. They can be considered as a matrix structure, with each row containing several columns of data.

Forms. The Forms element is an internal system which is used by the programmer to set up the appearance of

the computer screens used by those who will enter the data that will be stored in the Tables.

Reports. The Reports element is another Internal system that a programmer may use to develop the format for any and all reports which are to be obtained from the system.

Application Programs. By running various specific Application programs, operators may perform different functions, such as entering data into the database, modifying the data which has previously been entered, reviewing the data, or printing out the data in various formats. When using such an application program, the user is presented with a series of "menus" on the screen, from which the desired actions may be selected. This feature makes use of this system extremely easy and minimizes operator training efforts.

Specific Application Program

General. The specific application program that was developed during the study effort facilitates initial entry of all data concerning a ship's systems, equipment, and construction schedule.

All such data can then be modified as necessary whenever required. The program will do the calculations necessary to determine the early and late start and finish dates for each activity in the drawing development and equipment procurement processes.

Entry of the current estimated and/or actual start or completion dates of all controlling activities is then required. Thus, all the data necessary for producing printed reports of drawing and equipment schedules is developed by or entered into the database program.

By making appropriate selections from the options provided on the monitor screen, any desired report may be produced. The reports may be generated in whatever sorting sequence is preferred by the yard's data managers.

In addition, the program allows the current content of any of the database's Tables to be reviewed on the screen or printed out, a convenience for analyzing what combination of factors is controlling any scheduled date or for troubleshooting should any dates appear to be invalid.

computer Capability Required
The Relational Database System that has been used to develop the programs demonstrated herein is R:BASE FOR DOS,

available from MICRORIM. The full R:BASE FOR DOS 5.25 inch disk version of the program requires PC-DOS 2.0 or higher, 512K of main memory, a hard disk drive and one 5.25 floppy disk drive. plus a monitor. The 3.5 inch disk version requires PC-DOS 3.2 or higher for various versions. The 5.25 inch disk version was used for the subject application and all further discussion will be directed to that version.

The scheduling application program has been developed on an AT-clone with 512K of main memory and a 20 MB hard disk. It has not been prepared for network use, but this option is available with R:BASE FOR DOS and is considered a logical and desirable next step.

Approximately 4 megabytes of disc storage are required for installation of the full R:BASE FOR DOS product, although only about 2 megabytes are required for those elements of the program that are needed for this scheduling application.

The storage requirements for the scheduling application program and associated data will vary depending upon the amount of data stored. The requirements for a project which involves 125 different system diagrams, 1000 different items of equipment, 150 different units with an average of six system types per unit, where each system is installed in an average of ten units, is slightly over 1 MB. An allowance of a total of 2MB should cover any likely growth.

Using the Program

General - The following paragraphs provide a brief description of how the program can be used and what it will provide. A more detailed description of the basic elements of the scheduling program is provided in Reference 1.

Operation - There are at least three fairly different modes of operating the system, and it will probably be desirable to have different personnel available for performing these differing functions.

The first involves managing the system itself; making modifications to

the program as necessary to change the menu screen formats, to change the data entry or edit screen formats or to change the output report formats to suit varying requirements of different shipyards or different shipbuilding programs. This would be best accomplished by a single individual who will have to become familiar with the use of the R:BASE FOR DOS system and of the specific application program which has been developed. None of the other operators will need any understanding of computer programming.

The second operating mode involves entering the initial data and editing or updating that data. Ideally, initial data entry would be a one time effort, and in the vast majority of cases should be. Once a system or equipment and its supporting data, such as scheduled duration for the various activities relating to that system or equipment, are entered, it should not be necessary to make changes to those data. The values for these data should be determined by middle level managers, who could enter the data directly at their own keyboards, rather than having to write out the information for entry by others.

The third operating mode relates to the continual updating of current and actual dates for each of the activities being tracked and penetrating periodic schedule reports for various levels of management. Normally the input for these data will come from middle managers who will have marked up previous versions of schedule reports. It is probable that clerical personnel will be used to enter these data and produce the resultant reports.

Screens - The use of the program involves use of three types of "screens", or images which appear on the monitor, for the operator guidance.

Menu Screens - The first of the screen types provides the operator with a listing of choices of action. Selection of one of the options, which appear in a numbered vertical arrangement, as shown in Figure 5A, is made by entering the number of the desired choice. This choice may cause another menu screen to appear, giving the next logical series of choices. For example, selection of choice (1) from

MAIN MENU - INTEGRATED SCHEDULING PROGRAM	
(1)	SCHEDULE DATA (CURRENT/ACTUALS); ENTER, EDIT, OBTAIN REPORTS
(2)	INITIAL SYSTEM, EQUIP AND UNIT DATA; ENTER, UPDATE OR PRINT
(3)	QUIT

Figure 5A. Initial Menu Screen

SCHEDULING DATA FUNCTIONS -	
(1)	PRINT SCHEDULE REPORTS
(2)	ENTER CURRENT ESTIMATED SCHEDULED AND/OR ACTUAL DATES
(3)	UPDATE TABLES FOR NEW SYSTEMS, EQUIPMENT OR UNITS
(4)	QUIT

Figure 5B. Menu Screen for Scheduling Data Functions

SCHEDULE REPORTS MENU	
(1)	TO PRINT DIAGRAM SCHEDULE SORTED BY SYSTEM
(2)	BY START DATE
(3)	EQUIPMENT SCHEDULES SORTED BY EQUIPMENT SYMBOL
(4)	BY TECHSPEC START DATE
(5)	BY PO AWARD DATE
(6)	CONSTRUCTION DRAWING SCHEDULES SORTED BY UNIT
(7)	BY SYSTEM TYPE
(8)	UNIT COMPOSITE DRAWING SCHEDULE SORTED BY UNIT.
(9)	TO QUIT

Figure 5C. Menu Screen for Printing Reports

Figure 5A, will cause the next menu, Figure 5B, to appear. Selection of choice (1) from Figure 5B, "Print Schedule Reports", will bring up the Schedule Reports Menu, shown as Figure 5C. Selection of one of these choices will yield a printout of the desired report.

Data Entry Screens - The second screen type is for data entry. Separate data entry screens are provided for entering data for different purposes. An example is given in Figure 6A, which is the form provided for an operator to enter the initial estimates for current scheduled dates. The operator is led to enter a system symbol by having an area of the screen (just above "Early") highlighted.

As soon as the system symbol is entered from the keyboard, the program fills in the fields for the early and late scheduled dates, which have been calculated by the program and stored in their associated tables. Figure 6B shows how the screen appears after the system symbol, in this case "AF" for the AFFF system, has been filled in. The early and late scheduled dates are provided as an aid to the manager or operator in the initial selection of current dates.

Editing Screen - The third screen type, one of which is shown in Figure 6C, is provided for ease in making changes to information stored in the database tables. These data editing screens allow the operator to scan the data which exists in any chosen table and to change any data element in that

table. The example shown as very similar to Figure 6B, but Figure 6C shows all current scheduled and actual date data that has been entered into the table and shows it for two drawings at a time. The operator can modify only the current scheduled and actual fields in this particular screen, since all the other fields contain calculated data. Other editing screens must be used for modifying the data which are used for generating the calculated dates.

Output As previously noted, there are two types of reports generated by the program. All reports can be previewed on the monitor before printing, if desired.

(a) Schedule Reports - One type of report provides the schedules which are the primary reason for this whole effort. These reports show early and late scheduled start and finish dates, current estimated dates and any actual milestone completion dates. Separate reports are generated for the development of each type of drawing, i.e., for diagrams, unit composite drawings and installation and fabrication drawings, as well as for the equipment ordering schedule. Excerpts from a page of each of these report types are included as Figures 7, 8, 9, and 16.

Figure 7 as a Diagram Schedule Report. showing the information of interest relative to Systems Diagrams.

Figure 8 contains data for the Unit Composite Drawings. A different format has been used for this schedule,

Add Duplicate Edit again Discard Quit								
Enter/Edit Current Scheduled and Actual Dates For Diagrams :								
SYSSYMB	SHIPYARD DWG NO PHASE ONE		CUSTOMER DWG NO CALC		CONTR DES DWG NO PHASE TWO		CONTR DES DWG NO PHASE THREE	
	START	FINISH	START	FINISH	START	FINISH	START	FINISH
AF	SYDNR	XXXXXXD	555-12345678D		MM053D180			
Early:								
Late :								
Curr :								
Act :								

[ESC] Done [F2] Clear field [Shift-F2] Clear to end [Shift-F10] More
Form: DIACRACF Table: DIACRACF Field: SYSTSYMB Page: 1

Figure 6A. Data Entry Screen

Add Duplicate Edit again Discard Quit								
Enter/Edit Current Scheduled and Actual Dates For Diagrams :								
SYSSYMB	SHIPYARD DWG NO PHASE ONE		CUSTOMER DWG NO CALC		CONTR DES DWG NO PHASE TWO		CONTR DES DWG NO PHASE THREE	
	START	FINISH	START	FINISH	START	FINISH	START	FINISH
AF	SYDNR	XXXXXXD	555-12345678D		MM053D180			
Early:	05/18/90	05/29/90	06/01/90	06/26/90	06/29/90	08/21/90	08/24/90	10/16/90
Late :	05/03/89	05/16/89	05/20/89	06/14/89	06/17/89	10/18/89	10/21/89	12/07/89
Curr :								
Act :								

[ESC] Done [F2] Clear field [Shift-F2] Clear to end [Shift-F10] More
Form: DIACRACF Table: DIACRACF Field: CSPHASE1 Page: 1 Changed

Figure 6B. Screen After Entry of System Symbol

Edit Save Add new Delete Reset Previous Next Quit								
Enter/Edit Current Scheduled and Actual Dates For Diagrams :								
SYSSYMB	SHIPYARD DWG NO PHASE ONE		CUSTOMER DWG NO CALC		CONTR DES DWG NO PHASE TWO		CONTR DES DWG NO PHASE THREE	
	START	FINISH	START	FINISH	START	FINISH	START	FINISH
AF	SYDNR	XXXXXXD	555-12345678D		MM053D180			
Early:	05/18/90	05/29/90	06/01/90	06/26/90	06/29/90	08/21/90	08/24/90	10/16/90
Late :	05/03/89	05/16/89	05/20/89	06/14/89	06/17/89	10/18/89	10/21/89	12/07/89
Curr :	06/09/89	06/23/89	06/23/89	-	-	-	-	-
Act :								

[ESC] Done [F2] Clear field [Shift-F2] Clear to end [Shift-F10] More
Form: DIACRACF Table: DIACRACF Field: SYSTSYMB Page: 1

Figure 6C. Data Editing Screen

DIAGRAM SCHEDULE -

Based on Contract Award Date of 06/02/89
Printed on 07/11/89 at 11:57:11

SYSTEM NAME		SHIPYARD DWG NR		OWNER'S DWG NR		PHASE ONE		PHASE TWO		PHASE THREE	
PHASE ONE		CALCULATIONS		PHASE TWO		PHASE THREE		PHASE THREE		PHASE THREE	
START	FINISH	START	FINISH	START	FINISH	START	FINISH	START	FINISH	START	FINISH
=====											
AFFF DISTRIBUTN		SYDNR XXXXXD		555-12345678D							
E				06/29/90	08/21/90	08/24/90	10/16/90				
L	05/18/90 05/29/90	06/01/90 06/26/90	12/28/90 02/19/91	02/22/91	04/19/91						
C	05/05/89 05/16/89	05/20/89 06/14/89	06/17/89 10/18/89	10/21/89	12/07/89						
A	06/09/89 06/23/89	06/23/89 -	-	-	-	-	-	-	-	-	-
=====											
AUX SW COOLING		SYDNR YYYYYYE		520-23456789E							
E				06/29/90	09/04/90	09/07/90	12/04/90				
L	04/27/90 05/22/90	05/25/90 06/26/90	12/24/90 03/01/91	03/04/91	06/03/91						
C	08/12/89 09/10/89	09/13/89 09/14/89	09/30/89 12/07/89	01/14/90	03/22/90						
A	-	-	-	-	-	-	-	-	-	-	-

Figure 7. Schedule for Diagram Phases

UNIT COMPOSITE DRAWING SCHEDULE -

Based on a Contract Award Date of 06/02/89
Printed on 07/11/89 at 12:02:15

UNIT	ORIG SCHED FINISH	CURRENT EST START	CURRENT EST FINISH	ACTUAL START	ACTUAL FINISH
1110	10/15/91	-	10/01/91	-	-
1120	09/17/91	-	09/03/91	-	-
1130	09/10/91	-	08/28/91	-	-
1210	06/18/91	-	06/04/91	-	-
1220	06/25/91	-	06/11/91	-	-
1230	07/16/91	-	07/02/91	-	-
1310	04/23/91	-	04/09/91	-	-
1320	04/23/91	-	04/09/91	-	-
1330	05/21/91	-	05/07/91	-	-
1411	02/12/91	-	01/29/91	-	-
1412	01/22/91	-	01/15/91	-	-
1413	03/12/91	-	02/28/91	-	-

Figure 8. Schedule for Unit Composite Drawings

which is only used within the shipyard since composite drawings have not been considered to be deliverables.

Figure 9 contains data relative to Installation and Fabrication drawings and for production planning efforts. Other schedule reports could be generated from the same data base for tracking the fabrication and installation of parts for each type of system in each stage of every unit.

The Equipment related data presented in Figure 10 is that which would be of greatest interest to the

Design Engineering department of a shipyard. All of the information that is normally provided in an Equipment Ordering Schedule (EOS) is available in the database and can be used to produce the complete MOS or EOS.

Figures 7, 8, 9 and 10 provide schedule data for various types of drawings in formats most suitable to each type. Each of these reports can be modified easily to present the data in other formats, on different sized paper, etc., as well as by various sorts, to meet the different needs or preferences of an individual shipyard.

SYSTEM TYPE UNIT ASSEMBLY PROCESS SCHEDULE
Based on a Contract Award Date of 06/02/89
Printed on 07/11/89 at 13:45:42

UNIT	SYSTYPE		ASSEMBLY DRAWING NR.		FABRICATION DWG NR.			
	UAD		UFD		UFP		UFF	
	START	FINISH	START	FINISH	START	FINISH	START	FINISH
	=====	=====	=====	=====	=====	=====	=====	=====
1421	P		1421-PI-40-A		1421-PF-40--			
Early:	04/29/91	07/05/91	05/20/91	06/28/91	07/15/91	08/02/91	08/19/91	10/11/91
Late :	05/16/91	07/22/91	06/03/91	07/12/91	07/29/91	08/16/91	09/02/91	10/25/91
Curr :	04/29/91	07/05/91	05/20/91	06/28/91	07/15/91	08/02/91	08/19/91	10/11/91
Act :	-	-	-	-	-	-	-	-
1422	P		1422-PI-30-B		1422-PF-30-C			
Early:	06/03/91	08/23/91	06/24/91	08/09/91	08/26/91	09/13/91	09/30/91	11/29/91
Late :	06/20/91	09/09/91	07/08/91	08/23/91	09/09/91	09/27/91	10/14/91	12/13/91
Curr :	06/03/91	08/23/91	06/24/91	08/09/91	08/26/91	09/13/91	09/30/91	11/13/91
Act :	-	-	-	-	-	-	-	-
1421	S		1421-SI-20-B		1421-SF-20-A			
Early:	04/01/91	06/21/91	04/22/91	06/14/91	07/01/91	07/19/91	08/05/91	09/27/91
Late :	04/18/91	07/08/91	05/06/91	06/28/91	07/15/91	08/02/91	08/19/91	10/11/91
Curr :	-	-	-	-	-	-	-	-
Act :	-	-	-	-	-	-	-	-
1422	S		1422-SI-20-A		1422-SF-20-B			
Early:	04/15/91	07/05/91	04/29/91	06/21/91	07/08/91	08/02/91	08/19/91	10/25/91
Late :	05/02/91	07/22/91	05/13/91	07/05/91	07/22/91	08/16/91	09/02/91	11/08/91
Curr :	-	-	-	-	-	-	-	-
Act :	-	-	-	-	-	-	-	-

Figure 9. Schedule for Construction Drawings

EQUIPMENT SCHEDULES AND STATUS						
Based on Contract Award Date of 06/02/89						
Printed On 07/11/89 at 12:06:14						
SYSTEM EQUIPMENT NAME	SYMBOL	PO NR.		PO AWARD	PD RECEIPT	CD RECEIPT
		TECH START	SPEC FINISH			
AFFF DISTRIBUTN						
AFFF HOSE RACKS	AFHRK	-	-			
Early Sched	06/29/90	07/17/90	09/25/90	01/29/91	02/12/91	
Late Sched	09/21/90	10/09/90	12/18/90	02/19/91	02/12/91	
Current Sched	10/16/89	11/03/89	12/15/89	02/16/90	03/02/90	
Actual	-	-	-	-	-	-
AFFF CONC PUMP	AFPMP	-	-			
Early Sched	06/29/90	07/24/90	10/09/90	02/19/91	03/05/91	
Late Sched	09/21/90	10/16/90	01/01/91	02/19/91	05/28/91	
Current Sched	10/16/89	11/10/89	01/15/90	03/02/90	03/16/90	
Actual	-	-	-	-	-	-
AFFF PROPORTNR	AFPRP	-	-			
Early Sched	06/29/90	07/10/90	09/18/90	02/19/91	02/26/91	
Late Sched	11/02/90	11/13/90	01/22/91	02/19/91	05/28/91	
Current Sched	-	-	-	-	-	
Actual	-	-	-	-	-	-

Figure 10. Schedule for Equipment Procurement Activities

PRINTOUT OF SYSTEM DATA TABLE DIAGRAM DATA CONTENT
Printed on 06/12/89 at 15:03:30

SYSTEM NAME	SYMB	TYP	SHIPYARD'S DIAG NR			OWNER'S DWG NUMBER	
DURATIONS-WKS	-----DATES-----						
PH1 CLC PH2 PH3	MNSYSCDA	DIAGADAY	MNEQADAY	MNINDADA	MNDEPADA	SYSTADAY	
== == ==	=====	=====	=====	=====	=====	=====	
AFFF DISTRIBUTN	AF P	-			M05D180		
2 4 8 8	03/05/91	01/08/91	09/18/90	09/18/90	06/26/90	06/26/90	
AUX SW COOLING	AS P	-			M05D180		
4 5 10 13	03/15/91	01/04/91	09/07/90	09/07/90	06/26/90	06/26/90	
COMPRESSED AIR	CA P	-			M05D12		
3 4 8 5	02/12/91	12/18/90	09/25/90	09/25/90	12/10/99	09/25/90	
CHILLED WATER	CW P	444455023-12			01234-12-333D		
2 3 10 12	03/15/91	01/04/91	11/02/90	11/02/90	12/10/99	11/02/90	

Figure 11. Table Data Report - System Data Table

(b) Tabular Data Reports - The other type of report provides the contents of individual tables of the database. This type of report will be of primary interest to the Scheduling Program Manager because it allows analysis of any results which seem unusual. Figure 11 is an example. It shows the content of the rows of the System Data Table. This table contains the system diagram identifiers, the diagram numbers, the durations of the four diagram phases and the various dates which control scheduling of the drawings listed in this table. all of these data are stored in this table, even though the dates come from the results of calculations, rather than from direct entry by operators.

ANALYSIS OF RESULTS

General

Analysis of the results of the data and calculations can only be accomplished by review of the data stored in the database tables. There are a total of 12 tables in the current database, of which only five need be discussed here.

System Data Table

Durations - 9s previously noted, Figure 11 illustrates the report which shows the data stored in the System Data Table. These data include the durations of each diagram phase, in weeks, which are entered manually as initial system data.

Dates - The minimum system C-Date, listed under "MNSYSCDA", is the earliest of the Unit C-Dates of all the Units that the system is installed in. This data is obtained from the System-Unit Combination Table, a page of which

is shown in Figure 12, sorted by system and Unit C-Date. It can be verified by observation that the computer program has properly identified the earliest of the Unit C-dates for a system and stored it in the System Data Table.

The Diagram A-Date, "DIAGADAY", is the date by which the system calculations would have to be complete if the Phase Two diagram duration were to control meeting the System C-Date. This compares with date A1 in Figure 3.

The Minimum Equipment A-Date, "MNEQADAY", is the earliest of the Equipment controlled A-dates; that is, the earliest of dates A2, A3 or A4 in Figure 3. This date is obtained from the Equipment Data Table, 1s will be described later.

The Minimum Independent A-Date, "MNINDADA", is the earlier of the two preceding A-Dates. In every case shown, the Equipment A-Date is controlling.

This does not, however, mean that the hardware delivery date is the controlling date for that equipment, as will be shown by review of the contents of the Equipment Data Table.

The Minimum Dependent A-Date, "MNDEPADA", is the date by which the system calculations must be complete in order to provide necessary data to another system, so that the other system's calculations will complete on schedule. This date is calculated from the System Dependency Table, as described in the next section.

Finally, the System A-Date, "SYSTADAY", is the earlier of the two preceding dates. This is the controlling date for the system, and estab-

SYSTEM-UNIT COMBINATION TABLE DATA PRINTOUT				
Printed on 06/12/89 at 15:18:08				
SYMB	SYSTEM NAME	UNIT	UNIT C DATE	
=====	=====	=====	=====	
AF	AFFF DISTRIBUTN	1433	03/05/91	
AF	AFFF DISTRIBUTN	1421	03/15/91	
AF	AFFF DISTRIBUTN	1520	03/19/91	
AF	AFFF DISTRIBUTN	1422	03/29/91	
AF	AFFF DISTRIBUTN	1510	04/02/91	
AF	AFFF DISTRIBUTN	1423	04/02/91	
AF	AFFF DISTRIBUTN	1620	05/07/91	
AF	AFFF DISTRIBUTN	2510	06/18/91	
AF	AFFF DISTRIBUTN	2400	07/30/91	
AS	AUX SW COOLING	1421	03/15/91	
AS	AUX SW COOLING	1422	03/29/91	
AS	AUX SW COOLING	1423	04/02/91	

Figure 12. Table Data Report - System-Unit Combination Table

SYSTEM DEPENDENCY DATA TABLE PRINTOUT On 06/12/89 At 15:06:33									
SYSTEMS			FINISH-FINISH LAGS				PHASE 2 START		
USER	PRVDR	DRVR	USR PH1	USR CLC	PRV PH2	USR PH3	"A" DATES		
=====	=====	=====	=====	=====	=====	=====	PRPVDR'S	USER'S	
AF	SW	FM	2	4	2	2	07/24/90	06/26/90	
AS	SW	FM	1	4	2	1	07/24/90	06/26/90	
DB	SW	FM	3	5	2	2	07/24/90	06/19/90	
FM	SW	-	1	2	2	3	07/24/90	07/10/90	
PM	SW	FM	2	6	2	2	07/24/90	06/12/90	
PW	CA	-	1	1	1	1	09/25/90	09/18/90	
SF	CA	-	2	2	2	2	09/25/90	09/11/90	
SF	CA	PW	2	3	4	2	09/25/90	09/04/90	
SF	SW	FM	2	4	2	2	07/24/90	06/26/90	

Figure 13. Table Data Report - System Dependency Data Table

lishes when the system calculations must be complete. This date provides the basis for all of the scheduling programs produced by this program.

System Dependency Table

The contents of the System Dependency Table are shown in Figure 13. The only systems included in this table are those which are dependent upon services provided from another system. The dependent system is the "User" system, listed in the first column. The system which provides services is listed either in the provider column or in the "Driver" system column. When a system is shown as a driver, it means that there is a multiple dependency.

For instance, the AFFF system, AF, receives services from the Firemain, FM. But the Firemain receives services from the Main Seawater Cooling System, Sw, (at least on this pilot system). As a result, the AFFF system ultimately is dependent upon the SW system, and its scheduled completion dates will be controlled by those of the SW system's.

The Independent System A-Dates are obtained by the computer program from the System Data table and stored in the A-Date columns for the provider and user systems in this table. Then the computer program compares the data in these two columns, selects the earlier and stores it back in the System Data Table as the System A-date.

EQUIPMENT DATA TABLE PRINTOUT

Printed on 06/12/89 at 15:28:24

				DURATIONS										DATES									
SYSTEM NAME				T	R	V	V	V	E	M	T	S	W										
EQUIPMENT NAME	EQSYM	PO	NR	S	F	B	V	P	C	V	F	S	H	H	PD	C	DAY	CD	C	DAY	INSTL	DAY	
EQUIP A DATE				P	Q	D	L	D	D	D	R	T	P	S	PD	A	DAY	CD	A	DAY	HW	A	DAY
=====				==	==	==	==	==	==	==	==	==	==	==	=====	=====	=====	=====	=====	=====	=====	=====	=====
AFFF DISTRIBUTN																							
AFFF HOSERACKS	AFHRK	-		3	4	5	3	6	8	2	12	1	2	3	03/05/91	03/05/91	12/30/91						
09/18/90															10/09/90	09/18/90	03/21/91						
AFFF CONC PUMP	AFPMMP	-		4	4	5	4	7	9	3	26	3	3	3	03/05/91	06/18/91	12/06/91						
09/18/90															09/18/90	12/11/90	10/01/90						
AFFF PROPORTNR	AFPRP	-		2	3	5	2	4	5	1	25	2	3	3	03/05/91	06/18/91	12/06/91						
10/30/90															10/30/90	01/29/91	12/17/90						
AFFF CONC TANK	AFTNK	-		3	4	5	2	3	6	3	12	2	3	3	03/05/91	03/29/91	11/29/91						
11/02/90															11/06/90	11/02/90	02/18/91						
AUX SW COOLING																							
A/C COMPRESSORS	ASACC	-		4	5	5	3	6	9	2	18	3	3	3	03/15/91	03/15/91	11/11/91						
09/07/90															10/05/90	09/07/90	11/08/90						
REFRIG COMPRMP	ASCPM	-		4	5	5	3	6	9	2	18	3	3	3	03/15/91	03/15/91	11/11/91						
09/14/90															10/12/90	09/14/90	11/15/90						

Figure 14 Table Data Report - Equipment Data Table

EQUIPMENT - UNIT - STAGE TABLE DATA PRINTOUT
Printed on 06/12/89 at 15:34:04

SYS	EQUIPMENT		UNIT	STAGE	INSTALLATION	UNIT
TYP	SYMBL	NAME			DATE	"C" DATE
===	=====	=====	=====	=====	=====	=====
P	AFHRK	AFFF HOSERACKS	1433	60	02/07/92	03/05/91
P	AFHRK	AFFF HOSERACKS	1421	50	12/30/91	03/15/91
P	AFHRK	AFFF HOSERACKS	1422	60	04/06/92	03/29/91
P	AFHRK	AFFF HOSERACKS	2510	50	01/17/92	06/18/91
P	AFPMMP	AFFF CONC PUMP	2510	40	12/06/91	06/18/91
P	AFPRP	AFFF PROPORTNR	2510	40	12/06/91	06/18/91
P	AFTNK	AFFF CONC TANK	1422	50	02/03/92	03/29/91
P	AFTNK	AFFF CONC TANK	1423	40	11/29/91	04/02/91
P	AFTNK	AFFF CONC TANK	2510	40	12/06/91	06/18/91
P	ASACC	A/C COMPRESSORS	1421	40	11/11/91	03/15/91
P	ASACC	A/C COMPRESSORS	1422	40	11/22/91	03/29/91
P	ASACC	A/C COMPRESSORS	1423	40	11/29/91	04/02/91
P	ASCPM	REFRIG COMPRMP	1421	40	11/11/91	03/15/91

Figure 15. Table Data Report - Equipment-Unit-Stage Table

Equipment Data Table

This table is set up to store all data needed to produce the Equipment Ordering Schedule(s). As seen in Figure 14, it stores the durations for each activity in the equipment procurement process model shown in Figure 3. In addition, it stores various dates needed in the calculations carried out by the computer program.

The Equipment PD and CD C-Dates and the Hardware Installation Dates are

determined from other tables; the PD C-Date from the System-Unit Table, Figure 12, and the others from the Equipment-Unit-Stage Table, Figure 15.

The corresponding A-Dates are calculated using the durations given in the other columns of the Table. Finally, the earliest of the three A-Dates is selected as the Minimum Equipment A-Date, and stored in this Table and the System Data Table already discussed.

Observations

Equipment Data Table - Comparison of the three A-Dates for various types of equipment shows that, for the assumed construction schedule and various assumed durations used in the sample project, the Hardware A-Date was never the controlling date.

The C-Dates for both the PD and CD are often the same, but not always. The obvious explanation is that some parts of the system and some equipment of the system are to be installed in the same, earliest Unit for the system's installation. In such cases, because of the assumptions made about durations, the CD A-Date will always be earlier than that for the PD, and thus will control the POA date.

System Data Table - Analysis of the data shown in Figure 11 yields the conclusion that the Minimum Equipment Q-Date is always earlier than that related to the Diagram Phase Two effort. This is not surprising, but serves to emphasize that the time between the start of writing an equipment's Technical Specifications and the POA date is a significantly long period, and is deserving of close management.

In addition, the frequency by which the Dependent A-Date was earlier than the Independent A-Date demonstrates the importance of paying close attention to the integration of diagram calculation schedules.

CONCLUSIONS

POA Planning

The most obvious conclusion to be made from this study is that the normal practice of most shipyards, namely to schedule the POA of equipment based solely upon the need date of the hardware in the shipyard, should be changed. That approach will not provide the required vendor design data in time to efficiently support the ship design process. It is highly probable that many past problems blamed on "late drawings" were really due to inadequate equipment procurement planning, which precluded finishing the final drawings on time.

Program Applicability

Another major conclusion to be made is that the computer program developed as a Part of this study effort will provide shipyards with all of the information necessary for good, integrated scheduling of drawing development and equipment procurement.

It will identify the dates by which System Calculations must be com-

plete. Since these dates control all "downstream" activities of the design development and equipment procurement efforts, all other required dates can then be calculated.

Although not discussed previously, the program computes the required in-yard delivery date for every item of each type of equipment. This detail should be used whenever ordering multiple items of equipment, since it would minimize warehousing as well as encourage on-time partial deliveries.

The results of this study also highlight the importance of recognizing the design interrelationships of various systems, and the necessary control of design data transmission between dependent systems.

Reservations

The conclusions to be made from the results presented in this paper need to be qualified by noting certain aspects about the data used in the pilot test.

Construction Schedule - although the construction schedule data used was based on an actual shipbuilding project proposal, that schedule was relatively conservative, allowing a rather long time before start of construction. Of course, in order to obtain maximum productivity in modular shipbuilding efforts, the start of construction should be held off until the design has reached a mature state, so the schedule used is considered valid.

Size of Pilot Project - The number of systems used in the pilot project were relatively few, and included principally structure and piping systems. However, other distributed systems, such as HVAC and electrical wireways, are so similar to piping systems for purposes of this type of study that their inclusion would not change the conclusions.

The only impact on the computer program due to including more systems would be additional time for carrying out calculations. The calculation time for a complete recalculation of the existing data on a floppy disc is about thirty minutes. This time is increased by about three seconds for every additional row in any table. On the other hand, the full calculation is seldom needed. Once the initial data concerning systems, equipment and their unit-stage combinations are entered, recalculation can be limited to reflect only the specific changes made during future updates of the data. Also, with the database installed on a hard disc, the calculation time will be reduced.

Furthermore, no attempt has been made to date to optimize the computer program reported herein. Should the calculation time represent a true problem in the use of the program, a number of improvements are possible.

Finally, for the main purpose of the program, which is to generate integrated schedules for drawings and for equipment procurement, no calculations are necessary. Updates of current scheduled dates and actual completion dates, and generation of current schedules require no calculation time at all.

The reader will also have noted that many items of information such as drawing numbers, purchase order numbers, etc., are missing in many of the tables and reports. Obviously, these are items which have no effect upon scheduling. However, these fields ultimately will be mandatory, so a few were filled in to illustrate that they have been provided in the computer program.

FUTURE WORK

As in most research efforts, there are more things which can be done to further enhance the utility of the program presented herein.

One is to include other equipment related data for scheduling; specifically, ILS data. The inclusion of this data is an obvious extension, and can be accomplished with little difficulty.

A second as to make some minor modifications to the program in order to facilitate its use on a network.

This will allow data to be entered at different work sites simultaneously. It also will allow reports oriented to a specific organizations interests to be generated locally upon demand.

Third, a detailed description of the system and instructions for its use will be needed.

A proposal to accomplish the above tasks has been presented to the SP-4 Panel and tentatively approved. Hopefully these improvements will have been effected by the end of this year.

ACKNOWLEDGMENTS

The support of the members of the SP-4 Panel and, in particular the Ingalls Shipbuilding Division of Litton Industries, under whose guidance this work was accomplished, is gratefully acknowledged. The advice of a number of equipment vendors and vendor representatives was also of significant help in identifying the type of information which is crucial to a shipyard's receipt of good and timely information about equipment as well as of the hardware itself.

The conclusions and opinions expressed herein, and all of the estimates that were used for durations, etc., are the author's own, and do not necessarily reflect the conclusions of, or data from, any other source.

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A Design Oriented Model of Plate Forming for Shipbuilding

David Hardt, Visitor, Laboratory for Manufacturing and Productivity,
Massachusetts Institute of Technology, Cambridge, MA

Andrew Wright, Visitor and Edward Constantine, Visitor,
Department of Mechanical Engineering, Massachusetts Institute of
Technology, Cambridge, MA

ABSTRACT

Ship designers as well as product designers in general, are most concerned with the function and form of the design, and typically cannot pay adequate attention to the manufacturing consequences of their design decisions. Much of this problem can be alleviated by providing the designer with new tools that allow easy, yet thorough exploration of material and process options as part of the design process. This paper will present a prototype of such a tool, aimed at providing process information about bending and rolling of plate. The model presented is derived from first principles of mechanics and can provide a plethora of information. However the unique aspect of this work is the development and presentation of design-oriented information, such as optimization tradeoffs of process/material selection, and process control options ranging from purely manual to mechanized to fully automatic.

INTRODUCTION

In shipbuilding, as in general manufacturing, it is often difficult to address process oriented issues at the design stage. The designer's efforts are generally focused on the form and function of the marine structure, and little attention is paid to evaluating how design decisions affect the actual shipbuilding. Ship designers have very few analytical tools with which to evaluate these process oriented effects. The hypothesis here is that given appropriate process simulations, a designer could make choices which would also reflect fabrication considerations. This work concentrates on developing such tools.

The current scope of this research involves plate cutting and forming processes. Functional models have been developed for the processes of sequential bending and roll forming of metal plate for submarine hulls, and ongoing work is also directed at modeling typical plate cutting processes. A detailed discussion of the sequential bending model and its experimental verification is included in this paper along with a short description of the roll bending model.

It is essential to provide process models which, in an interactive format, allow the designer to accomplish several related tasks. First, the models permit a "single run" simulation of the process in which output geometry, stress state, and deviation from specifications can be evaluated for a particular set of input parameters. As an extension of this analysis, the models allow for "multiple run" process simulation in which typical control algorithms from operator control to fully automatic process control can be modelled and evaluated. Finally, the process models have been integrated into a wider evaluation scheme in which output data is used to generate sensitivity curves. From these curves, the designer can determine regions in which the process is less sensitive (i.e. more "robust") to variations in machine and material parameters. This set of information is of considerable value at the design stage. Constructive application of simulation information should result in a more successful design that is both easier to fabricate and less likely to deviate from specifications.

DESIGN-MANUFACTURING INTEGRATION

The research presented in this paper looks at the issue of design-oriented process simulation. This specific area of work is focused on plate cutting, forming and limited fixturing. As previously discussed, the specific intention is to create a prototype tool with which the designer can take fabrication considerations into account at the design stage. This effort is part of a larger ONR sponsored project at MIT which is concerned with the general issue of design-manufacturing integration in shipbuilding. This project also includes the modeling of welding distortion [1], and complex fitup [2]. In addition, CAD issues are being addressed with the intention of providing better methods of representation for the complex geometries encountered in hull design [3]. Figure 1 illustrates how this work combines with these of fixturing and distortion modeling.

The application of process models and simulations by the designer permits the prediction of part geometry, and more importantly the

prediction of deviation from desired geometry. This information is of significant interest when looking at the issue of fitup for assembly. Proper process investigation can significantly reduce the fitup effort. Also, the evaluation of sensitivity functions allows the designer to "discover" trade offs in the process, and use them to advantage. These sensitivity functions can also be used to minimize forming error, as they would facilitate a choice of process operating point that is less sensitive to parameter variations such as changes in material properties.

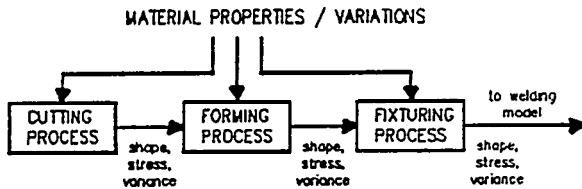


Figure 1: Integrated Weldment Design System

PROCESS MODELS

In describing the modeling aspects of this work, it is essential to make the semantic distinction between the terms "process model" and "process simulation". In describing a process model, one generally refers to an analytical tool developed from first principles that allows for the prediction of process output characteristics for a given set of input parameters. In this case, a model accurately predicts the geometry and state of stress of a bent plate, for a given set of inputs (machine geometry and material properties). One can incorporate the model into a process simulation by looking at the actual steps involved in "using" the process at the shop floor level. Here, one would examine the sequence of steps involved in bending a plate to a desired radius. This could, for example, involve an operator control algorithm (bend, measure, rebend) or an adaptive control scheme (bend, measure, then use this information to more accurately predict performance by re-estimating material parameter values). Also, one could apply the model to a closed loop, real time control scheme such as discussed in Hardt and Chen [4]. Thus, the simulation program incorporates a process model, and a measurement model into a parent program which follows a particular control algorithm.

The sequential bending and roll forming models have been designed so as to permit a "non-zero" initial geometry and state of stress for the plate being bent. This feature allowed for the development of a plate bending simulation which makes use of these fundamental forming models. This simulation is of significant value to the investigative designer.

User-interface programming has been added to the simulation, to permit the easy modification of model input variables, and a clear display of graphic data. This interface was written so as to be model independent making it flexible for future use. The graphics facilities have been implemented on a DEC Vax Station 3200 in the Ultrix/X-Windows environment, with all programs written in "C". Figure 2 illustrates the overall arrangement of the process model in an integrated process simulation program, and Figure 3 shows the basic display screen available on the engineering workstation.

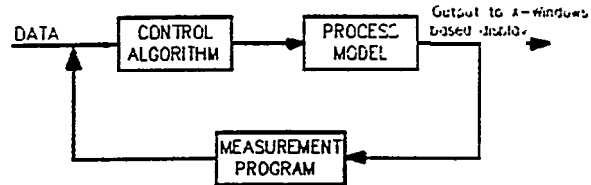


Figure 2: Simulation Block Diagram

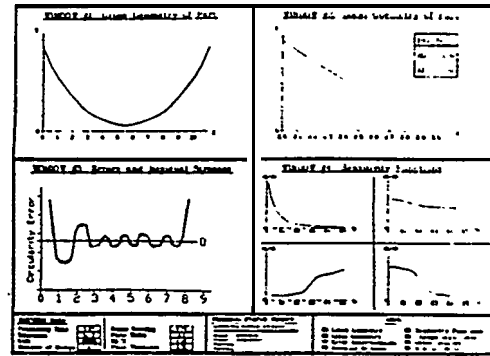


Figure 3: Sample Simulation Screen

SEQUENTIAL BENDING MODEL

The process of plate bending to achieve a circular hull section involves creating a series of overlapping plastic deformation zones to achieve an acceptable average curvature. However, unlike roll bending, this process will not produce a uniform curvature with arc length, but will instead result in a periodic variation in curvature about an average value. The following model has been developed to allow a process designer to examine the effect of machine geometry, bend line spacing and punch penetration on both the average and continuous curvature distribution along the arc length of the part. To assess the amount of yard-level control that will be necessary to achieve tolerance on a part (or alternatively the achievability of a part tolerance) the model is used as well to calculate local gradient in outputs with respect to process parameters of material yield strength (σ_y), thickness (t) and machine control accuracy via the punch displacement (Y_n).

The geometry of the bending process is simple three point beam bending as shown in Figure 4. As the punch penetrates into the workpiece, the maximum bending moment (under the punch) increases. If a linear moment distribution with arc-length is assumed (as done in all similar bending analyses [5,6,7]), then a corresponding loaded curvature distribution can be found given the basic constitutive relationship for the material, which for bending is the Moment-Curvature relationship. (Note that the latter is typically derived from stress-strain information assuming simple beam theory and pure moment bending. Although the influence of large deflections and transverse shear is important, it is assumed herein that such effects are of second order to this analysis.)

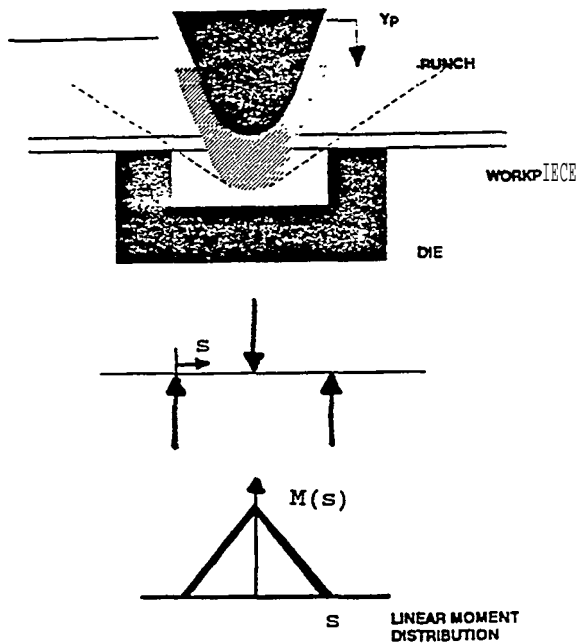


Figure 4: Basic Geometry of Bending

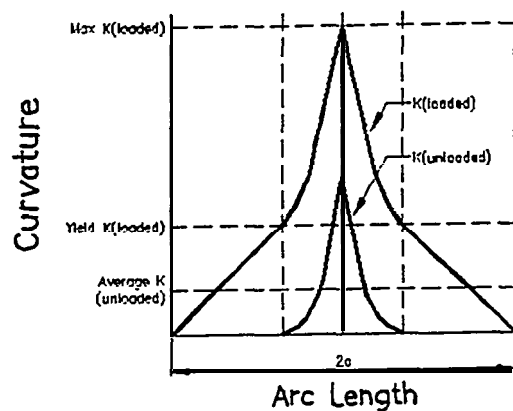


Figure 5: Single Bend Curvature Distribution

The bending model used here starts with a given machine geometry (die half-width a) and material properties (based on a linear strain hardening material model with elastic modulus E , plastic modulus E_p , and yield stress σ_y), and is then driven by a specified punch penetration Y_p . The maximum moment M_{max} is then matched to Y_p by an iterative series of calculations that integrates the curvature to find the center point deflection. Given M_{max} and the resulting linear moment distribution across the plate: $M(s)$, the M-K relationship can be applied to find the corresponding loaded curvature $K_l(s)$. Finally, the unloaded curvature distribution, $K_u(s)$ is found by applying an elastic moment of equal and opposite magnitude to the original load to account of the elastic springback. Thus we obtain:

$$K_u(s) = K_l(s) - \frac{M(s)}{S_e}$$

where $S_e = EI(1-\nu^2)$ is the equivalent bending stiffness of the plate section.

The key output of the model at this stage is, therefore, the curvature distribution $K_u(s)$ that results from a single bend. A typical result is shown in Figure 5, where the effect of springback is evidenced by the lack of permanent curvature change at the periphery of the die region. Also shown in the figure is the superposition of a sequence of identical bends to produce the desired average curvature. However, this figure does not accurately represent the process of deformation overlap that is the heart of sequential bending.

To appreciate this effect, consider the problem of the first few bends of a flat plate. After the first bend, the plate now has some initial curvature (see Figure 6). When it is incremented along the line of curvature, and the next punch penetration occurs, two important changes have occurred. First, much of the material that will be plastically deformed was also deformed on the previous step, and has potentially undergone strain hardening and certainly contains residual stresses. More importantly, the point of contact of the punch on the plate is lower than for a flat plate, and since the process is controlled on the basis of absolute punch position, this means a lesser effective penetration for a pre-formed piece than for a flat sheet.

Such effects must be included to properly simulate this process, as the curvature distribution of Figure 7 illustrates. Here a fixed punch penetration has been used for successive bends. The above effect is immediately obvious the first "bump" is of high magnitude (since the plate was flat) and the next bump is smaller owing to less "effective" penetration. Then a steady-state is reached as each sequence leads to a consistent ini-

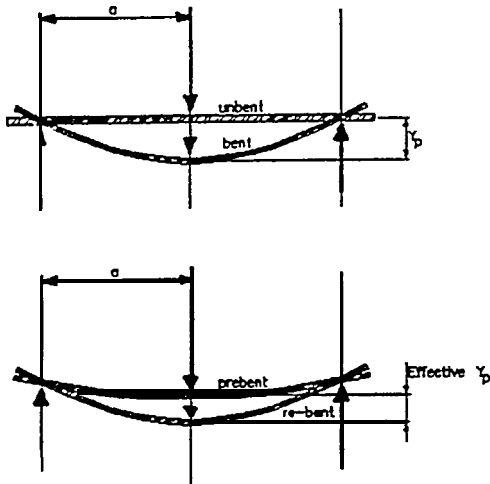


Figure 6: Effect of Prebend

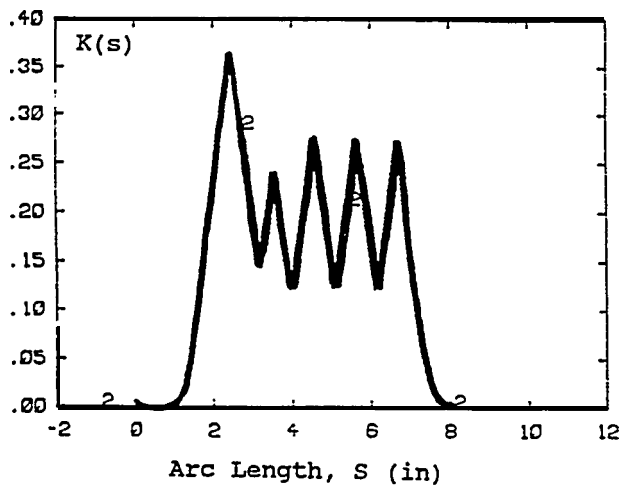


Figure 7: Total Bump Sequence

tial geometry.

As currently implemented, the model accepts a punch penetration and a bend spacing as inputs, the pre-bend plate curvature and residual stress state as in-process inputs and produces outputs of curvature distribution, $K(s)$, part geometry, (x,y) , and residual stresses, $\sigma_r(y,s)$. The model parameters include the plate properties (modulus, yield point, thickness, and strain hardening properties). This model structure is shown in Figure 8.

The analytical details of the model and its solution details are found in [8]. However, the basic structure of the solution is shown in Figure 9, where the multiple iterative solutions are shown. These are necessitated by the indeterminate nature of the punch penetration - plate curvature relationship.

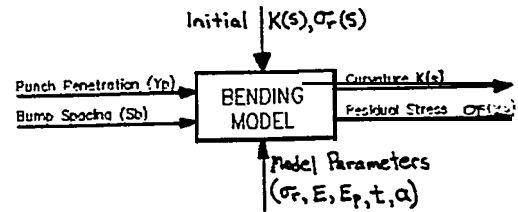


Figure 8: Bending Model Structure

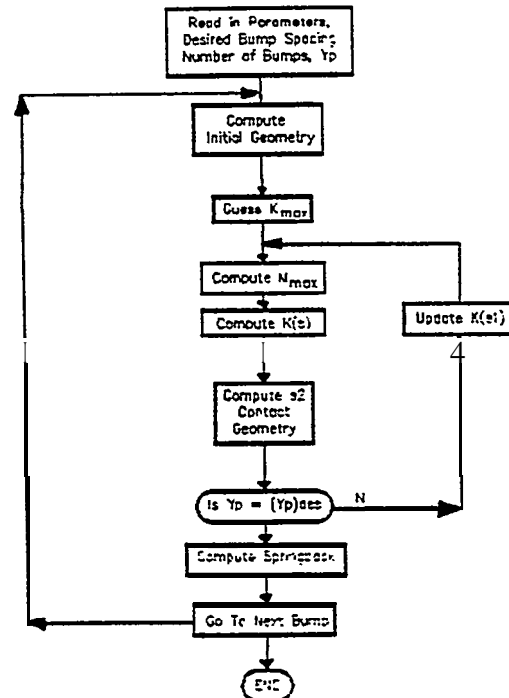


Figure 9: Bump Forming Model Flowchart

A typical set of results from the model is shown in Figure 10. Here, a sequence of 5 bends spaced 1 inch apart on 1/4 inch HY 80 is simulated. The punch penetration is fixed at 0.25 inches, and is kept constant. Thus, following the above definitions, this is a use of a *model* rather than a *simulation* since the latter would vary penetration to achieve a desired curvature. Figure 11 shows the net effect of all five bends in Cartesian coordinates.

Finally, the model is used to generate sensitivity functions that will be used to aid a designer in choosing operating points for the process that minimize output variations. The iterative calculations preclude analytical gradients, and thus local gradients must be explicitly calculated by perturbing the appropriate process parameter and observing the resulting outputs change. This must then be repeated for each parameter and is only valid at a given operating

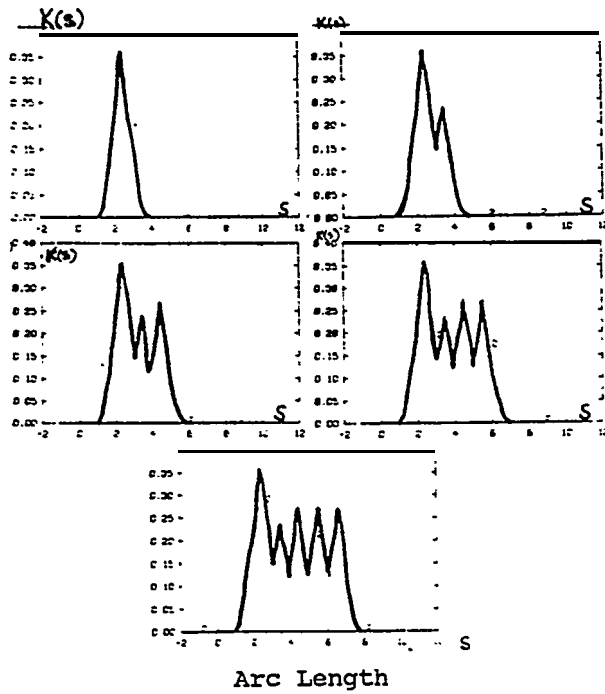


Figure 10: Sequence of Five Successive Bends

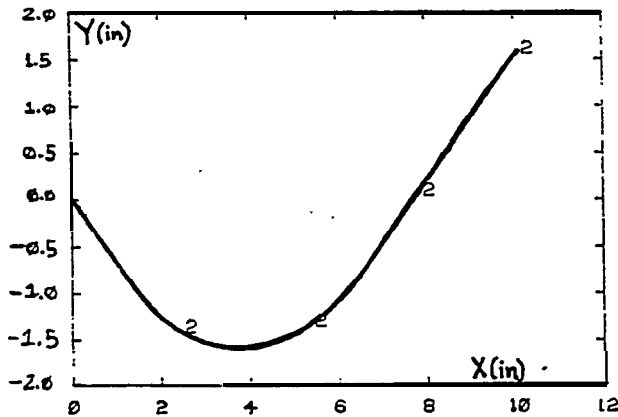


Figure 11: X-Y Profile of Part

point (i.e. machine geometry and desired curvature). The following gradients have been generated

$\frac{\Delta K_{ave}}{\Delta t}$	$\frac{\Delta K_{ave}}{\Delta \sigma_y}$	$\frac{\Delta K_{ave}}{\Delta E_p}$
$\frac{\Delta e_R}{\Delta t}$	$\frac{\Delta e_R}{\Delta \sigma_y}$	$\frac{\Delta e_R}{\Delta E_p}$

(where e_R is defined as the deviation in radius of curvature)

By far the most sensitive quantities are those relating to thickness and plastic modulus (since strain hardening has a strong influence on

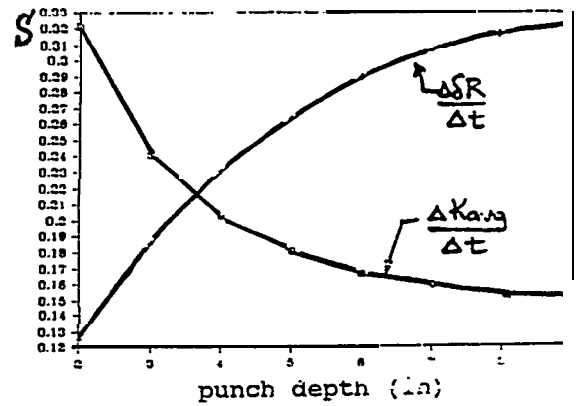


Figure 12: Sensitivity to Thickness

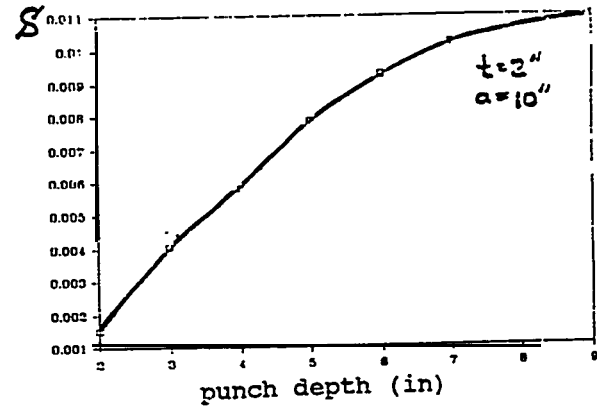


Figure 13: Sensitivity to Plastic Modulus

the size and shape of the plastic zone during bending). Figure 12 shows typical functions for circularity and K_{ave} thickness variations, as a function of punch penetration. This figure indicates, for example, that when thickness variations are significant (as they can be with thick plate), there is an optimal punch depth/bend spacing (which is related to punch depth for a given radius) that minimizes both average curvature circularity errors.

Figure 13 illustrates the effect of changes in plastic modulus of the material on the radial or circularity error. This measures the effect of changes in the work hardening of the material on the resulting variation in curvature. Notice again the strong dependence on the operating point (punch penetration), which in this case favors the choice of a shallow punch penetration.

The model presented here for sequential bending can be used for several purposes. One use demonstrated here is to study process sensitivity to parameter variations. This can in turn be used to develop a statistical picture of the expected variation of the process outputs. For ex-

ample, the parameters can be described by probability distributions and these in turn can be propagated through the model using the sensitivity gradients to develop a measure of the output's variance.

As previously discussed, this model can be incorporated into a process simulation, which facilitates broader exploration of the process. By evaluating the results of simulated process steps, the designer can obtain information about process behavior in general, and particularly about the tradeoffs which are involved in process optimization.

EXPERIMENTAL VERIFICATION

The sequential bending experiments were performed on a Cincinnati Inc. 90-ton pressbrake. A positive stop system was added to the machine to permit exact control of punch penetration. The workpieces used were 6 x 21 x 1/4 inch thick HY80 high strength steel. The objective of the experiments was to bend several pieces to a radius of 18 inches, with a 30 degree arc of approximately constant radius. It should be noted that this radius measurement refers to the radius of the bent plate, measured by a template, without taking the "head" and "tail" of the piece into account. Figure 14 illustrates the die and workpiece used in this experiment, and the steps involved in bending a plate.

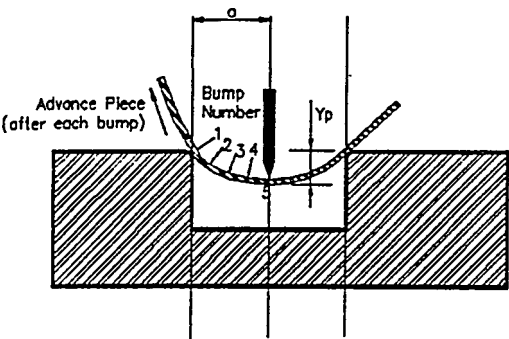


Figure 14: Press Brake and Sequential Bending Illustration



Figure 15: Roll Bending Geometry

In bending the plates, an "operator control algorithm" was used. Specifically, a given piece was first bent using a fixed punch penetration over a sequence of evenly space bends. The punch penetration was then incremented for the next bend. The amount of penetration change was chosen intuitively, by the "operator" with the intention of "sneaking up" on the desired radius without overbending. During each experiment the bump spacing and sequence of punch penetration values were recorded. Measurement of each radius was done using radius templates.

To verify the model, the exact sequence followed in each experiment was simulated. This involved starting with material properties values gleaned from a series of tensile tests performed on the same material, and applying exact measured values of plate thickness, initial geometry and machine geometry to the computer model. After each simulated bend, a measurement program was used to fit a circle to the plate's geometric data. This radius was then compared to the measured intermediate and final radii found experimentally. For each bend, the previously calculated state of geometry was used as an initial description of the plate.

This sequence of steps was carried out for three pieces. In each case, the punch penetration sequence was varied, so as to investigate the effects of changing the bending history of the plate. Tables I through IV describe the data obtained for this sequence of three confirmation experiments. From Table II it is apparent that the model, as initially calibrated, did not provide accurate predictions of the forming tests. However, as is implied by Table III, this discrepancy was overcome by modifying the initial calibration data, specifically the material properties of yield and strain hardening. These are, as expected, the most indeterminate of the process parameters, and such variations can be expected. Comparing

Table I:
Initial Model Calibration Data:

Plate Thickness	= 0.278	inches
Plate Width	= 6.0	inches
Plate Length	= 21.0	inches
E	= 3.0e10 ⁷	psi
E _p /E	= 0.15	
σ _{yd}	= 90,000	psi
a _{yd} (die half width)	= 2.4	inches
Y _p (punch penetr.)	= VARIED	
ΔBS (bump spacing)	= 1.25	inches
# of Bumps	= 11	

Table II:
Experimental Results and Initial Model Predictions:

Plate #	Bend	Yp	Ravg (exptl)	Ravg (model)
01	1	0.204	211	15.70
	2	0.220	209	15.70
	3	0.236	201	15.68
	4	0.268	180	13.77
02	1	0.173	220	18.99
	2	0.236	205	15.66
	3	0.268	180	13.75
03	1	0.236	17.8	13.32

Table III:
Modified Model Calibration Data:

Plate Thickness	= 0.278	inches
Plate Width	= 6.0	inches
Plate Length	= 21.0	inches
E	= 3.0e7	psi
E _p /E	= 0.25	
σ _{yd}	= 100 000	psi
a (die half width)	= 2.4	inches
Y _p (punch penetr.)	= VARIED	
Δ _{BS} (bump spacing)	= 125	inches
# of Bumps	= 11	

Table IV:
Experimental Results and Revised Model Predictions:

Plate #	Bend	Yp	Ravg (exptl)	Ravg (model)
01	1	0.204	211	20.87
	2	0.220	209	20.87
	3	0.236	201	19.88
	4	0.268	180	16.78
02	1	0.173	220	22.50
	2	0.236	205	17.57
	3	0.268	180	15.46
03	1	0.236	17.8	17.30

Tables II and IV, it can be seen that this re-estimation of these material parameters results in much improved model predictions. Also, it is significant to note that the model successfully predicts the radius of the plates for three different bending histories. The first plate was bent much more gradually than plates 2 and 3, however good agreement between the model predictions and the experimental results can be seen in Table IV for all 3 plates. This is due to the fact that this process model takes the "initial" geometry of the plate into account before running each iteration of the simulation.

It is readily apparent that by modifying the initial values of material parameters slightly, agreement between the model and the experimental data was obtained. A primary source of

error in this experiment was the initial lack of flatness of the plate used. This plate was found to be out of flat by as much as 0.050 inches. Correction for this lack of flatness was made in the "runs" shown in Table IV, above.

ROLL BENDING MODEL

The objective of this model is to relate the process input (the roll diameters, spacing and center roll displacement) to the desired outputs of plate radius and residual stresses. In addition, the model will provide sensitivity functions for these outputs with respect to material property and geometry variations.

The basic geometry of the process is shown in Figure 15. The model employed here is based on one developed by Hansen et al. [7]. Only the basic form of the model is presented here. The basic calculations follow much of what is described above, except that the shape of the plate is different between in-coming and outgoing sides. While the same triangular moment distribution applies here, the incoming material sees this as a loading moment, thus the loading portion of the M-K relationship is applied to find $K_1(s)$. However, once the material passes the center roll, it is unloading, and the M-K relationship becomes linear. Thus, a non-symmetric $K_1(s)$ will result. This greatly complicates the calculation of the center roll penetration since this is found by integrating plate curvature to find plate contour. As a result, the execution of the model requires iterative calculations that seek to match roll penetration, boundary conditions and plate shape.

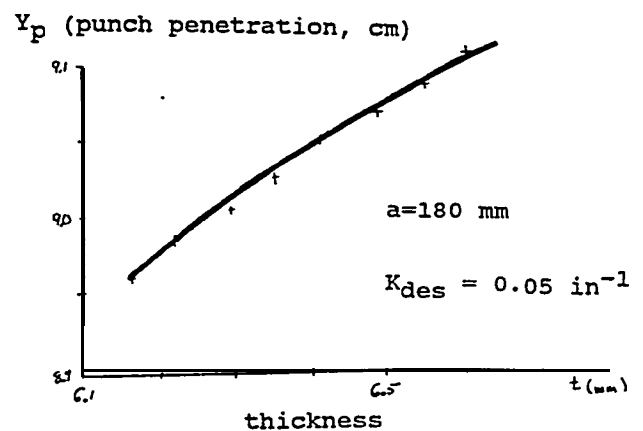


Figure 16: Effect of Thickness on Roll Displacement

As opposed to bending, rolling does not have the process "freedom" to modify input, since there is only one: the center roll displacement. However, the model does allow one to examine the effect of process uncertainty and to explore

the effects of machine geometry (i.e. roll spacing and radius). Since the roll bending process does indeed ensure circular parts, the main use of the model at this point is to generate sensitivity functions so that process optimization studies and statistics propagation can be performed. For example, the effect of thickness on center roll displacement can be seen by the data in Figure 16. Clearly, variations in material thickness will cause significant errors if the roll displacement is not corrected.

This process model, like the bending model, can be incorporated into a process simulation scheme. The graphics and user interface features (Ulrix / X-Windows based) which have been developed can be used with either process model. This approach also supports the implementation of control algorithm and measurement programs for the simulation of various fabrication methods.

CONCLUSIONS

Design oriented process simulations can provide a wealth of information. It is constructive and useful to provide the ship designer with tools that permit the investigation of process oriented questions through accurate simulation. The prototype presented here, for the investigation of the sequential plate bending and roll forming processes, is an example of such a "designer-focused tool. The implementation of such tools in ship design stage would result in a better product, since fabrication considerations could then be evaluated by the designer in a simple yet thorough manner.

ACKNOWLEDGEMENT

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A Systems Approach to Small Parts Painting

Les Hansen, Visitor and William Appleton, Visitor,
National Steel and Shipbuilding Company, San Diego, CA

ABSTRACT

Shipyard painting is most often viewed as pure ship construction operations, where the painting of the hull, deck, superstructure, and cargo spaces makes up the total effort and cost. This view may be justified when analyzing various trade production costs as parts of the total ship cost. However, parts preparation and painting costs are significant when looked at in summary as a new construction or repair contract sub-cost item.

Once addressed, the historical means and methods for small parts painting in shipyards appears to leave much room for improvement. What happens, then when a systems approach is applied to shipyard small parts painting? Can study techniques, analysis and design be adapted to facilitate painting systems which are cost effective for this industry? This paper attempts to answer these questions by presenting discussion of:

- 1 Manufacturing Concepts of Parts Painting
- 1 Use of Industrial Engineering Analysis
- 1 Systems Configurations
- 1 Systems Cost and Justification

FOREWORD

This feasibility study represents the reincarnation of a research project initiated several years earlier by Avondale Shipyards under the pervue of SNAME Panel 0-23-1 (now SP-3), Surface preparation and Coatings. Avondale discontinued work on this project shortly after contract award. The objective of the earlier study was to establish the feasibility of automated painting of small parts, with emphasis on state-of-the-art automated material handling, blasting and coating equipment and systems.

The focus of the present study has been shifted to include the broader scope of all collateral parts painting operations, as well as coating process methodology. Automation is viewed not necessarily as an end, but rather one choice in a series of possibilities to maximize shop efficiency. The revised objective has therefore become the establishment of a true "Systems Approach" to small parts painting. The desired result is reduced shop painting costs through improved productivity and ultimately overall shipbuilding cost savings.

The economic significance of productivity improvements in shop painting should not be overlooked. Combined costs of painting small parts at NASSCO, averaged for the previous several contracts, are estimated to comprise nearly 20% of the entire ship painting budget.

The authors have intended this report to be highly user oriented. The target audience, then, is the Production Departments and specifically Paint Supervision. In addition, Shop Managers, Planners and other Staff Support personnel may glean useful information from the discussions herein. Hopefully, the ideas and recommendations put forth in this report, in whole or in part, will benefit the entire shipbuilding industry.

INTRODUCTION

Automation. . . . A high sounding term, a stock seller on Wall Street, a bright beacon to an undergraduate engineer, "tomorrowland" to the man on the street, and reality for manufacturing of the 1980s and 90s. It is here, it works and more often than not, it is expensive-very expensive. Therein lies the reason for addressing automated painting of small parts in a feasibility study.

- 1 What level of automation fits?

- What are the costs?
- Are the costs justifiable?
- Is there something else?

These are the questions; this study is intended to provide the answers. However, this project is not intended to address automation for painting small parts in a narrow context, but to develop a larger overview of maximizing shop painting operations. This study, therefore, also deals with planning, scheduling, handling and handling equipment, and rework reduction—in short, a Systems Approach to painting small parts. Some specific problems will be addressed and solutions will be proposed along with costs versus potential savings.

The study will utilize the latest painting technology from various sources and accepted Industrial Engineering practices to develop improved methods or systems and determine the feasibility of implementing these improvements in terms of capital investment, time, and ongoing costs.

To address automated painting of small parts in a shipbuilding/repair setting without a full comprehension of that setting would be a useless exercise. Since highly developed, sophisticated systems require equally balanced systems and methods for planning, scheduling, identifying and controlling materials and material movements, this must be a study in overview which ultimately works down to detailed possibilities.

This study will:

- IDENTIFY and CLASSIFY Groups and Families of Small Parts. [Group Technology]
- DETERMINE CURRENT SYSTEMS and METHODS In Use for Controlling and Processing Small Parts.
- DEVELOP PROPOSED IMPROVED SYSTEMS for Doing the Same: Planning, Scheduling, Handling, Mechanizing and Automating.
- ANALYZE the FEASIBILITY for Such Improvements.

STUDY PREPARATION

A feasibility study conducted with a view toward shipyard industry-wide benefits suggests several things concerning potential results:

- Certain results or data presented by the study may be applicable to one yard and not to another.
- Even where two yards may have exactly applicable situations, the view on economic justification may vary widely resulting in acceptance by the one and rejection by the other.
- Only partial data extracted from context could be applicable.

Therefore, at the outset, this study required scope and objectives which could permit generalization of results and, at the same time, maintain clear and specific details for ease of application and use. Moreover, a base of reference was needed. . . . actual small parts painting operations. Since the project did not permit a scope whereby multi-yards could be used as a basis, NASSCO'S more recent work contracts as well as the current contract for the Navy AOE-6 were selected.

If automation and the many other factors leading up to and/or supporting automation were not already present in the operations (and they were not), other bases were needed. Leading paint suppliers for coatings, equipment and shop systems would be approached along with production organizations outside the shipyard industry. This, then, formed the three position bases for study references.

- NASSCO AOE-6 Contract Planning: Actual Shipyard Requirements
- Most Current Equipment and Systems: New Sources Data
- Other Industry Users: Actual Operational Data

The generalized objectives of the study could be lost if the process started from a current condition (NASSCO operation) and worked through a single revised (improved system) condition, thus being rather heavily subjective. As a matter of fact, the capability to do exactly that was a most desired result of the study; however, it had to be applicable to essentially any shipbuilding or repair yard, wholly or in part. Therefore, the study had to work from several perspectives. simultaneously; gathering data from the three study bases and analyzing the applications to both specific NASSCO operations on one hand and a valuable industry-wide potential on the other. Thus, the study was initiated on several fronts.

A further question arose in completing the preparations. How could data best be compiled concerning current small parts painting operating practices? Ultimately, some quantitative analyses would be made in order to deal with economic justification, and the industrial engineering method filled this requirement. The application of this technology is discussed in a later section.

These were guidelines for the work of this study:

- A Scope Permitting Generalized Results Supported By Sufficient Details.
- A Three-Point Base of Reference.
- The Industrial Engineering Method.

SMALL PARTS PAINTING: A Manufacturing Operation

Let us place small parts painting into the context of building a ship. When a part has been fabricated, it requires painting; and when a weldment (sub-assembly/assembly) has been completed, it requires painting. Some purchased parts require painting other than supplied by the vendor. Therefore, small parts painting is technically an operation within a continuum for the completion of a part prior to the next order of assembly.

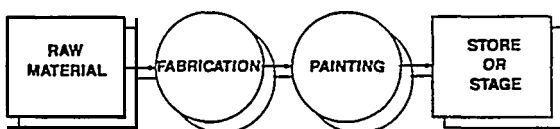
This relationship can be seen in the Classic Manufacturing Shop, where work flows through fabrication operations to paint to inventory or shipping. Thus, a yard may ask if paint operations shouldn't be contiguous to other fabrication source operations, What does this do to transportation costs, control costs, damage or other factors?

Should painting operations be self-contained and for what reasons? Is this justified? It may be that a highly cost-effective automated or semi-automated Paint Shop should be self-contained and centralized due to decentralized fabrication and receiving sources (in the case of purchased items).

Nevertheless, painting is difficult to define as an "independent operation" for small parts when viewed as part of a continuing process flow.

Parts Painting is not just some unrelated operation...

IT IS PART OF THE MANUFACTURING PROCESS.



Once painted, the part can be stored, even in bad weather, for the next weld or assembly operation.

Painting may be an independent operation for many reasons from yard to yard. These reasons should be analyzed.

- Painting is a *SEPARATE TRADE*, a *SEPARATE DEPARTMENT*.
- Mixing painting with other fabrication is not desired.
- Air pollution controls, requirements, etc. present complications.

These may be some concerns and there are others.

To be contiguous, the parts painting operation does not have to be housed with the afore occurring fabrication operations, however, the flow relationship should be evaluated. Is the cost to move to and through the paint operation reasonable or are there cost effective alternatives? This study offers" some methods for evaluating the problem.

PLANNING FOR MANUFACTURE

If a yard wishes to advance the cause of small parts painting through automation or semi-automation, should it go for the expenditure, train some people and turn the paint group loose? Hard-Iy! Well, it might just work for the yard that has perfect flow, perfect planning and scheduling, and perfect methodization for small parts painting, but is any yard at this point?

The assumption is that most yards need to get through an evaluation of the current state of their "Planning for Manufacture" as relates to small parts. Problems exist whether the painting operations are centralized or decentralized.

PLANNING FOR MANUFACTURE

- Part Operation Planning
- Part Operation Scheduling
- In-Process Control
- Finish Part Storage
- Proper Identification

These activities need to be perfected as a foundation for a good manual paint operation as well as the most automated one. Therefore, let us examine each in some detail.

Planning: Either the part fabrication planner must know paint planning as well as fabrication planning, or a fabrication planner and paint planner must work side by side. A shop routing card saying "paint" or "paint green" just is not enough.

What surface preparation is required? What paint system and which coats are required? Are there special instructions? What is the post-paint routing? These questions, properly answered, are the foundation of any good planning practice.

Scheduling This goes hand in hand with planning. Whether your yard works to "Just in Time" or "Inventory" or, as is common in most cases, a combined approach, you should be clear as to a finish date and, therefore, the start date. The latter is where each yard tends to develop its own best method. When to start a part, based upon a given finish date, has to do with: How long the fabrication cycle takes; how much level loading of labor, machines and processes are required; and what particular bottle necks or limiting operations exist.

This study cannot deal with these issues in detail, but it is most important to give recognition to the essential nature of good scheduling.

Parts painting schedules are derivatives of parts fabrication scheduling. It's fair to say, "Who gets to schedule parts painting? The parts come, always late, and you blast and paint them as best and fast as you can!" This study tends to find agreement that parts painting by nature is a vassal to the fabrication operation, however, all the more reason for the dual, simultaneous planning for fabrication and paint. There is reason to look at communication across the related activities (yard trades) to test the strength of these foundations.

in-Process Control: This is an individual function with each yard and each shop within a yard. There are many ways to achieve this control. The important point in this study is simply that it be done, be re-evaluated, and upgraded as necessary.

The key to any flow lane, any shop, any process is "through-flow". Handling and re-handling does not improve or change the value of a part... never did and likely never will. The physical layout and facilities relationships of a good small parts painting operation are covered later. However, the best

through-flow layouts tend to yield the easiest In Process Control Systems and procedures (and least in process delays).

Storage, Staging and Routing What good does it do a yard to perform all that precedes this point to perfection and not do well here? The ultimate operation for the properly fabricated and painted part is the proper and safe location for that item to be used at the next level of assembly.

Evaluate this function as a key to analyzing your state of planning for manufacture.

Identification: It is all too easy for a yard to expend costly labor hunting, correcting, repainting or remaking misidentified parts. Most yards are not having problems with original identification, this is covered on the prints. The real problem is the physical identification of the part(s), which has to do with how (The Method) and what data need be included. Will Part Number do or is next assembly identification required as well? The answer will generally depend on the coding system employed by design engineering. Both questions are important.

There are many supporting techniques for good manufacturing planning. Quantification of process time and man-hours is of the utmost importance. Operation overview through flow process and operation analysis along with some other industrial Engineering Methods deserve some review and are discussed later.

A Thru-Put Technique

If a yard can schedule parts painting as the last fabrication operation as suggested previously, a delivery date can be determined and a specific priority schedule can be followed through the painting cycle. If a "first-in/first-out" policy is the norm, some kind of priority-setting is required. Here is a simple thru-put technique which requires order and discipline to set up and maintain but will offer a good plan for man-loading action.

Desired things to know:

- (1) Delivery Date or need date. Where this is not predetermined, set this date from receipt plus three days or five days...whatever fits.
- (2) Available Date or date received. Make certain to manifest all parts received daily. Tag the parts with a brightly colored tag.

- 3) Process Time Available is the difference between (1) and (2). If Parts are late or will be late when complete even if expedited, these are the number one priority.
- (4) Establish a Measurable Unit (M.U.). This may be a large or medium part like a foundation or large valve. It is also a quantity of small parts, maybe 25 hangers.
- (5) Determine a Rate Per M.U. in man-hours. How many man hours to blast? To paint? (Include all handling and set-up time).

Now, on a daily basis record the date received, the delivery date required and the number of M.U.s for every work item (along with proper identification, work item numbers, etc.) Then, by day or week all M.U.s can be summed and the product of (M.U.) x (RATE) can be determined. If a small computer is available, a D-base or Lotus 1-2-3 spread sheet can be used. The computer is not, however, necessary.

A sample analysis for a six period thru-put (Figure 1) shows how simple this can be.

The leveling analysis, which deals with the over demand or under demand for a given work period, is most important (Figure 2). Since the mean (man-hours) for six periods will vary with the production requirement, management must decide whether to vary the manpower provided from period to period or to move the work forward and backward in order to keep a fixed crew size over the six periods.

The key questions are:

1. Can manpower be easily and efficiently moved from small parts painting to other operations?
2. Is the work available for forward moves in schedule?
3. Can some work be moved backward in schedule? Which work?

in the combining of periods for further level load analysis (Figure 3), it can be seen that two levels exist with a mean difference of almost 250 man-hours (243.75). This strongly directs management to look for work "to fill" or manpower to move tooth-er operations after period four.

THE INDUSTRIAL ENGINEERING METHOD

The Industrial Engineering Method, like all technology of the twentieth century, has simple beginnings, a rapid history of development, and a high-tech presence. Simple and more basic tools were needed for this study and, fortunately, these are easy to learn and apply no matter the size or complexity of yard operations under study.

The Flow Process Chart can be the foundation for analyzing a small parts painting operation (or any yard operation for that matter). A sample from our study is shown here in Figure 4.

This form is classic and the symbols have been standardized through years of practice. The chart can be used for actual studies where a person can observe what is being done and record the work, the time it takes, the distances involved, and notations, therefore establishing basic data (1), (2).

PERIOD	1	2	3	4	5	6
M.U.* Count	1000	1500	1250	2000	900	1000
RATE/M.U.**	.5	.5	.5	.5	.5	.5
Manhours	500	750	625	1000	450	500
Mean***	637.5	637.5	637.5	637.5	637.5	637.5
Leveling	+137.5	-112.5	+ 12.5	-362.5	-187.5	+137.5
COMBINED PERIODS	A			B		
	1	2	3	4	5	6
Mean M—Hrs (A)	718.75	718.75	718.75	718.75		
Leveling (A)	+218.75	- 31.25	+ 93.75	-281.25		
Mean M—Hrs (B)					475.0	475.0
Leveling (B)					- 25.0	+ 25.0
* M.U. is Measured Unit ** Manhours/M.U. *** Average for 6 Periods						

Figure 1

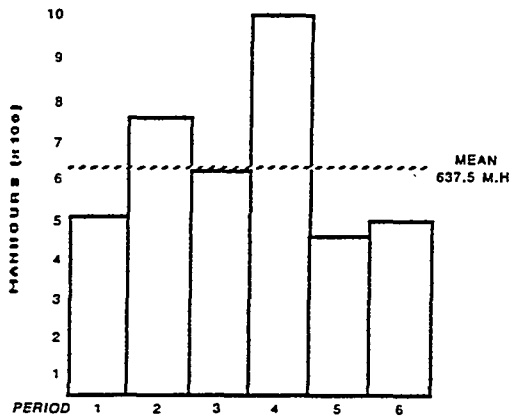


Figure 2

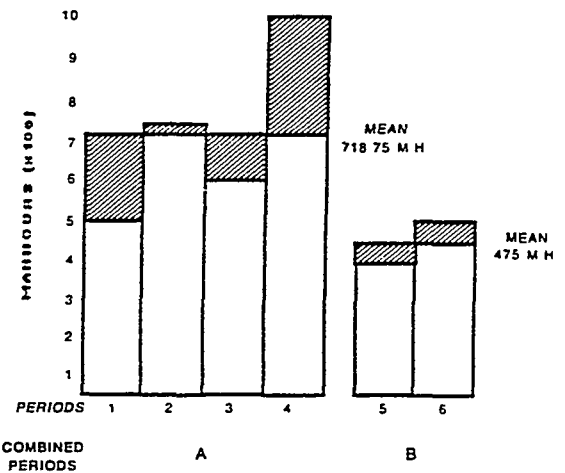
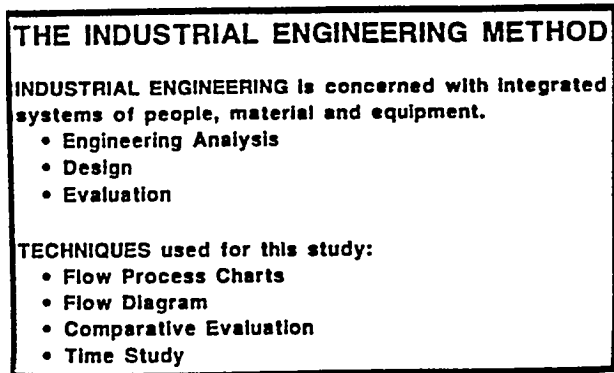


Figure 3

FLOW PROCESS CHART

SUBJECT: VENT DUCT/STEEL - BLAST & PAINT 4' LG X 8" DIA. (LOT SIZE) - ONE PIECE PER PALLET CHART BEGINS: SHEETMETAL STORAGE CHART ENDS: POST-PAINT STORAGE (AREA 'A')						
DESCRIPTION	SYMBOLS	DISTANCE MOVED IN FEET	UNIT OPER TIME IN HOURS	UNIT TRANS TIME IN HOURS	DELAY TIME IN HOURS	STORAGE TIME IN HOURS
PER SHOPCARD, MOVE PALLET FROM S/M STG TO AREA 'A'	○ → □ ▽	1500		.31		
MAT'L REC'D BY MAT'L HANDLER AND PAINT DEPT.	● → □ ▽		.08			
MOVE FROM AREA 'A' TO BLAST	○ → □ ▽	800		.20		
BLAST STORAGE	○ → □ ▽					
MOVE TO PARTS AREA OF BLAST	○ → □ ▽	40		.10		1 SHIFT - 3 DAYS
BLAST (MANUAL)	● → □ ▽		.78			
MOVE TO STAGING AREA	○ → □ ▽	50		.10		
BLOW-OFF MATERIAL	● → □ ▽		.02			
INSPCT	○ → □ ▽		.03	.10		
MOVE TO PAINT AREA STORAGE	○ → □ ▽	100				
PAINT STORAGE	○ → □ ▽					MINS - 2 SHIFTS
I.D. AND MARK COATING	● → □ ▽		.08			
INSPECTION (NAVY)	○ → □ ▽		.03		(4)	
MOVE TO PAINT WORK STATION	○ → □ ▽	40		.10		
PAINT (PRIME ONLY)	● → □ ▽		.79		(DRY) 4.0	
INSPECT	○ → □ ▽		.03			
REMOVE AND PLACE ON PALLET	● → □ ▽		.02			
MOVE TO AREA 'A'	○ → □ ▽	40		.10		
STORAGE PRIOR TO SHIPPING	○ → □ ▽					1 SHIFT - DAYS

Figure 4



The chart can also be used in analyzing a proposed operation using the basic data established by previous study observations. Final procedures or instructions for a new operating plan can be presented on the chart, which is easy to read and understand.

The Flow Diagram is the product of the flow process study(s).

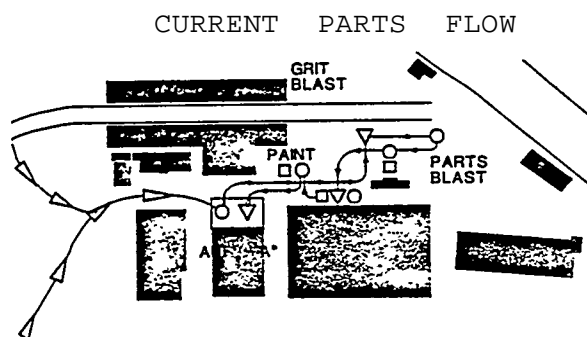


Figure 5

The use of a scale plan view of the physical area is recommended for analysis as well as presentation to management. The "before" and "after" effect can be dramatic since movements and distances are vivid. Often it is necessary to use large scale sizes (and therefore print sizes) for this work when there is great detail within an area or great distances to show.

Flow Symbols and a recommended use are important. Make certain that a common understanding exists as to what each symbol is to represent. Define this before any studies are started and then maintain these definitions throughout the project.

Not all activities are necessarily identified above. However, each and every significant activity should be assigned a standard symbol for consistency of data accumulation and evaluation.

These accepted uses of the symbols are recommended.

SYMBOL	GENERAL REPRESENTATION	FOR THIS FEASIBILITY STUDY
○	OPERATION	PAINTING OPERATIONS BLASTING OPERATIONS SET-UP OPERATIONS MANUAL HANDLING
◻	TRANSPORTATION	INTRA-AREA MOVEMENT INTER-AREA MOVEMENT
▽	STORE	PARTS OR MAT'LS HELD FOR PROCESSING OR DELIVERY
D	DELAY	DRYING TIME CURING TIME ANY WAITING TIME
□	INSPECT	CALL INSPECTOR WAIT FOR INSPECTOR INSPECT PARTS OR MAT'LS

Figure 6

Time Values are important to the ultimate study accomplishments. Time to perform work is the direct labor cost of the painting or related activity and idle time is a probable non-productive cost. The use of a wrist watch with a sweep second hand is recommended in these kinds of Flow Process Chart studies. A minute is an acceptable level of accuracy although .25 minute intervals may be desired and can be easily read and recorded. Where something more critical is desired the time study watch or decimal stop watch will be needed.

When a number of studies are made (this will generally be the case) the data must be correlated. This is most easily done by a spread sheet recap. Accumulate all like elemental work time values, delays, distances, etc. and arrive at unit time values, such as: time per piece, square foot, 100 feet moved.

Comparative Evaluation, niost popularly called the Before and After, has to be the ultimate objective of the Industrial Engineering Method. This forms the bases for action, direction, and justification.

Where two or more existing or proposed small parts painting operations or systems can be flow analyzed and timed, total times and total distances and all other appropriate data can be compared and a total cost for one possibility versus another (or others) established. This then determines the levels of expected improvement, payoff, return on investment, or whatever basis a yard may use to justify expense and/or capital funding.

COMPARATIVE ANALYSIS

- BEFORE AND AFTER
- THIS VERSUS THAT
- SYSTEMATIC ANALYSIS OF EXISTING AND/OR SUGGESTED CONDITIONS
- RELATIVE EVALUATION OF ELEMENTS AS WELL AS TOTAL EFFECTS

Subsequent sections will include some actual applications of the Industrial Engineering Method just discussed.

SMALL PARTS IDENTIFICATION AND CLASSIFICATION

The first order of business for the project was identification and classification of small parts to be included in the study. This step would, in effect, define "small parts" and provide a scope for all further studies and analyses to be conducted. Theoretically, any item painted prior to block (module) or unit assembly, or prior to on-board installation, could be considered a painted "part". There are thousands of such items on a typical large hull.

A reasonable starting point for small parts definition would be to include all, or nearly all, items traditionally painted in NASSCO's Main Paint Area (an open air "shop") or any "satellite" paint area adjacent to the fabrication shops. Points of origin (NASSCO shops, outside vendors, etc.) for these items are significant for sections of the study related to planning, scheduling, routing and handling.

Next, a grouping by size and weight would be required to further narrow the parts scope to a meaningful range for the project. The maximum part size chosen was 60" X 60" X 24" to permit inclusion of a majority of the steel angle foundations commonly encountered. This upper limit size corresponds to a weight of several hundred pounds or more and would require a fork lift and/or small crane for handling. The smallest part could be a 2" x 3" staple weighing a fraction of a pound.

In addition to parts, raw stock shapes (angles, flat, bar, pipe, etc.) to be used in parts fabrication or on-board outfitting, were also included in the study since much of this material is primed in the Main Paint Area. Raw stock varies in cross sectional dimensions and weight and is generally handled in twenty foot lengths.

A parts classification list was developed using NASSCO's AOE-6 contract as a point of reference. Parts were grouped by type, indicating origin, and an approximate quantity was noted. From this list, thirteen items were selected as best representatives to form the "Typical Parts List" used as a basis for further study. (See Appendix 2 for List).

A further approach to classification would be to examine parts in the context of their respective coating requirements. Parts can be grouped by the type of coating and extent of the system to be applied at the shop painting stage. For example, some parts may receive primer only, others one or more intermediate coats, and still others a full system including topcoats. Parts receiving identical coatings can then be grouped together for purposes of surface preparation and painting. Typical coating systems used as a basis for this study are those specified by the NAVY for AOE-6. (Figure 7)

At this point, a question may arise concerning how to determine the extent of the coating system to be applied at the shop painting stage. Is it best to apply primer only, a full system, or somewhere in between? This clearly is a production planning issue and should be given considerable attention early in the planning process with strong input from the Paint Department.

Several factors will need to be considered and analyzed, however the bottom line is the overall cost of shop painting vs. painting at other construction stages. On the surface, it would appear shop painting is clearly most cost-efficient, since an industry rule-of-thumb says on-board labor costs are generally two to three times higher than shop labor costs for identical work. However, when inserting onboard and on-block paint rework costs into the equation, the picture may change significantly.

Consider the amount of potential coating damage encountered after a part leaves the Paint Shop: Transportation and handling damage; environmental damage from the elements; dirt, grease and oil contamination; and probably most significant is the damage caused during installation, either by welding or installation tools. In addition, ECNs, PCNs or missed schedules frequently create hotwork damage long after part installation.

When these paint rework costs can be accurately determined and analyzed, they may make a strong case for applying only prime or intermediate coats in the shop and all finish coats as late as on-board schedules will allow. Certainly, this analysis should

COAT No.	LOCATION		
	EXTERIOR TOPSIDES	INTERIOR, DRY SPACE	INTERIOR, WET SPACE
1	INORGANIC ZINC SILICATE	MIL-P-24441 EPOXY (F-150)	DOO.P23236 EPOXY
2	MIL-P-24441 EPOXY (F-151)	DOD-C-24596 W.B. FINISH	DOD-P-23236 EPOXY
3	TTE-490: SILICONE ALKYD	DOD.C-24596 W.B. FINISH	—
4	TTE-490: SILICONE ALKYD	—	—

WATER BASED

Figure 7

be made on a case basis for individual outfitting items or families of parts. Where coating damage is expected to be minimal or non-existent (such as on machinery), a full-system shop application would likely be justified. Finally, all attempts should be made to reduce on-board paint rework to a bare minimum.

In passing, we mention a technique that we consider the best methodology for properly setting up a classification system of parts where numbers, variables, and computer codification are involved. This methodology is broadly known as Group Technology and is covered in a forthcoming SP-1 Project Report. An example is shown in Figure 8.

CURRENT METHODS

Small parts painting procedures and methods have remained virtually unchanged over NASSCO's long history of building ships. This aspect of operations has been, for one reason or another, basically overlooked whenever facility improvements were considered. Possibly, parts painting is the victim of the adage: "If it works, don't fix it", or "Out of sight, out of mind" since the parts area is set off in a remote corner of the shipyard. Whatever the reason, we think it will be obvious from this discussion of NASSCO's current parts painting methods that there is plenty of room for improvement. More than likely, this will be the situation at many other shipyards.

San Diego is "blessed" with a very mild and dry climate. So NASSCO, unlike most yards, is in the unique position of being able to perform much of the blast and paint operation in the open air, without the need for enclosures or even covered areas. The few rainy days that do occur in the winter may present a minor problem in the form of schedule delays. This seemingly ideal situation may, however, be a mixed blessing. Having a large, undelineated area available for parts blasting and painting can foster inefficient use of that space, while the physical limits inherent in a building or enclosure usually encourage a close look at flow and efficiency.

A few comments regarding parts scheduling are appropriate at this point. This subject was discussed in a previous section, "Planning for Manufacture". Scheduling of material into the paint/blast shop is virtually nonexistent. That is to say the fabrication shops that supply parts to be painted cannot adequately predict, in advance, when those parts will be completed and ready to ship. Therefore, blast and paint supervision is forced into a reactive mode for manpower and material planning on a daily basis. Level-loading of shop work and personnel becomes nearly impossible, impacting overall departmental scheduling and budgeting performance.

NASSCO's small parts blast and paint areas are separate and adjacent, with the paint area located upwind from blasting to avoid dust contamination

GROUP TECHNOLOGY:* A technique which identifies and categorizes parts based upon the "sameness" or similarities of physical specifications or processes in order to improve the manufacturing economics of those parts.				
Referring to earlier comments of this section, a GT matrix of classification (and possible codifications) would be as follows:				
PHYSICAL SIZE	PRIME	INTERMEDIATE	FULL SYSTEM	SPECIAL
Small	11-	12	13	14
Medium	21	22	23	24
Large	31	32	33	34
* This is not a direct quotation but rather a combination of many definition in order to emphasize GT application in this study. Codes may be added for zone storage location. etc.				

Figure 8

(see Figure 5). The two areas are operated independently by shop General Foremen under the overall jurisdiction of a Blast/Paint Manager. Daily work planning is the activity common to both, since coordination is required to ensure that blasted parts are painted quickly.

Each area requires a staging zone for incoming and outgoing material. All parts arrive and leave by forklift on pallets or in baskets. Forklifts are also used for transporting and handling (positioning, turning, etc.) material between work stations, so a high level of forklift activity is usually the norm. A "mule train" transportation system consisting of several rolling carts pulled by a single forklift was created several years ago to alleviate the problem. This system has proven to be a good solution for improving the efficiency of NASSCO's forklift-dependent transportation operations.

Parts arriving in the blast receiving area are logged in and stored to await blast (several hours to several days). No formal prioritization system presently exists, so the informal "first in, last out", or "whoever screams the loudest gets their's first" systems are usually in effect. As previously mentioned, most blasting is performed manually, outside, and on pallets at ground level with at least one turning operation required per piece. Steel grit is used where possible and reclaimed/recycled via brooms, shovels, sweepers, 'bobcats' and a collector/classifier. An automatic airless table blast machine and wheelabrator are also available for specialized blasting operations.

When blasting is completed, parts are moved (via forklift) to a blow-down/inspection station to remove residual dust in preparation for painting.

The first step in the paint operation is a check of the part identification and determination of the coating requirements. If precise instruction do not accompany the work piece, labor-consuming research of engineering drawings and the ship's paint schedule is necessary prior to coating. Painting is accomplished on pallets at ground level, or parts are arranged on worktables or racks and usually require turning for complete coverage. Portable air spray or airless equipment is used as appropriate. Parts are dried in place between applications or coats, creating an obvious bottleneck in the system, especially with long dry time epoxy coatings.

Following the coating and drying processes, parts are inspected and then moved, again by forklift, to a shipping/holding area to await transportation to a storage or installation location.

The procedures described above apply to NASSCO's central paint area or shop. Painting is also performed in satellite facilities adjacent to fabrication shops—most notably the sheetmetal and machine shops. These are small, open air areas for painting (no blasting), operating similar to the main shop. The use of these satellites reduces transportation to and congestion in the main shop.

Study Conditions, Method and Results

Flow process studies were conducted of NASSCO's small parts operations to obtain time and cost values for the current situation. The data was accumulated in work elements, averaged for SLUs (Single Load Units) of 3' x 3' to 5' x 5' mean, and summarized for comparisons to alternative proposals.

The time values were recapped, summed and evaluated with respect to various types of work performed: handling, blasting, painting, etc. Idle time which could not be specifically related to personal needs, work or other factors was ignored.

When work elements were developed per average SLU, only specific work values were included. Fatigue, rest and personal time were added to the work cycle as a standard allowance. Total study time was grouped (in this case all time for both Blast and Paint was treated as the data universe) and a distribution set by percentage was taken.

Peterson Builders, Inc. of Sturgeon Bay, Wisconsin conducted in SP-3 Project, the Economics of Shipyard Painting (2), and have developed work distribution percentages that greatly compare to those developed by NASSCO. A comparison is made for reference and illustration. (Figure 9)

When the data is grouped further into five major sub-divisions the following results:

This grouping graphically points out the importance of performing methods and equipment analysis for all work factors, and not subjective work factors (blast and paint) alone. It follows that blast and paint productivity will rise if blast and paint operation time, as a function of total time, is increased. Doubling the latter would double productivity (or reduce by one half the crew size). Can setup and teardown time be reduced? The same for other groups?

As the summary and bar chart shows (Figure 11), the data is quite comparative and suggests that small parts blasting and painting operations may be relative throughout shipyards.

PERCENT OF TOTAL TIME			
OPERATION	PBI BLASTING	PBI PAINTING	NASSCO COMBINED
1. Blast or Paint	20.6	21.6	18.9
2. Setup and Teardown Equipment	27.4	18.6	24.3
3. Cleanup	4.9	5.2	6.1
4. Instructions	2.7	5.2	5.5
5. Prepare Surface (Other than Blasting)	1.3	3.6	4.5
6. Setup and Teardown (Operation)	5.4	1.5	3.2
7. Taping/Untaping	7.6	12.4	10.1
8. Remove Spent Abrasive	16.6	—	*
9. Load/Unload Parts	—	13.4	14.4
10. Mix Paint	—	4.1	3.0
11. Rotate Parts	—	2.6	*
12. Get Tools	—	1.5	1.3
13. Rest and Personal	13.5	10.3	8.7
	100.0	100.0	100.0

* Not categorized in NASSCO study

Figure 9

PERCENT OF TOTAL TIME			
OPERATION	PBI BLASTING	PBI PAINTING	NASSCO COMBINED
Blast or Paint	20.6	21.6	18.9
Setup and Teardown	32.8	20.1	27.5
Supporting Operations	16.6	32.5	27.5
Miscellaneous Work	16.5	15.5	17.4
Rest and Personal	13.5	10.3	8.7
	100.0	100.0	100.0

Figure 10

WORK DISTRIBUTION

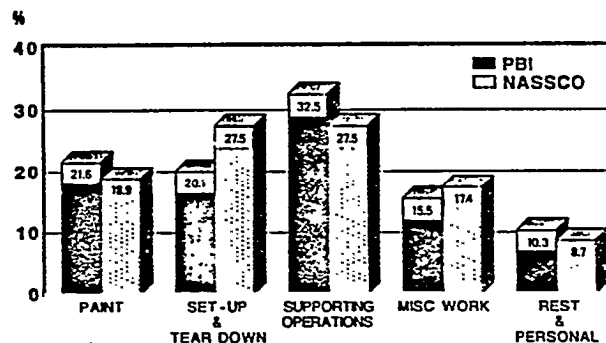


Figure 11

Field Studies:

Small Parts Painting in other Industries

Field surveys and interviews were conducted to determine what other industries are doing. The sources were:

- Air Frame Manufacturer
- Mobile Equipment Manufacturer
- Oil Tool and Equipment Manufacturer
- Medium Size Shipyard
- Steam Turbine Manufacturer
- Large Sheet Metal Job Shop.

While each source had widely varying conditions of material and surface preparation requirements as well as paint coating and curing, one inevitable factor ran throughout. ..they all used conveyors. Overhead conveyors were prevalent, but floor type were used where more desirable. Floor types have a disadvantage of "fouling" due to foreign items getting in the drive. The more sophisticated systems used switchable conveyor trackage and several used power and push (manual) sections. These features depend upon the needs and variations of the system.

What Do Conveyors Do?

Handling (direct cost) is sharply reduced for a rather reasonable cost. This is not meant to say that automated paint booths are inexpensive, but ordinary conveyors are far less expensive. It should be noted that only one source used automated paint application and that was, surprisingly, the job shop. Economics is addressed later in the report.

Handling was found to be 144% of the blast and paint work cycles from the NASSCO studies. This does not include the forklift handling caused by a lack of thru-flow that a well planned mechanized system can eliminate. Equipment setup and teardown was 24.3%. since the work was not "moved thru" but rather the equipment "moved to" the work.

It appeared that the genius of the conveyor would be the center piece of any system intended to decrease parts handling and equipment setup. The sum of handling and setup in the NASSCO studies was 38.7% and it was estimated, based upon the experience of others, that this could be reduced to 10% to 15%. These are reasons for targeting mechanization prior to automation.

In most systems where cold rolled or galvanized steel is being painted the preparation is chemical washing, however, shipbuilding generally uses blasting. Paint booths were single (one man painting both sides of a part) or double (two booths facing opposite each other and two men paint opposite part sides). Larger, flat parts work best with the latter.

From Current Methods To Revised Methods

The study developed a focal point and ironically it was the non-painting work, rather than specific painting of small parts that took the spotlight.

SOME NON-PAINTING AND PREPARATION COSTS ARE...

- 1 Transportation To and From The Facility
- 1 Handling Within The Facility
- 1 Identification
- 1 Scheduling

THESE CAN EQUAL OR EXCEED THE PAINTING AND
PREPARATION COSTS.

To dramatize this we asked painting supervisors the following:

IF YOUR PAINTER HAS...

- 1 The Right paint
- ½ The Right Equipment
- 1 Proper Support
- ½ The Right Part

HOW LONG DOES IT TAKE TO PAINT A 5'X5' PANEL?
HOW MUCH TIME DID ALL THE REST OF THE WORK
AND SUPPORT TAKE TO PAINT THE 5'X5' PANEL?

The answers varied between two minutes and five minutes to perform the actual painting and an hour to two hours to perform all the supporting work. The exact numbers will vary greatly from yard to yard. However, it is safe to say that 75% to 90% of all the work is non-painting.

This new perspective therefore weighed heavily on the direction that the project should take and resulted in the decision to look at a Systems Approach to small parts painting. Analyses of the three levels of automation, semi-automation and mechanization were developed. A fourth and somewhat separate level, that of semi-mechanization, is included so that a more complete economic range of systems are represented. The latter will be treated as an appendage to the main three levels which have "mover" systems in common. (See Appendix 1)

THE IDEAL SYSTEM (MODEL)

Let us start at the beginning with the Ideal System. Many managers and engineers might argue that since nothing in ship production is ideal, such an approach is a waste of time and effort. There are always restrictions: physical, economic, time, facility or equipment life span, and others. This is most true. However, if a system attempted for production and cost improvement reasons is started with all restrictions as a forefront criteria, two important possibilities are sacrificed. First, the ideal system allows for the 100% potential level, never attainable, but measurable (The ultimate system can be measured against the ideal). Second, the forefront objectives should be stated and constantly pursued throughout the proposal development and evaluated with respect to each restriction as each comes into play. This permits separate, justified decisions relative to each restriction rather than a predefined or implied acceptance of the restrictions at the outset.

For example, if an ideal system is developed and given a rating of 100% based upon all attainable objectives and carries an implementation cost estimate of \$1,000,000, another more economic proposal could be related to it. It is possible that 50% of all attainable objectives might cost \$250,000, a considerable difference in cost. The ideal permits comparison in a dramatic way and thus a relative merit can be easily seen between proposals.

The ideal small parts paint system for a representative yard would contain the following:

- A mover system: an overhead conveyor.
- A blasting system.

- A prime and paint booth.
- A drying system: air or force.
- A curing zone.

The basic configuration to this system is shown in Figure 12.

IDEAL BLAST, PRIME & PAINT LINE

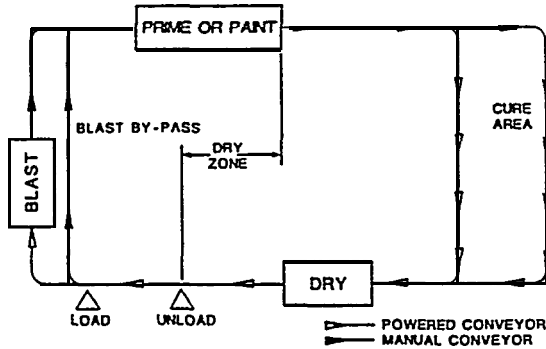


Figure 12

The ultimate possibilities for the system are virtually unlimited and this study recognizes that condition, however, certain narrow assumptions were required in order to focus upon specific issues. Moreover, each yard will be required to do methodization, and costs should be included for this work when preparing a proposal.

The Ideal System shown in Figure 12 operates as follows:

1. The parts are loaded to the overhead conveyor at the load station. Some fixturing in a "Christmas Tree" fashion is required for smaller parts, but medium and larger parts are hung individually.
2. Parts proceed via the conveyor line through the blast station. All surfaces are blasted to the required condition. Since blast may require three to five times the paint cycle time, some variation in the line is necessary. A five minute blast cycle per SLU is assumed for the Ideal System. Expanded blast capacity can be developed to permit the volume of blast work to be balanced with the painting work.
3. The parts are primed or painted as required. The assumed paint cycle time for this system is one minute. This

represents the average time needed to apply a single coat to an SLU.

4. The parts are dried. Where there is sufficient conveyor length and speed, this can be accomplished simply by air drying on the conveyor from the point of painting to unloading.

For example: Ten feet per minute is a common speed for many lines. If the distance from the paint station to the unload station is 150 feet the dry time is fifteen minutes.

5. A cure area will be needed for various paint coatings. In a conveyorized system this is done via switching and manually control led track "spurs". Parts can be held in these areas for extended periods while the main system continues operation.
6. A by-pass for blast will be required where already blasted/primed or painted parts require additional coats. Another option would be to shut down the blast booth and run the parts through.

Balancing the Ideal is a necessary early step in developing the system concept. Here the intent is to be able to load, blast, paint, dry and unload without a "bottleneck" or out-of-balance operation. The flow process chart is the place to begin.

The Ideal System in Figure 12 shows a basic priming operation. The assumed Single Load Unit (SLU) is a large or medium part or a "Christmas Tree" of small parts. At a conveyor line speed of five FPM and the developed line length of two hundred feet it will take thirty-four minutes without line stoppages for a single load to make a total cycle (the forty minutes for the line cycle less the six minutes (30 ft.) of "dead space" between the assumed load and unload points). However, the productive rate of the system will be the same as the "limiting cycle", in this case five minutes to blast the SLU. That is, as in any manual blasting operation, where one man takes five minutes to completely blast the single load unit. In other words, when this system operates without stoppages, a SLU is produced every five minutes, twelve items per hour.

Three systems were developed, using various configurations of equipment. These establish a reference for this discussion as well as further applications covered in the next section.

System A: Manual Blast and Manual Paint

System B: Auto Blast and Manual Paint

System C: Auto Blast and Auto Paint

All three systems use the conveyor routing as shown in Figure 12.

Referring to System A, a Single Load Unit is produced with fifteen man-minutes or .25 man-hours operating the line with three men (5 min. x 3 men).

System B changes the limiting cycle to one minute since the blasting time is now shortened, via automation, to match the paint time. This is potentially five times faster than System (A) with sixty SLU's per hour. Manning the line with three men, the production rate is three man-minutes per unit or .05 man-hours.

System C has the same limiting cycle of one minute but potentially can be operated by two men at a production rate of two man-minutes per unit or .033 man hours.

Recognizably, great arguments can be made concerning this data and the related assumptions. However, while these assumptions are based on real, observed conditions, they are submitted within this study as a point of reference and not an absolute. The greatest value in this exercise is the applicability of the concept to any small parts system proposal, whether a continuous line or a separate forklift fed work station basis is used.

Making The ideal Model Real

The ideal model and flow analysis was exactly that . . . a pure ideal, but capturing a very workable concept(s). What then is REAL? How do we make it workable?

First, the flow analysis can be re-evaluated in terms of reasonably expected line stoppages or delays. These are:

- Mechanical or electrical maintenance.
- Wait for materials.
- Supervision.
- Miscellaneous.

Some history for these types of systems suggests an expectation of 10% to 25% (of course in an actual application this should be established as early as possible once the learning curve settles down). For study purposes, the most conservative delay value was utilized (25%). Applying the delay factor increases the total system cycle time from thirty-four to fifty minutes.

Second, and most importantly, the manual activities require evaluation. Basic questions need to be asked:

- Can a man maintain the one minute work cycle in loading and unloading?
 - Not without some fatigue, rest and personal time allowances.
- More seriously, can a man maintain the painting cycle of one minute?
 - This type work probably requires the highest allowances for fatigue, rest and personal time.
- When the Single Load Units are small parts hung on "Christmas Trees" won't an auxiliary handler(s) be required?
 - Yes, and at least for planning analysis purposes the general practice is to add an auxiliary man (or more) to the line crew and include that time in the expected operating labor cost.
- If manual blasting is to be used, won't two blasters be required since that is the limiting cycle?
 - Not necessarily. This would appear to be the best answer if the system is planned to run "full out" for extended periods. When one blaster works the other rests. This must be evaluated on a per piece basis since it might be better to have both blast and rest in unison.

The manpower utilization is much better when working in unison, as shown in Figure 13.

Applying some of these intuitive factors will bring the ideal system further into the area of the real system. Each system is adjusted to show man-hour effect for system and human delays. (Figure 14)

	WORK CYCLE (Minutes)	DELAY TIME (Minutes)	DELAY % OF WORK CYCLE
1 Man Blast	5		
1 Man Rest		5	
TOTAL	5	5	100%
2 Men Blast	2.5		
2 Men Rest		1	
TOTAL	5	2	40%

Figure 13

		MANHOURS PER SLU	
SYSTEM	DESCRIPTION	IDEAL SYSTEM	REAL SYSTEM
A	Manual Blast	0.250	0.344
B	Auto Blast	0.050	0.138
C	Auto Blast & Paint	0.033	0.093

Figure 14

Men/machine charts are shown below for System A in Figures 15 and 16. The initial (Ideal) and expected (Real) are compared. This is an effective method for depicting time, work operations, and system relationships. It will work well for facilities utilization analysis in general.

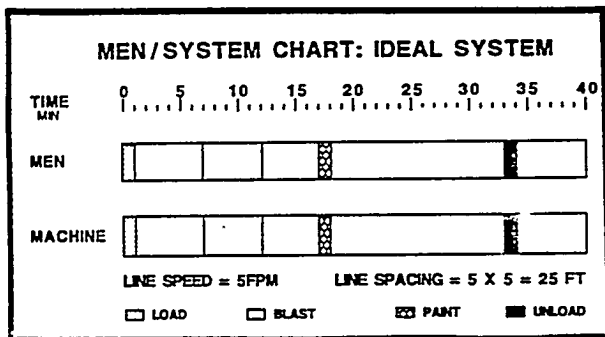


Figure 15

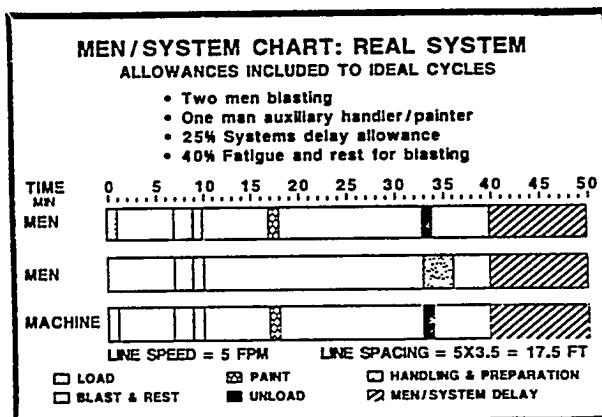


Figure 16

A final set of comments concerning this exercise:

The conveyor type system can be analyzed at whatever speed and length of line is reasonable. Most systems viewed as part of the study moved at 10 to 12 feet per minute. The ultimate length will be governed by the air dry cycle required, economics, or space.

The manning of the system is totally variable based upon the degree of automation and system reliability. One system had over a thousand feet of continuously moving conveyor and a two man crew—one a handler and the second a line operator/maintenance man. The total system was automated except for loading and unloading the conveyor. It should be added that this line used a washer system rather than blasting to prep parts.

For shipyard conditions and practices, blasting holds equal importance with painting. Automated blast cabinets require much research prior to acquisition and much operational methodization after acquisition and installation.

Also, the "Christmas Tree" method for handling small parts has great impact. Remember, if ten small parts are contained in one SLU the expected man hours per part is factored 10 times.

Finally, once the initial analysis has been reduced to reasonable expectations, the Ideal nature of the system will still exist, but in a Real form. Answer questions like: Do you have the physical space? What configuration will fit? Are utilities adequate? Access to and from? Parts staging? Then begin the process for developing the proposal.

SMALL PARTS PAINTING SYSTEMS

What will these kinds of systems cost? Can automation be affordable and justifiable or should mechanization at a lower level be the goal?

Herein lies the heart of this feasibility study. To answer these questions, a separate survey was made by the Empire West Corp. of Cerritos, California. The survey used as a model the same ideal system as in Figure 12 in order to permit direct comparisons of data.

Three types of parts painting systems are being considered:¹

1 These systems are relative to Systems A, B and C described earlier. However, they are not identical and therefore should not be-compared directly.

- SYSTEM 1 (Mechanized/Manual)
- SYSTEM 2 (Semi-Automatic)
- SYSTEM 3 (Automatic).

This survey is based on the following general assumptions:

Surface Preparation:

The blasting requirement for items to be coated with inorganic zinc primer is near white blast cleaning (SSPC-SP-10). All other items require either commercial blast cleaning (SSPC-SP-6), or brush-off blast cleaning (SSPC-SP-7).

For occasional items which do not require blast cleaning, other manual cleaning methods can be considered. A limited quantity of parts will require masking of some areas prior to blast cleaning and/or coating application.

Coating:

The coating requirements for the parts include five basic paint material systems:

- Inorganic zinc primer
 - Epoxy tank coatings
 - High build polyamide epoxy primer
 - Alkyd primer
- 1 Topcoatings for each specified coating system.

All parts will require a minimum of one coat of primer.

Forced Drying:

Most of the coating materials will air dry in ambient conditions. The curing times for most materials can be reduced significantly by processing through a drying oven after a specified flash-off time period. An oven is included in each of the three preliminary systems to increase production.

Material Handling:

The vast majority of parts can be handled by an overhead powered conveyor system with start/top stations for loading and unloading. A combination power and free system could be considered for Systems 1 and 2, but is not included in the survey. Sec-

tions of horizontal conveyors in some process areas may be considered, along with four wheel carts for handling of unusual parts.

Small Parts Data:

Size: Minimum, 3" x 2" x 1"

Maximum, 60" wide, 42" high x 20' long

Weight: Maximum 100 pounds/piece

Configurations: Small assemblies (foundations), pipe hangers, U Bolts, wire-way hangers, light brackets, ladders, etc., as typical.

Substrate: Mild steel.

System 1

This plan will have the lowest purchase cost, but the highest operating cost of the three systems, as it is the most labor intensive. The plan will utilize more floor space because of the staging areas required as work flows through the processes.

Surface Preparation: All blast cleaning will be done manually in a blast booth with dust collector.

Coating: Coating application will be done manually, in a water-wash spray booth.

Drying: One two-pass conveyORIZED drying oven is included.

Material Handling: For this system, material handling will be accomplished primarily by overhead conveyor. Four wheel carts for special items are included.

System 2

Surface Preparation: This plan reduces manual blasting and adds a Turnblast semi-automatic machine or a table-blast machine.

Coating: An additional spray booth is included. Semi-automatic (non-computerized) coating application machines are added to reduce personnel and increase quality control.

Forced Drying: The drying oven is increased in size with two chambers to force dry the primers and top coats continuously in separate temperature zones.

Material Handling: System 2 will allow the parts to be carried, via conveyor, through the blast cycle, the primer application, flash-off period, drying oven, cooling, top coat application, flash-off period, drying oven, cooling, to unload station—all without manual handling.

System 3

Surface Preparation: This plan utilizes a four wheel airless (centrifugal) automatic blast cleaning machine in place of the manual blast booth. With proper fixtures, this machine should process all of the parts included in the survey..

Coating: The coating equipment will be fully automatic, with electronic control and sensing systems to coordinate with the conveyor drive. Four spray booths are included for continuous line flow.

Forced Drying: Drying will be through a double oven as described in System 2, to allow predictable coating application sequence.

Material Handling: The overhead conveyor will carry most parts through the automatic blast cleaning machine and all other processes.

If all included assumptions are reasonably accurate, this will be the optimum one cycle system. After loading the parts on fixtures on the conveyors, blast cleaning, coating, and drying will be automatic until the parts are unloaded, ready for inspection.

Preliminary cost estimates of each system (at the time of survey), for budgetary purposes only, areas follows:

SYSTEM 1	\$235,000.00
Option: If air compressors are required, add the approximate amount of	\$50,000.00
SYSTEM II	\$345,000.00
Option: If air compressors are required, add the approximate amount of	\$30,000.00
SYSTEM 3	\$440,000.00

The equipment costs contained in the Empire West survey were further analyzed with respect to the three systems as originally discussed. This permits the reader to see a continuum of comparative data as would be required in any specific system proposal.

These are guide line costs and can be used to develop strong indications of what system is feasible for a given yard.

SYSTEM A (with variations)	
A Manual Blast System with 200 feet of conveyor a single blast booth a single paint booth, and	
single oven	\$140,500.00
The same system without the oven	\$105,000.00
A Manual Blast System the same as above with two blast booths and two paint booths	
	\$177,000.00
SYSTEM B	
An Automatic Blast System with conveyor, auto blast cabinet. two paint booths. and single oven	\$272,000.00
SYSTEM C	
An Automatic Blast and Paint System with auto blast cabinet, auto paint booth set of two ovens and 200 feet of automated conveyor line	\$399,000.00

JUSTIFICATION

Justification for a proposal is necessary and vital for management review and decision. The proposed system must be compared to existing operations. The savings to be realized must provide return on investment and fully satisfy management criteria.

The most direct method for determining current operation methods and productivity is observation. As set forth previously under the Industrial Engineering Method, the flow process study is recommended. Complete eight hour studies, or, at a minimum, four hour studies will yield the best quality information. The time a man is working is important, how he works and at what task must be observed closely and properly recorded as well. However, of equal importance is idle time, and the reason for the idle condition requires close observance and recording. Personal time, rest, and fatigue are simply states of human-kind and have well-engineered standard values for that reason. Waiting for something is idle time, which can be changed to productive time, but must be first properly identified.

Determining how work is being done can lead directly to methods changes, which in turn increase productivity. Unneeded movements of materials, excessive handling, identification problems, instructional problems, and poor workmanship by others can be changed or eliminated. Often these changes cost little.

Observation studies were conducted at NASSCO as part of this project and were previously discussed. The specific data used to develop work cycle times was developed from those studies. Results are shown in Figures 17 and 18.

BLASTING	MIN/SLU
Load/Unload/Handle Parts	2.3
Blast Parts	3.6
Setup/Teardown Equipment	3.8
Taping	1.6
Cleanup	1.0
Instructions	0.9
Total Work Cycle	12.6
Fatigue, Rest & Personal*	2.5
Total Expected Time Per SLU	15.1 minutes

* Fatigue 10% All time of this type was deleted from
Rest 5% the study and standard allowances
Personal 5% were added to work values.
Total 20%

Figure 17

PAINTING	MIN/SLU
Load/Unload/Handle Parts	2.1
Paint Parts (Multiple Coats)	2.7
Setup/Teardown Equipment	3.5
Taping	1.4
Mix Paint	0.4
Cleanup	0.9
Instructions	0.8
Surface Preparation	0.6
Total Work Cycle	12.4
Fatigue, Rest & Personal*	2.5
Total Expected Time Per SLU	14.9 minutes

* Fatigue 10% All time of this type was deleted from
Rest 5% the study and standard allowances
Personal 5% were added to work values
Total 20%

Figure 18

Figure 17 summarizes time study results for blasting and related operations for a Single Load Unit (one or more individual parts), while figure 18 shows results for painting. Note that in both cases equipment setup or teardown times exceed the actual blast/paint operation times. Therefore it is important to maximize work package or lot size to absorb the equipment handling time (cost). Also note that the total work cycle times are nearly equal for blasting and painting. This results from comparing blasting to painting multiple (2-3) coats. Applying a single coat to a part is usually three to four times faster than manually blasting that same part.

The details of data accumulation, analysis and evaluation must be left to a specific proposal pro-

ject manager or engineer. However, for this report, in order to carry through the concept originated with the Ideal System, that particular example was taken all the way through a proposal cycle.

At this point, it is recommended that all new costs for the proposed operation be evaluated and that the particular financial form related to the yard doing the proposal be followed. Since policies, and therefore calculations vary, this example will end here.

In closing, some additional comments about the example may be appropriate. First, the potential savings versus capital investment for System A may suggest a reduction in the expenditure by deleting the oven and proposing a capital expenditure of \$105,500. This would offer a very safe economic trade-off. Moreover, proposed System C (see Figure 19) yields the greatest potential percentage of time saved (81.4%), however this same system shows the lowest annual ROI (122%.) due to high investment cost ($ROI = \text{annual savings} / \text{investment}$). System B would yield the greatest ROI (160%) and have the shortest payback period—about 7.5 months. Also note that the calculations assume a production rate of 60,000 SLUs per year. If the actual quantity of small parts processed for a particular operation was less, say 30,000, the analysis for System B would be adjusted to show a ROI of 80% and a payback period of fifteen months.

Clearly, specific SLU counts, current operation values, proposed system configurations and expected operation values, and specific equipment and installation costs will yield wide variations between individual cases.

SUMMARY AND CONCLUSION

Is automation, semi-automation, or mechanization feasible for a given yard? This study suggests that there are definitely possibilities that deserve review and analysis. The study further shows that there are cost improvement potentials with very little capital cost and that the techniques utilized here can be applied to most, if not all, shipyard operations.

The project represents a wide view. As intended, it deals with automation and mechanization of small parts painting. However, along the road to these high ends many simple and easy to perform planning, scheduling and industrial engineering techniques have marked our way. Possibly, and without original intention, the exposure to these management tools will be of the most universal value.

SYSTEMS COMPARISON					
		MAN-MINUTES/SLU	MANHOURS/SLU	REDUCED HOURS/SLU	TIME SAVED%
CURRENT	Blast	15	.25		
	Paint	15	.25		
	Combined Total	30	.50		
PROPOSED	System A		.344	.156	31.2%
	System B		.138	.362	72.4%
	System C		.093	.407	81.4%

POTENTIAL RETURN ON DIRECT CAPITAL INVESTMENTS						
	SLU'S PER YEAR	SAVING PER SLU (HOURS)	ONE YEAR DOLLAR SAVINGS*	CAPITAL INVESTMENT	RETURN ON INVESTMENT (ROI)	EXPECTED INCREASE IN OPERATING COSTS
System A	60,000	.156	\$187,200	\$140,500	133%	Power to operate conveyor and automated systems
System B	60,000	.362	434,400	272,000	160%	Ditto
System C	60,000	.407	488,400	399,000	122%	Ditto

* Assumes \$20/Hr. Labor Cost

Figure 19

The emphasis placed upon "Planning for Manufacture", as well as the side trip into "A Thru-put Technique" in the same section, may serve any yard well for very little cost. The Industrial Engineering Method, by design permeates the complete project. Identifying and analyzing the "Existing" and "Proposed" is at the heart of good, well-managed economical evaluation and justification.

The specific review of various levels of system mechanization and the ultimate of automation, along with potential costs for each, may be just what the large yards need next.

Yes, it is agreed that this project looks like "something for everyone"-and that can't be all bad. From here on, it's a "do-it-yourself" project: look at your family of painted small parts and see what can be changed and improved. Conduct the studies and use whatever techniques help.

SUMMARY

- Look at the **WHOLE PARTS PAINTING PICTURE**
- Be Aware of **NON-PAINTING and PREPARATION COSTS**
- Look at **PLANNING FOR MANUFACTURE**
- Analyze **FLOW**
- Take a **SYSTEMS APPROACH**
- Develop the **RIGHT PROPOSAL** for your yard
- Establish the **ECONOMIC JUSTIFICATION**

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The study was conducted and the report prepared by NASSCO, with Les Hansen serving as Project Manager and Principal investigator. William Appleton acted as Industrial Engineering Consultant and contributed significantly to the research, as well as co-authoring the report.

The special support and assistance offered by the following persons at NASSCO is gratefully acknowledged:

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Naval Shipyard; and Oren Funkhauser of Todd Shipyards, San Pedro.

In addition, SP-3 Panel members have freely contributed comments and other useful input at panel meetings during the course of the study.

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APPENDIX 1: THE SIMPLE SYSTEM

A simple approach to small parts painting, the previously identified Semi-Mechanization, is not to be overlooked.

Economics, a need for a small decentralized Paint Shop, or the relative volume of work may not support the kinds of systems previously discussed. This study suggests that all the principles developed thus far can be further applied to a simpler approach. (As a matter of fact, simple time study and methodization will yield immediate cost reductions).

The order of working up a proposal is exactly the same:

- Define and classify the parts
- Evaluate current methods and time values for the operations
- Develop an Ideal Plan
- Evolve to a Real Plan
- Determine Equipment and Facilities Requirements and Proposal costs
- Economically justify the proposal.

When evaluating current operations and making the transfer to the Ideal/Real System Proposal, work on Flow Concepts.

- Is a manufacturing operation continuum possible? Will transportation from the last fabrication operation to the first blast and paint operation be at a minimum?
- Will the blast and paint operations be a flow-through layout with a minimum of handling and rehandling?
- Will the layout afford good thru-put planning and in-process control?
- Can the proposal improve the cost of painting small parts?

The flow diagram in Figure 1 shows a simple flow-through arrangement that can use multiple "mover" methods: fork lift, hand cart, track, or conveyor (with or without a return loop). This system is envisioned as having manual blast and paint, air dry or oven dry facilities. However, blast could be semi-automated. If a track or conveyor is used, parts can be worked individually or "Christmas Tree" fashion as an SLU, and with a limited production demand the operation could be handled by a single worker.

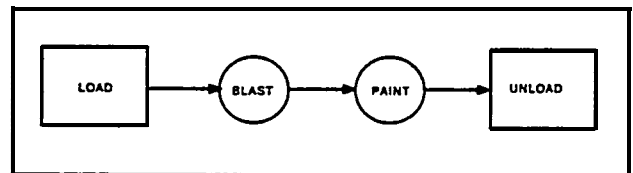


Figure 1

Spacing of the facilities will be most important in order to queue parts for each sequential operation. The key is to keep the materials moving through without double handling. This strongly suggests that the handling method or "mover" is the most important function of the system and may prove to be the most cost effective investment in the proposal.

Develop a flow process chart complete with work times and process values. Use an SLU as the basic production measure and calculate the potential savings for the proposal. Remember...keep it simple!

APPENDIX 2: TYPICAL PARTS LIST

DESCRIPTION	APPROXIMATE SIZE/RANGE	APPROXIMATE USAGE
ANGLE, REGULAR, CARBON STL., RAW MAT'L	1×1 - 9×4×20'L	100,000 FT
BAR, FLAT, CARBON STL., RAW MAT'L	1×1/8 - 6×3/8×20'L	50,000 - 100,000 FT
BAR, ROUND, CARBON STL., RAW MAT'L	1/4 - 2 DIA×20'L	25,000 - 50,000 FT
BRACKET, STANDARD	6×6 - 45×45	5,000 - 10,000
COLLAR, TIGHT, FOR TEE STIFFR	4×12 - 6×26	2,000 - 5,000
CABLE SUPPORT (MULTI-CABLE)	4×20 - 20×20	5,000 - 10,000
DAMPER, FIRE, H.V.A.C., MAN, RECT.	4×4 - 50×50	500 - 1,000
DECK SOCKET, VECH. LASHING	3×10-3×12	500 - 1,000
FLANGE, H.V.A.C., RECT., NON-TIGHT	7×7 - 54×54	> 10,000
FOUNDATIONS, STEEL, MISC., BOLTABLE	12×12 - 72×72	500 - 1,000
HANDGRAB	3×7	500 - 1,000
HANGER, DUCT, H.V.A.C.	2×28	> 10,000
HANGER, PIPE, CLAMP TYPE	1/4×4 - 12×30	> 10,000
LADDER, VERT.	16×3' - 20'L	100 - 500
MANHOLE, RAISED, OILTIGHT AND WATERTIGHT	18×23	100 - 500
PADEYE, LIFTING, PERM.	2×4 - 12×36	100 - 500
PADS	3×3 - 18×18	500 - 1,000
PENETRATION, PIPE, FLANGED, WT.	1" D×12 - 25"D×24	2,000 - 5,000
PIPE HANGER SUPPORT, U-BOLT, UNBRACED	2"×2"×2' - 3'	500 - 1,000
RAIL, HAND, 3 COURSE PIPE	42×5' - 20'L	500 - 1,000
RAIL, STORM, EXTERIOR	21'L	100 - 500
RUNG, LADDER, STIRRUP	10×16	1,000 - 2,000
STAPLE	1/2×1 - 6×8	1,000 - 2,000
VENDOR ITEMS:		
ELEC. BREAKER BOXES	18×24×6	500 - 1,000
MOTORS, SMALL	18×18	50 - 200
PUMPS		50 - 200



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No. 20

NAVSEA MCM-1 Product Model

Jeffery D. Arthur's, Member, Naval Sea Systems Command, Washington, D.C.

ABSTRACT

The MCM (Mine Countermeasure Minesweeper) Product Model is the Navy's first true representation of a fully Computer-aided Acquisition and Logistic Support (CALS) oriented information system that integrates automated processes to create, store, retrieve, use and exchange weapon system technical, logistics, manufacturing and management information. The following three processes support the integration:

- data source, definition, and flow analysis;
- configuration baseline establishment and management;
- graphic representation and geometric (three dimensional) modeling.

NAVSEA CALS data flow diagrams document existing processes, organizations, and data flows; subsequent analyses will document specific data elements, their sources, interdependencies, and relationships.

The three dimensional (3D) MCM Product Model integrates engineering, design, logistics, production and configuration management processes. It also produces a variety of information products from the same data base, including piping isometrics, work packages and damage control diagrams.

Three projects have been combined to produce the MCM 3D Product Model. Equipment components designed in the 3D geometric model are linked to a central file of current configuration and logistic information maintained in the Weapon Systems File (WSF) Prototype data base. Access to this central file eliminates the need for many duplicative, independent data bases to generate various reports and products as required by different users. Each component has been assigned a unique functional description and hierarchical structure code that permits integration with the WSF Prototype for access to the appropriate configuration and

logistic data. This integrating mechanism also enables access to optically stored technical manuals, engineering drawings, maintenance repair procedures, etc. which comprises the third part of the Model.

INTRODUCTION

Computer-aided Acquisition and Logistic Support (CALS) is a DoD strategy to utilize the latest computer technology and data exchange standards to automate the technical and logistic data associated with weapon system acquisition and support. The twin objectives are to digitize current paper-oriented technical and logistic support data processes, and concurrently to modernize the acquisition and logistics infrastructure. A primary goal of the NAVSEA CALS Program is the integration of current Navy processes which have become increasingly narrow and discipline-specific with regard to the acquisition, development, and modification of technical and logistic support data. Natural integration processes that should exist in ship design and construction have been disrupted by existing methods which resist change. Therefore, NAVSEA CALS is not only concerned with the successful development and transfer of digital data, but with the development of an Integrated Weapon System Data Base (IWSDB). The IWSDB provides the mechanism for establishment of an integrated set of information during acquisition or data base initiation and for maintenance and sharing of that data throughout the life cycle of the weapon system. It requires integration of the infrastructure processes to assure that planning and support are consistent with the defined engineering configuration of the ship and weapon systems.

The MCM Product Model is NAVSEA's first IWSDB. The Product Model captures the natural integration processes of configuration baseline development, digital design, engineering analyses,

and logistic support data. It demonstrates not only digital access to this technical and logistic support data, but also proves the technology concepts behind integrating automated processes to create, store, retrieve, use and exchange weapon system technical, logistics, manufacturing and management information. NAVSEA's implementation of CALS is intended to maximize the total benefits to be derived from this technology, and to mitigate the negative impacts of change in order to stimulate prompt acceptance and implementation of actions.

NAVSEA APPROACH TO CALS IMPLEMENTATION

The Problem

Acquisition programs of the 1970s and 1980s have been confronted with continuously increasing costs, weapon system complexity, and demands for additional documentation. These increases have resulted in the acquisition, development, and maintenance of engineering, technical, and logistic support data becoming increasingly narrow and discipline-specific processes. This is due, in part, to the fact that the specification and receipt of predictable, well-defined, established products reduces the impact of change, its associated risks, and its potential costs. The change in focus rewards the use and independent refinement of existing, established methods to meet restricted, not composite or integrated supportability goals. It has resulted in the loss of natural integration processes that are present in ship design and construction. This loss of integration is manifested in some new weapon systems, where, for example, the initial introduction is plagued with excessive down time, spare parts are not available or do not match maintenance concepts, costs of repairs are high due to part usage vastly exceeding failure predictions, technical documentation and training does not match the configuration of the equipment, etc. Figure 1 shows the multiple configuration baselines which must be maintained for systems and equipment design, construction, and life cycle support. Throughout the life cycle, information from all four configuration baselines will be required. To improve weapon system productivity, quality, timeliness of procurement, and life cycle support, the information and products produced from these baselines must be integrated.

It should be noted that integration is a fragile commodity. Establishing an integrated set of information during the acquisition process in no way guarantees that integration will be

preserved. Preservation requires constant, consistent, coordinated, and knowledgeable attention and the presence of a central integration authority responsible for directing and controlling the competing influences resulting from dispersion of responsibility for maintaining that information. Thus, despite a number of initiatives within NAVSEA, the achievement and maintenance of the integration of configuration, engineering, technical, and logistic information has been an elusive goal.

NAVSEA's Solution

The NAVSEA CALS strategy conforms to DOD CALS policy and supports a three phased approach for CALS implementation (see Figure 2). The first phase (present to 1991) emphasizes applying the latest CALS standards to achieve uniform digital data flow. Phase II (1992-1996) focuses on developing an integrated and automated Navy infrastructure to create, store, retrieve, use and exchange digital data. By the year 2010, Phase III will have promoted the widespread use of CALS products and refined the acquisition process and infrastructure to use the latest technologies.

NAVSEA's approach to implementing CALS technology is not intended to fundamentally change the way the ship is designed or to disrupt the methods for development of specific data within the shipyard (e.g., R&M calculations, provisioning, technical manual development, etc.). It is intended, however, to capture the data that is developed as a natural part of the ship design and shipbuilding process, and establish key relationships among the data to ensure functional integration of information systems and processes. This will reduce or eliminate the need for multiple iterations of the data in redundant files, reduce the volume and cost of deliverables, and improve the quality, accessibility, and responsiveness of the deliverables.

The NAVSEA CALS strategy also promotes the modernization of the infrastructure (i.e., headquarters and field activities and organizations) that will receive, review, store, and use those digital data products. The breadth of NAVSEA activities indicates the enormity of the NAVSEA infrastructure:

- 1 63 Field Activities
- 1 32 Detachments
- 1 107,000 Military and Civilian Workforce
- 1 \$26 Billion Annual Budget
- 1 300 Acquisition Programs
- 1 850 Foreign Military Sales Cases.

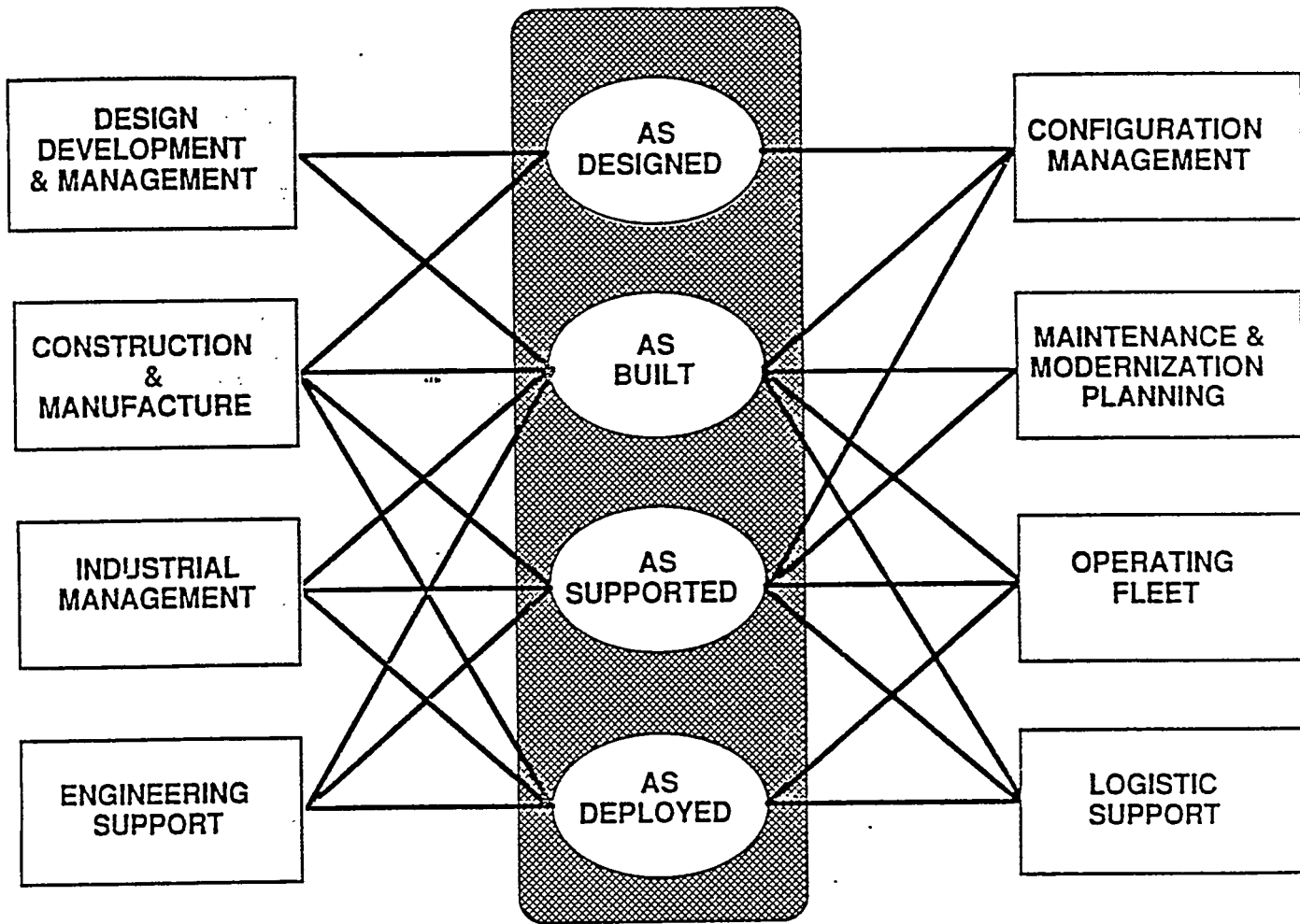


FIGURE 1 - Multiple Configuration Baselines

NAVY PHASED CALS STRATEGY

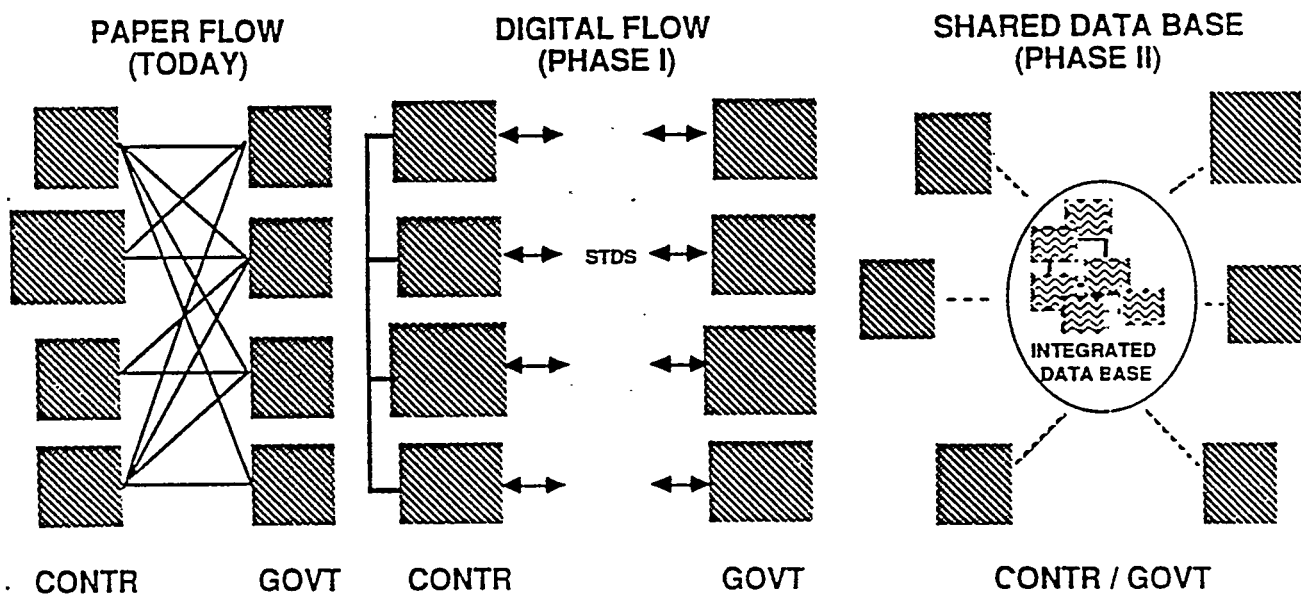


FIGURE 2 - NAVSEA Phased CALS Strategy

Data Flow Analysis

Various activities within the NAVSEA infrastructure are applying CALS technology. The data flows and data relationships in NAVSEA processes, policies, procedures, products, activities, and hardware/software configurations must be identified and analyzed within the context of CALS technology to ensure that NAVSEA proceeds in a responsive, orderly, efficient, and cost effective manner. To help define areas of automation and targets of opportunity for automation and technology infusion in the NAVSEA environment, information modeling techniques have been utilized. Data flow analysis of NAVSEA processes determines what should be incorporated into the IWSDB and how it should be linked together, by defining existing processes (ship design, configuration management, LSA, supply support), activities, and products produced as a result of those processes (technical manuals, drawings, etc.). The products are broken down into data elements to identify redundant data and determine interdependencies. Figure 3 describes this process for infrastructure modernization and concurrent development of an IWSDB (Phase II).

The MCM Product Model demonstrates that a shared data base environment (Phase II) is accessible today. Prototype demonstrations such as the MCM Product Model are crucial for leading the Navy towards the acceptance and implementation of CALS initiatives. These demonstrations have shown that an important benefit derived from the use of prototypes and working files is the significant advancement of knowledge of the nature, scope, and type of difficulties to be encountered in future applications. This knowledge assists in reducing risks, forcing early resolution of problems, developing and substantiating budget and other resource considerations, and overcoming understandable organization uneasiness in accepting new technology and methodologies.

THE MCM PRODUCT MODEL - A THREE DIMENSIONAL (3D) GEOMETRIC REPRESENTATION OF THE SHIP/SHIP CLASS

Three Dimensional Modeling

Traditional ship design and shipbuilding processes have been drawing-based. Computer Aided Design and Manufacturing (CAD/CAM) systems are replacing much of the draftsmen effort

IWSDB DEVELOPMENT

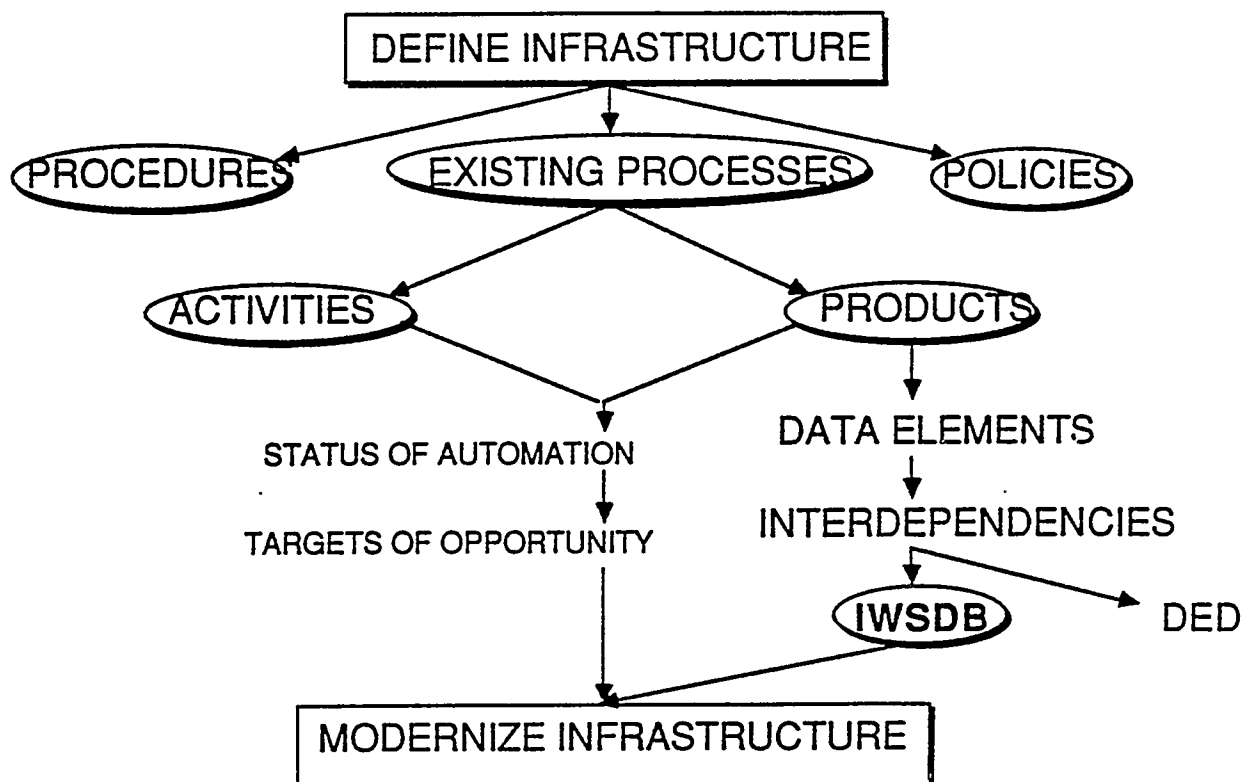


FIGURE 3 - IWSDB Development

with computer generated drawings and files which have reduced the costs of performing traditional drawing functions. This has not, however, significantly altered the approach or methodologies used to develop the final products (e.g., the CAD concept of "layering" closely follows the traditional use of tracings to integrate the design). Thus, integration of the ship systems with the hull structure has been a difficult process with system interference causing significant increases in redesign, rework, and cost. The problem with these systems remains that they are not fully integrated and may have internal inconsistencies. The initial versions of the 3D CAD systems offer new perspectives and many new enhancements and features, but continue to be based on the traditional layering concepts for construction of the model and, therefore, continue to have the consistency problems associated with earlier 2D versions. A second problem is that while these systems provide the basis for the engineering baseline during design and construction, they are very large and may be somewhat cumbersome for daily use in managing a ship or class configuration baseline.

Alternate three dimensional modeling technology uses various mathematical programming to create a single, relational, geometric model of the "as designed," "as built," or some other baseline condition of the ship. The MCM Product Model uses this type of technology to provide a geometric engineering model of structural components and ship systems. It was created from 600-700 engineering drawings provided by Petersen Shipbuilding in Wisconsin. Figure 4 is an external view of the modeled MCM ship. The main advantage of the three dimensional modeling technique is the ability to create an item or entity only once and retain only sufficient attributes to physically and spatially describe the item within the model context. These entities are then related to the specifications, standards, documents, and other data that define the item and to the analytical logistic, configuration, and other technical data. Establishment of these relationships document and support the integration of the engineering, configuration, and logistic data.

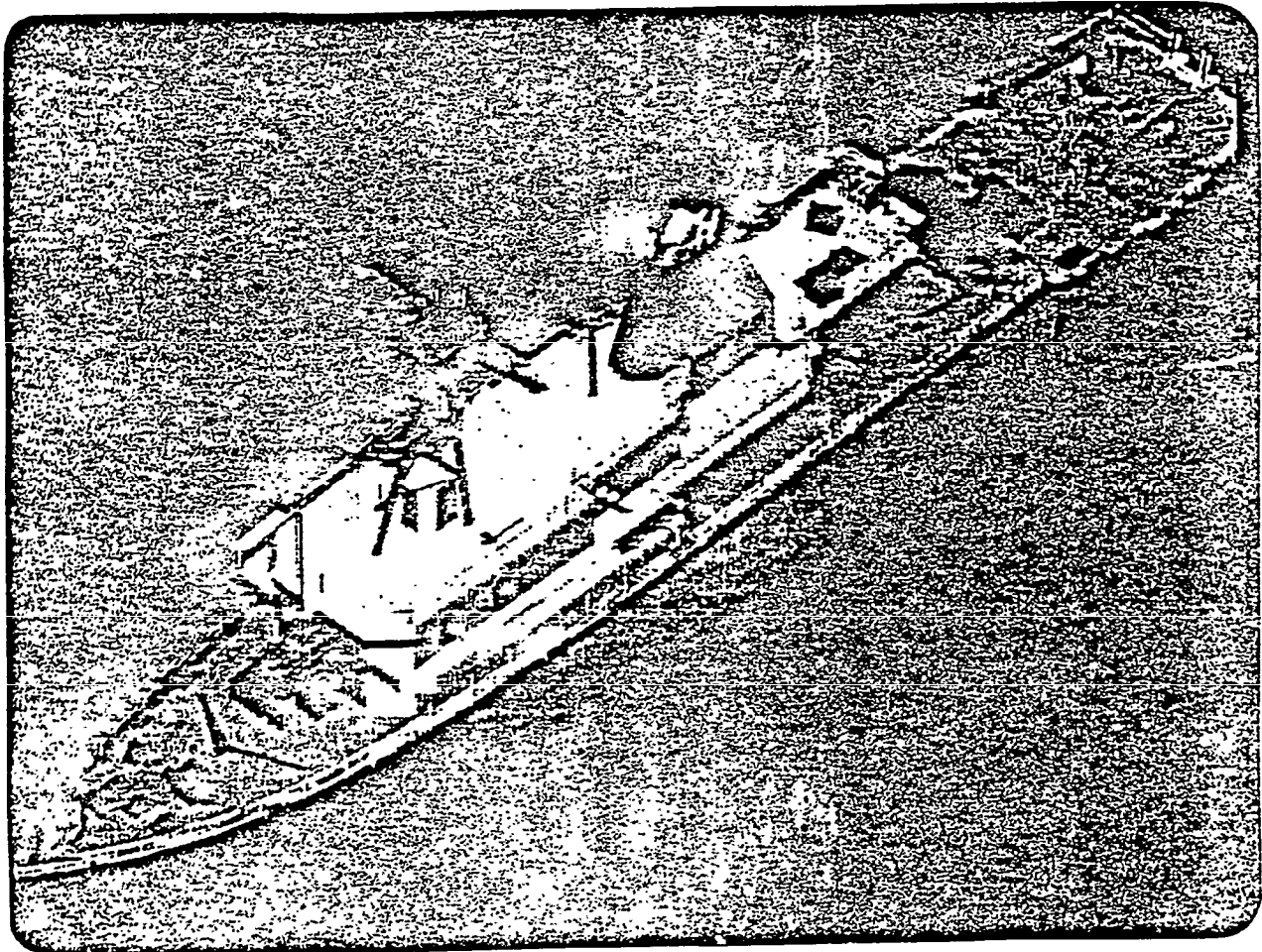


FIGURE 4 - 3D View of Mine Counter-measures (MCM) Ship

CM Product Model Description

Three projects have been combined to produce the MCM 3D Product Model, providing access to a variety of information products and permitting identification of components, systems and work packages. Figure 5 is a graphic representation of the capabilities and concepts underlying the MCM Product Model. Equipment components designed in the 3D geometric model are linked to a central file of current configuration and logistic information maintained in a Weapon Systems File (WSF) Prototype data base. Access to an optical work station comprises the third part of the Model.

Modeling began with hull and external features, followed by the internal structuring and development of the main machinery room. The depicted systems, equipment, and components were developed directly from actual MCM engineering data and technical documentation; that is, the data was not scanned in, but manually converted into 3D. Any position or view can be created, both external and internal to the ship (see Figure 6). The Model provides the ability to simulate a walk

through the ship a pace at a time, is look right, left, up, or down, is remove components that construct vision, and so forth. Figure 7 is a black and white photograph taken of a Computer Color Monitor screen upon which the MCM Product Model is being displayed. Although not apparent in the figure, color Coding of Ship systems and structure is included in the model. For example, two of the four diesel engines are shown in dark red, green ventilation pipes, yellow controllers, and blue decking are also shown. The Model can be used to identify equipment scheduled for removal for SHIPALTs, indicate interference to be removed (e.g., ventilation ducting), detect equipment interference before installation at the waterfront, or entertain "what-if" scenarios. Unlike CAD systems, entities within the 3D Model are coded by structure types so that specific components or systems rather than layers can be removed to accommodate different views. Spatial and other dimensional integrity of individual equipment components are retained in the Model for viewing or manipulation, even though internal structures and equipment are removed.

MCM PRODUCT MODEL CAPABILITIES

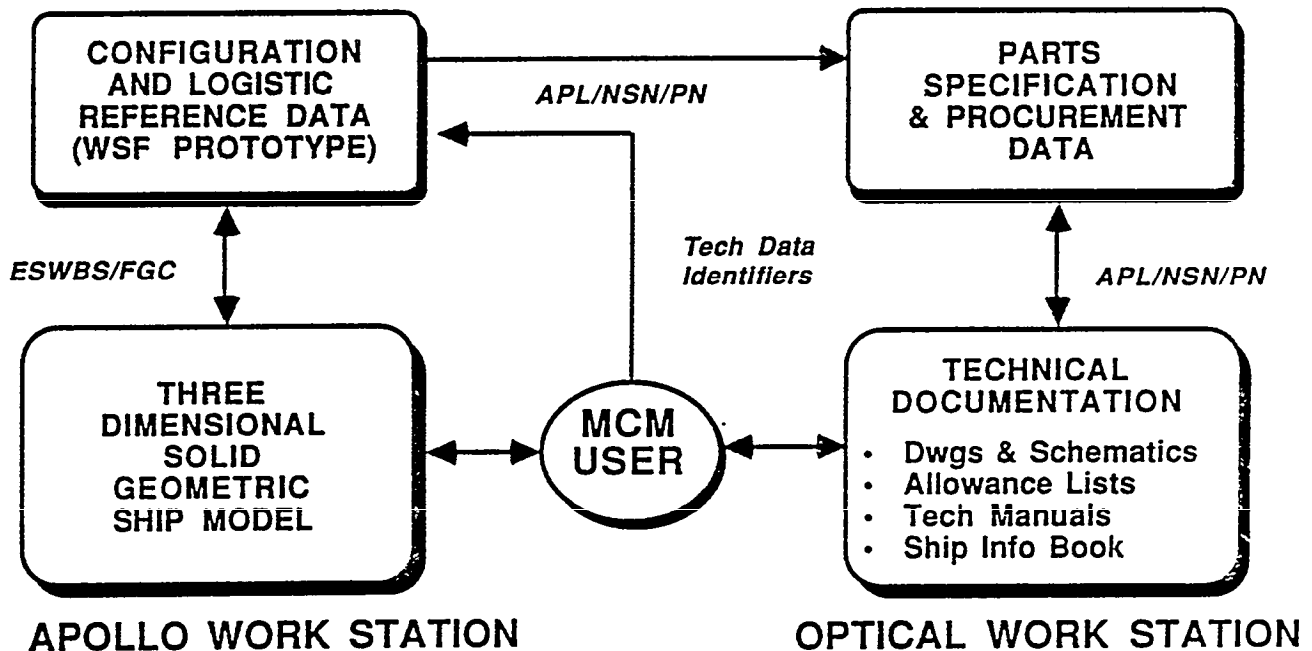


FIGURE 5 - MCM Product Model Capabilities

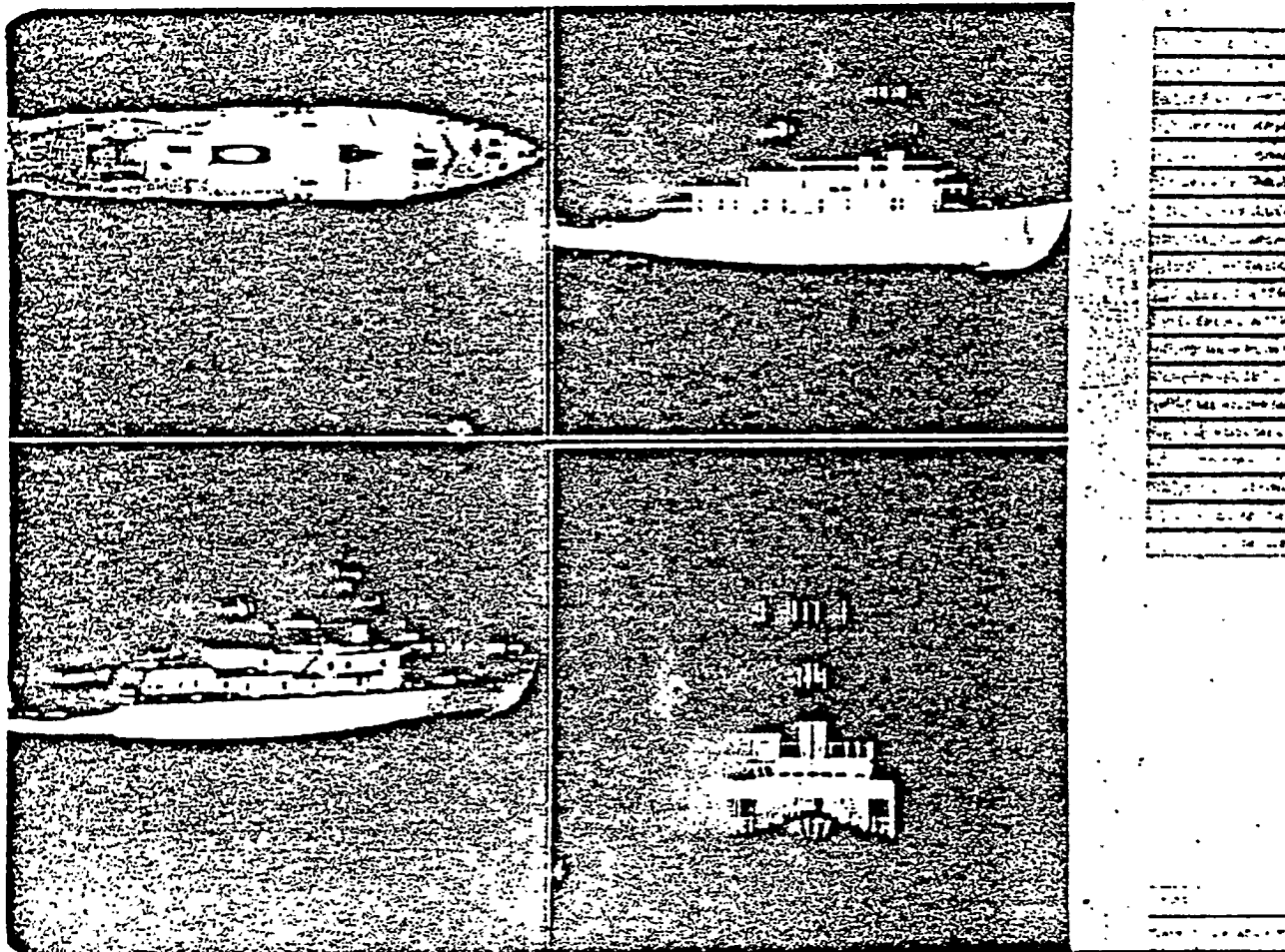


FIGURE 6 - Four Views of the MCM Product Model

The fully relational Model provides you access to the type of information requested as it is needed. Each component in the Product Model has been assigned a unique functional description and hierarchical structure code (Expanded Ship Work Breakdown Structure/Functional Group Code) which permits integration and interaction with respective technical and logistic information stored in a remote configuration and logistics data base. Figure 8 shows the propulsion system. Because of the integrating ESWBS/FGC, the user is able to access the WSF Prototype and retrieve pertinent configuration and logistics information filed for the propulsion system. The user could also begin inquiry with data information in the WSF Prototype, and then request a three dimensional view of the appropriate equipment. The integrating mechanism is the ESWBS/FSZ. It also enables access to technical data stored on optical disk, so that for example, any technical manual can be retrieved, maintenance repair package reviewed, or engineering

drawing examined. An enlarged drawing of the engines is depicted in Figure 9. These documents have been scanned onto optical disk and stored in raster format.

CONFIGURATION AND LOGISTIC DATA SYSTEMS MANAGEMENT

Each equipment component in the MCM Product Model is linked to the WSF Prototype for access to the appropriate configuration and logistic data. Access to this central file eliminates the need for many duplicative, independent data bases to generate various reports and products as required by different users. The configuration and logistic information is logically divided into several groups (or files) that support efficient information management, eliminate redundancy and duplication of data, and ensure that all users have a common, consistent information base to

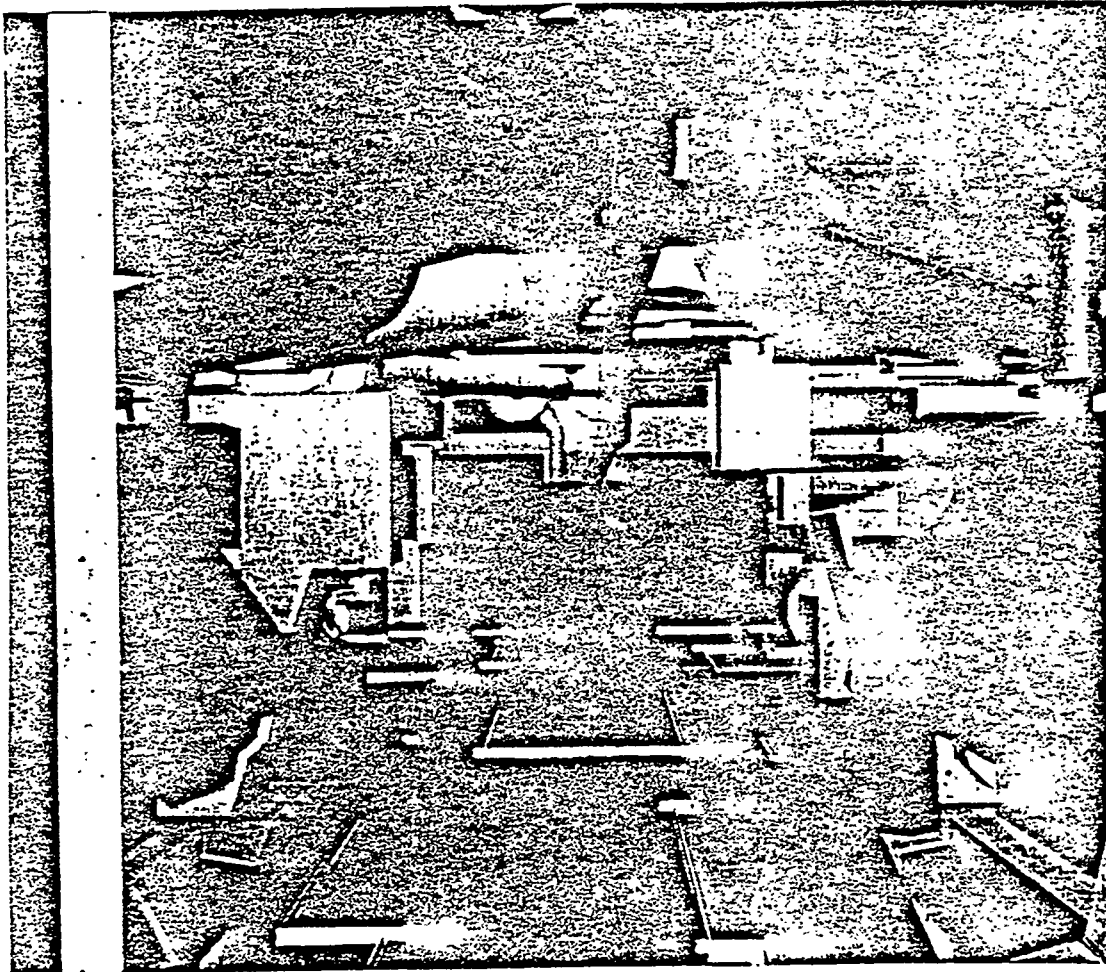


FIGURE 7 - Walk Through the Engine Room

use in executing their functional responsibilities. The division of information allows for management of:

- Ship class and ship configuration baselines;
- System and equipment baselines;
- Technical information (e.g., logistic support and analytic data); and
- The integration of class, ship, equipment, and - technical information (TI) with each other as well as with other files (e.g., three dimensional model and image management systems).

This approach to configuration and logistic information management decreases the number of unconnected and inconsistently structured computer files and replaces them with a system that integrates data managed by a variety of functional activities, makes that data available to appropriate users, eliminates duplicate data, and avoids the potential data accuracy and integrity problems. Each piece of data stored in file must have an accountable

activity responsible for its identification, creation, maintenance accuracy, and currency. Other file users provide quality assurance by identifying perceived inaccuracies to data managers.

Development of the Product Model for Configuration Management of the Engineering Baseline

The Product Model is the key configuration management integration tool because it defines, at least at the summary level, all configuration items that are contained within the structure. Drawings are the primary tool for establishment, management, maintenance, and control of the engineering configuration baseline of ships, weapon systems, equipment and components. Use of CAD, CAM, three dimensional models and other automated design, development, and storage media to supplement or replace traditional drawings is a key feature in the development of an IWSDB. The Product Model provides relational structuring of a geometric model with automated linkage to:

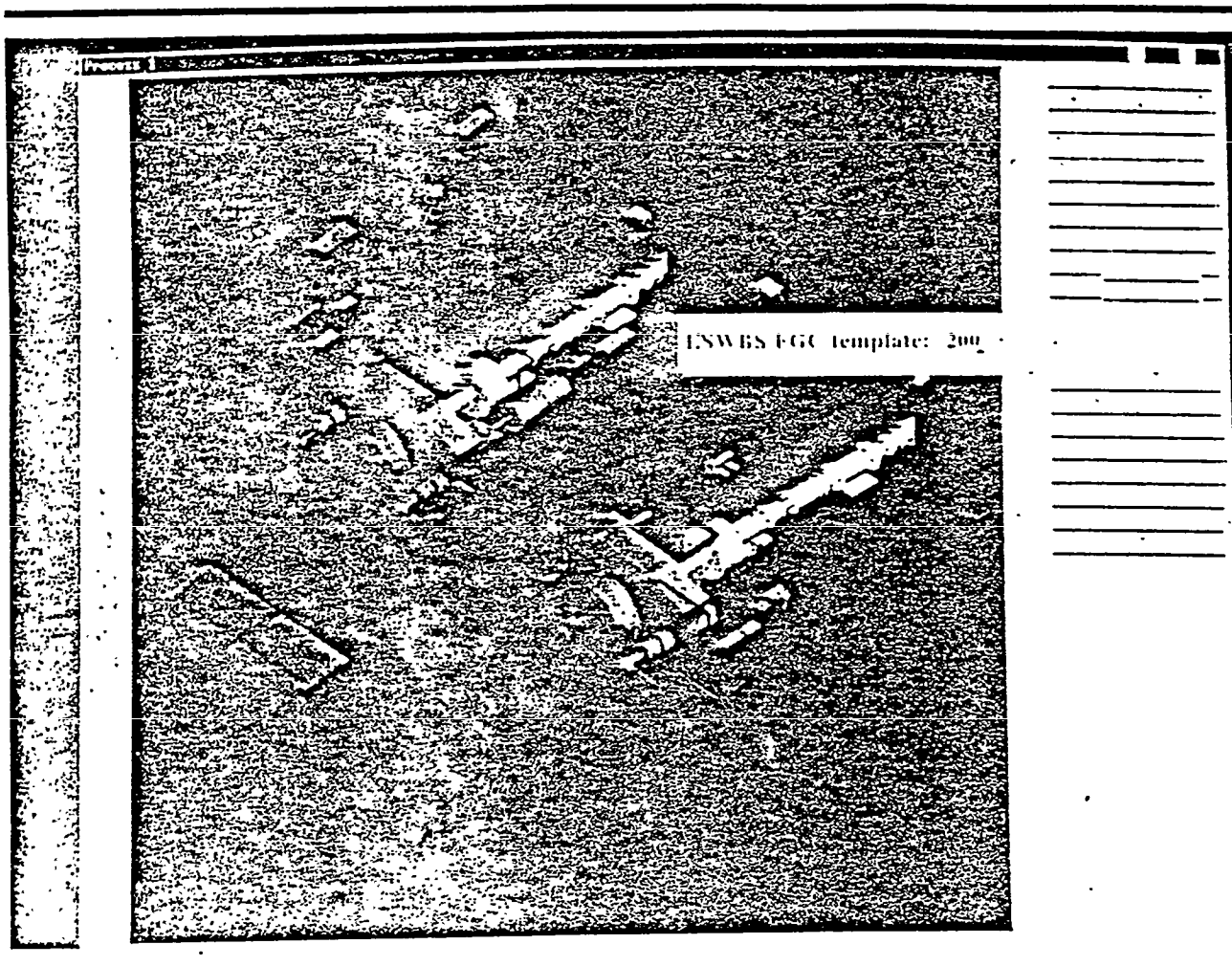


FIGURE 8 - Propulsion System (ESWBS/FGC)

- specific entities, systems, and areas within the hull structure;
- Documentation and files that define (e.g., specifications, standards, performance requirements) and analyze (e.g., R&M, test, weight and moment studies, LSA) systems, equipment and components; and
- Other related configuration, logistic and technical data

The natural processes and relationships which define the ship, its systems and equipment by function, are integrated in the Model with the physical attributes that satisfy those functional requirements based on performance, specifications, and standards.

INFORMATION INTEGRATION

Integration of the Product Model with Design, Construction, Engineering, and Logistic Data

The long-term goal of CALS is for the complete integration of all weapon

system information through the use of shared data bases. This is a radical departure in both concept and practice. Ship specifications, military and other Specifications and standards, performance specifications, and operational requirements provide the parameters for the development of procurement specifications. They also define the detailed design of systems that integrate the shipbuilder's procured physical equipments and the Government Furnished weapon systems and equipments within the ship's structure. They provide parameters for analytic processes and performance and engineering studies. The following engineering and logistic deliverables are examples of typical data products that can be prepared using the product model:

Weight Reports
Test Procedures and Reports

Drawing Equipment Data List
Damage Control Diagrams

Compartment Areas-and Volumes
Material Ordering Schedule

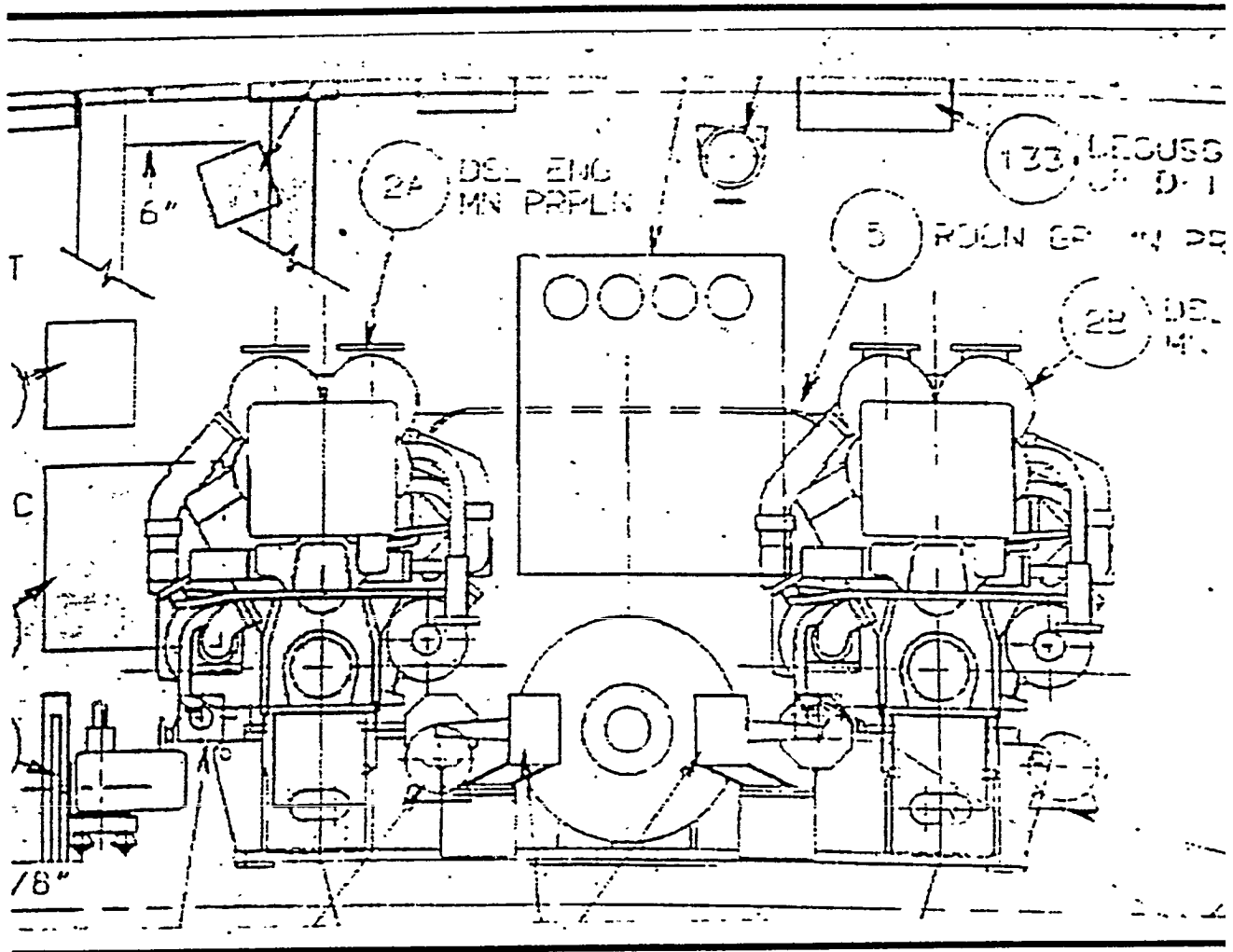


FIGURE 9 - Optically Scanned Drawing

Crew Training Aids
Drawing Schedule

Electrical Load/ Power Analysis
List of Electrical Data

Figure 10 is a samplework package which presents a bill of material, piping isometrics, an internal view of the equipment, and an external view of the ship. All were retrieved from the Model which exemplifies the integrative nature of the Product Model.

of the Product Model with

To provide automated and responsive access to graphic data and text many of the documents have been raster scanned and stored on optical disk. As much of the engineering, technical, analytic, and logistic data is created and presented in paper form, it is bulky and difficult to handle, store, retrieve, transmit, and update. This applies equally to information that is Government Furnished, procured from vendors, and created by the shipbuilder

for delivery to the Government to satisfy CDRL requirements (e.g., provisioning documentation, draft technical manuals). Much of this documentation is static or requires only periodic update (e.g., specifications, standards, DIDS and CDRLS, shipbuilder plans), while others require costly, high volume submissions (e.g., cost and performance reports) with monthly or quarterly updates to multiple users, while still others are large volume documents that require periodic update (e.g., drawings, test plans, compartment closure plans). Use of optical storage and retrieval media with raster scanning can significantly reduce both the time and cost of preparing and transmitting data, significantly reduce the volume of files and data storage, and significantly increase the accessibility to, availability of, and responsiveness of all or selected portions of the data and data deliverables.

The MCM Product Model represent the successful combination, integration,

DEPARTMENT OF THE NAVY		- PLME COMMEASURESHIP CRIP			
PIPING BILL OF MATERIAL ISB TYPE: ISB NUMBER: ISB4					
LINE NUMBER: PL 4521-504442-000					
OBJECT NAME: PL521111					
ITEM	DESCRIPTION	CODE	TYPE	SIZE	QUANTITY
1	3" SCH 40 PIPE	PIPE		3	FE
11	3" SS BALL VALVE	V	BA	3	SS
12	3" SS SOCKET WELDED ELL	ELL	SW	3	SS
13	3" STRAIGHT TEE	TEE	S	3	SS
14	4" REDUCING TEE	TEE	R	4	SS

FIGURE 10- Sample Work Package

and interaction of three independent demonstration projects. The combined projects provide access to, extraction of, and use of a variety of information products and permit identification of components, systems, and technical data. The power of the Model is demonstrated in the integration of different data and processes for production planning, configuration management, logistic support, etc. It also enables access to technical data stored on optical disk to enable, for example, retrieval of any technical manual, examination of engineering drawings or review of maintenance repair packages.

WHERE DO WE GO FROM HERE

There are three basic thrusts for future MCM Product Model applications: documentation, assessment, and demonstration.

The development of contractual

documents and implementation procedures is key to the successful pursuit of CALS. Examples of the types of documentation to be developed are described below.

Statement of work (SOW).

Descriptions of the processes required to produce and integrate the basic types of data needed for and resulting from design, construction, delivery, and initial and follow-on logistic support for operational units. The SOWs should discuss methods for consolidating and coordinating those data into basic, integrated data bases, provide methods for interfacing those data bases and require the bidder to define and describe his or her plan to implement the procedures described and to assess the costs and offsets.

DIDs and CDRLs. Descript of the products to be developed and delivered. Implementation of these DIDs/CDZLs will improve operation or reduce Costs of preparing final products through reduction of redundars requirements, reduction of many submission requirements (e.g., direct

access to contractor files will obviate the need for many reports), and through the development of integrated files and data structures.

Implementation Instructions.

Practical procedural instructions that aid acquisition and life cycle managers, engineering organizations, and logisticians in planning for and executing CALS responsibilities, including interfacing with other IWSDB.

The conversion of contractor efforts from their current paper-constrained, discipline-oriented data development and delivery processes will not be easy. Impacts on cost, schedules, quality, competition, and other factors must be carefully weighed against near- and long-term realizable benefits for the individual program and against the requirements of an evolving and increasingly automated life cycle management system. Similarly, Navy organizations must be able to receive, process, and use the digital data provided. While the need for modernization of the infrastructure is clear, the questions of how much is needed, when, and where present a formidable resource challenge that demands immediate attention.

NAVSZA'S use of prototypes and demonstrations, using live or actual data and documentation and actual on-site workers, has provided significant insight and hands-on experience (e.g., real problems had to be solved in real time and could not be assumed away). This has proven concepts and allowed for initial capability establishment without significant investment. The expansion of this concept to include the establishment of a working model of the MCM Product Model at the planning yard, NSY Charleston, is being pursued as the most effective method for assessing the NAVSEA documentation and resource requirements for full CALS implementation.

CONCLUSION

The MCM Product Model demonstrates integration of engineering, design, logistic, production, and configuration management processes. It also generates a variety of products from the same data base, including piping isometrics, work packages (bill of material combined with view of ship, system and/or equipment), and damage control diagrams. The Product Model not only shows the feasibility of transferring paper data to digital format; it also assigns intelligence to shared or common data, permits different ways of accessing the same data, and integrates various processes. As such, the MCM Product Model demonstrates the

feasibility and affordability of implementing CALS for delivered weapon systems in a current environment with semi- or non-automated systems and non-integrated data.

The end result of CALS is the complete transformation of the NAVSEA acquisition and logistic infrastructure to meet the challenges of automated technology advancements and new data management and networking concepts. The MCM Product Model, together with other CALS projects, have demonstrated the viability of applying evolving information integration and automation technology to today's processes. Application of these tools will improve productivity, maximize resources, and at the same time accelerate infrastructure modernization.



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No. 21

Information System Models — As a Tool for Shipyard Planning and Control

A.Y. Odabasi, Member and D.R. Patterson, Visitor,
BMT International Inc., Columbia, MD

ABSTRACT

This paper proposes the use of information system models of production as a tool to achieve rationalization and integration goals and to create a learning organization. It is shown that through use of these models it is possible to identify cost-benefit ratios for various rationalization and modernization tasks, and to create an action plan for their implementation. Proposed production information model aims at reducing every job into its smallest elements in the form of processes and activities as well as rationalizing the subjective concepts of complexity, size, quality etc. through the use of metrics. The paper also discusses the increasing reality variance of accounting systems and proposes the introduction of single-factor and total factor productivity for correct evaluation of operating performances and of investment decisions. While the model is generic enough to cover all eventualities, its application to specific yards require additional tailoring to reflect the effects of layout, facilities, organization and labor resources on the yard performance. The paper suggests that adoption of such models avoids sub-system optimization or importation of methods and techniques which might have been successful in some other operation and yet may not be appropriate in given circumstances.

1. PREAMBLE

During the 1970's, at the early stages of the decline of U.K commercial shipbuilding industry, BMT (then as BSRA) was asked to study the 'state of practice' in U.K. shipyards which, in 1977, led to a major effort with the title of 'Advanced Technology Shipbuilding'. One of the serious concerns of the project was the role of Management Information Systems (MIS) and its impact on shipyard performance. This report resulted in a comprehensive report [1], reflecting the state of affairs within that day's understanding. Since then periodical updates to the study have been issued to reflect the changes in technology, methodology and management practices: This paper is a summarized version of an update of the previous Studies

to account for the changes in information technology and the emergence of a new manufacturing management philosophy, [2].

The problem faced by the shipbuilding industry is to produce a working design and to build the product from this information in a cost-efficient manner. The design of modern ships, especially warships and submarines, is a very complex process providing a configuration design to house the shipboard systems and equipment. During this process a large body of information is created and this information together with facility, yard layout, material and cost data has to be captured, analyzed and utilized in decision making for the shipyard to operate successfully. The volume, variety and complexity of this data especially in the face of compartmentalized thinking in various departments, may create confusion and turn into a liability instead of being an asset. The aim of this paper is to provide an overview of total system requirements, its components and their functions with due emphasis on integration. It is, however, to be understood that each yard, based on its facilities, production methods and management infrastructure, need to tailor the system as there can be no universal remedy valid for all shipyards.

2. THE NEED FOR RATIONALIZATION AND INTEGRATION

Since the Second World War manufacturing technologies, especially shipbuilding steadily declined in U.S.A. and U.K, gathering further pace since 1970. To some this was the manifestation of David Ricardo's famous law of comparative advantage '...that such an ancient and labor-intensive item should rightly be produced in countries whose workers had simple manual skills and low wage rates.' However, when high-technology companies found themselves losing position to foreign competitors (often from countries viewed as followers and copiers rather than technological innovators) the problem started to receive more serious attention.

Within the context of U.S.A. and U.K three alternative explanations have been proposed. According to the first school of

thought there was no real problem. The difficulties being experienced by the industry were simply the normal response of an economic system to a series of external shocks the maturation of certain "sunset industries and the symptoms of an accelerating transition to a post-industrial service-dominated society [3]. This view became increasingly difficult to defend as industry after industry collapsed under the pressure of Far Eastern competitors.

An alternative explanation suggested that a serious problem existed and it was primarily due to macro-economic policies. The main causes being high interest rates and a tax system that warped investment decisions implicitly favoring consumption and borrowing over saving and investment, and residential construction over industrial modernization.

A third school also believed that the problem was serious and persistent, but simply correcting some of the obvious inconsistencies and imbalances in macroeconomic and industrial policies would not be sufficient to restore the industrial competitiveness. The main problem laid in the areas of manufacturing management and technological development [4]. Within this explanation, when one looks upon something as a liability, not as an asset, it tends to change management attitudes. One manages around it, not through it. It receives less of the corporate resource allocation with predictable consequences. Equipment runs down, buildings get old and dirty, and workforce relations get even more strained. In an effort to regain control, management installs more sophisticated central control systems which tend both to increase the overhead costs and to stifle innovation. Power and expertise increasingly migrate from the factory floor to the corporate accounting room. The prime motivator becomes the fear of failure and punishment. A downward spiral of performance, confidence and investment follows, leading to the closure of plant.

This trend can be reversed and recent resurgences in some manufacturing companies through rationalization and integration is the clear proof of potential of constructive action. Rationalization, in the first instance, require that management should focus on organization's resources, capabilities and energies on building a sustainable advantage over its competitors along one or more dimension of competitive differentiation; relative cost, relative quality, and relative innovativeness. Once it has been decided what kind of competitive advantage the organization is going to seek, it has to configure itself to achieve and continually enhance that competitive advantage. This requires making a series of coordinated decisions of both analytical and infrastructural nature. Analytical decisions refer to matters where estimates can be made, such as

the amount of total production capacity.

how this capacity should be broken up into specific production facilities,

what kind of production equipment and systems should be adopted by these facilities,

which materials, systems and services should be produced internally and which should be sourced from outside organizations, including the degree of relationship with suppliers.

By infrastructure, on the other hand, refer to management policies and system which are used in the implementation of analytical decision. These are:

Human resource policies and practices, including training and management selection,

Product and process development policies,

Capital investment policies,

Performance measurement and reward systems,

Organizational structure design.

Integration on the other hand eliminate compartmentalized thinking, increases communication and awareness, encourages standardization and design for production and reduces redundancy and duplicity. Within a large organization one identify four levels of integration: design, decision and organizational integration.

Most organizations believe that they have successfully implemented a new operating technology when the system is working without serious bugs, reliably and new technology has a high utilization rate. However, this definition ignores the most important reason behind the implementation of a new technology value for investment. One can therefore propose two levels of success in the implementation of technology

Technical success

Realization of benefits
(economic success)

Technical success generally refers to reduction in errors and effort requirement to the elimination of paper-driven steps, a growth in enabling capability and functional Economic success, on the other hand, implies

Realization of productivity increase
(e.g. reduced labor, increased throughput, reduced cycle-time, etc)

Realization of non-productivity benefits
such as reduced lead-time, quality improvements, increased flexibility, cost-effective design, etc.

Translation of these benefits into competitive gain (value).

Various surveys conducted in different segments of the manufacturing industry indicate that successful design and data integration generally leads to technical success with only limited economic benefits. The real competitive advantage comes with the decision and organizational integration. However, unless design and data integration is complete, decision and organizational integration cannot be achieved successfully.

Achievement of these goals "require time and investment. Figure -1 illustrates time and cost implications of integration where design integration is included within the data integration. Successful implementation of rationalization and integration relies heavily upon the design and operation of a distributed data collection, analysis, planning and control systems and the establishment of a data base and an information system satisfying these requirements, which contains at least three levels of information covering strategic, functional and operational aspects and appealing to the needs of different tiers of the hierarchy (see Figure 2). in a larger organization strategic information of one tier may well become and operational level information of a higher tier.

3. SHIPYARD INFORMATION SYSTEMS

During the evolution of the shipbuilding industry each shipyard has

developed its own systems by which to plan and control its operations. These systems varied from yard to yard, each being developed according to its own needs. Small yards building simple vessels with only a few hundred employees sometimes relied largely verbal communication whereas large yards, perhaps spread over a number of separate sites, and employing many thousand of workers needed to resort to a more formalized approach by instituting standard forms, standard reports, uniform collection of manhour data etc. Invariably, the larger companies use computers as an aid to handling information.

However, despite the wide spectrum of systems found in the industry, it is felt that the objectives underlying those systems correspond to a common framework of requirements and it is the development of this into a set of minimum requirements, with due emphasis on planning and evaluation, that has been the object of this work. The existing systems have been examined in detail and the essence of each of the various functions extracted. From this it has been possible to identify a number of system modules, i.e. routines or procedures each with a well defined purpose, and with inputs and outputs which are recognized requirements for planning and controlling the functioning of a shipyard.

As an aid to clarity of presentation these system modules have been grouped together into seven main functions. These

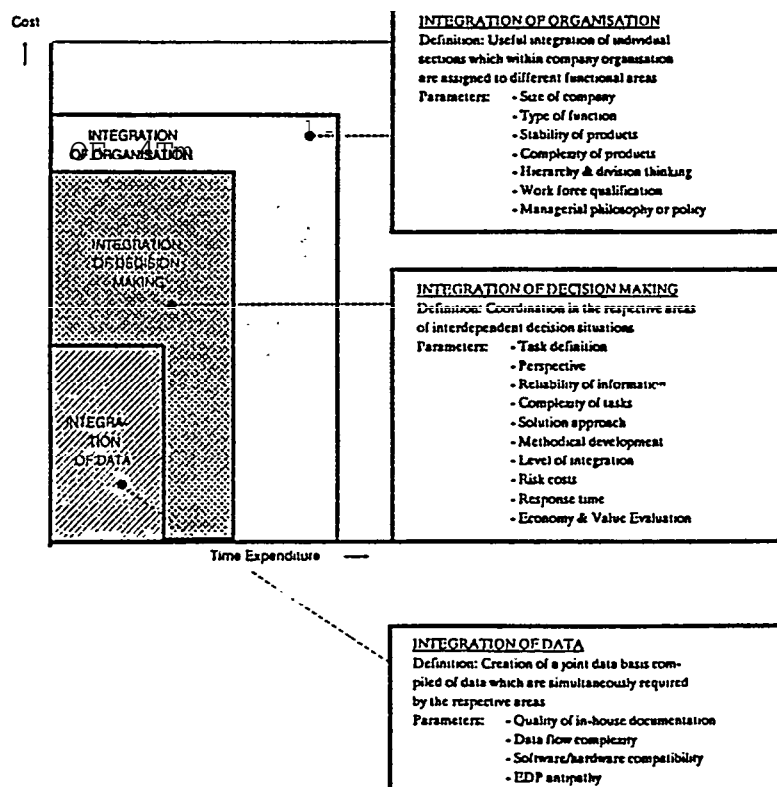


FIGURE - 1. LEVELS OF INTEGRATION - TIME & COST IMPLICATIONS

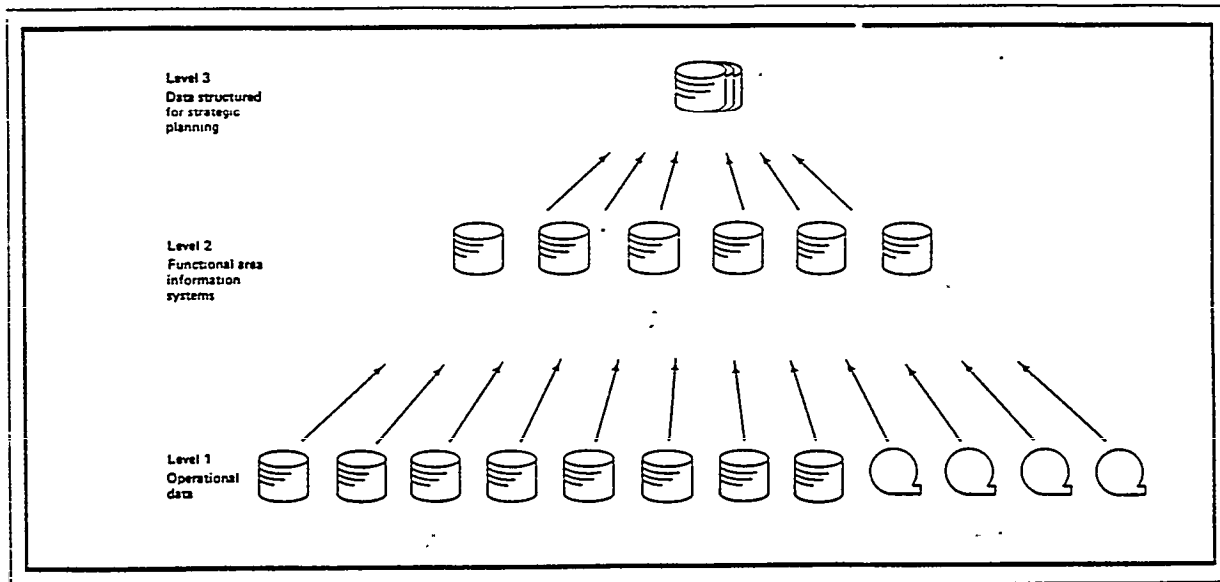


FIGURE - 2. HIERARCHIAL INFORMATION & DATABASE STRUCTURING

functions correspond to established shipyard practices but a clear distinction must be drawn between activities which are carried out within each function, and any departmental structure which may be found in a particular shipyard. Only by recognizing this distinction will it be possible to correctly assess current systems and procedures in order to discover areas in need of improvement. These main functions are

CONFIGURATION DESIGN: To create a ship configuration with all of its elements and to analyze its functionality to ensure the proposed design satisfies the attribute requirements and accommodates producibility demands of the shipyard.

PLANNING: To set dates, targets, and cost and quality implication which will ensure compatibility between the requirements of production, the availability of resources and technical information, and the limitations imposed by financial and contractual obligations.

PRODUCT DESIGN: To convert configuration design into a detailed product, to identify and specify the total material and equipment required for the construction of a ship, and to prepare technical information to meet the requirements of production.

MATERIAL CONTROL To procure all materials and services for the construction of a ship and operation of a shipbuilding business at economic cost to meet contract requirements.

Production ENGINEERING: To define, in conjunction with planning the, building methods and units of work for the construction of a ship, to define the sequence of operations and the material requirements for each unit of work and to collate production information for each unit of work.

Production CONTROL To initiate the production process by means of a short term schedule, having regard for the availability of material and status of work in progress.

MANAGEMENT ACCOUNTING: To accumulate and collate all data relating to labor, material and overhead costs for a contract and present reports for control action by management.

Three important supporting functions are also identified as 'cost/value engineering', 'financial accounting' and 'personnel'. The purpose of the definitions is more as a descriptive aid to the reader as opposed to a definitive statement or constraint. From the viewpoint of shipyard efficiency cost and value engineering provides a critical role both in terms of the selection of the appropriate building strategy as well as the utilization of resources, by linking design, planning and production engineering functions.

It must also be stressed that the grouping of the system modules into functions has been done on the basis of the work done in each module. Thus the planning function contains all the elements of planning even though done at widely varying levels of detail. In structuring the system modules it is essential to reduce the description to a level which corresponds to a function within the yard with a defined action and information flow logic as shown in Figure -3.

A useful format to adopt is to show the function within which the module lies, the title of the particular module and its objective and then to consider three elements of each module. The first essential element is the input data required if that module is to operate. This itself is divided into internal and external information. Internal information exists

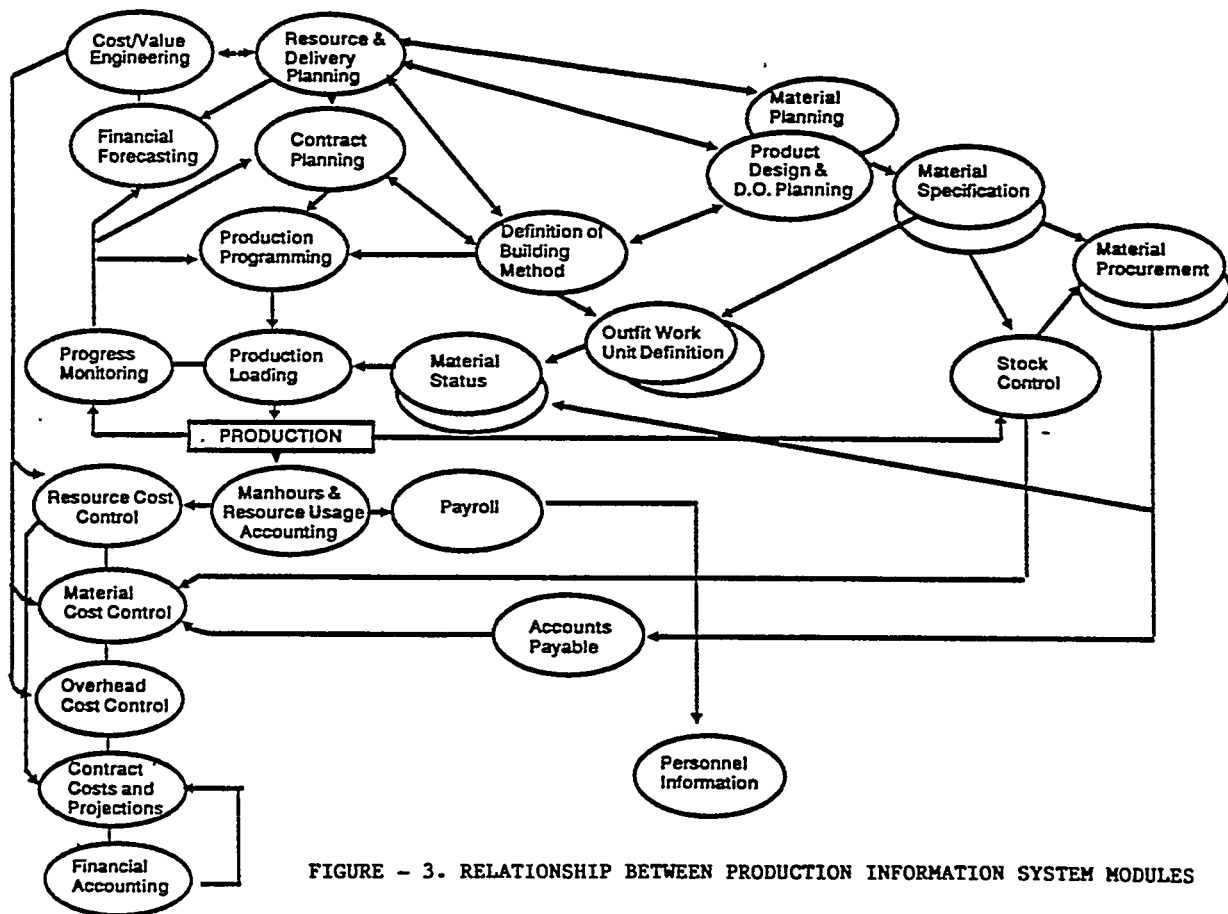


FIGURE - 3. RELATIONSHIP BETWEEN PRODUCTION INFORMATION SYSTEM MODULES

within, or is generated by the function, i.e. files of data reference information etc., or the expertise or experience of personnel. External information is generated as output from other system modules and transferred physically or verbally between the modules. In many cases (where advanced computer systems are in use) this transference of data may be achieved by many modules having access to the same database.

The second element is the output from the module. As with the input the medium of transfer is not usually specified, but in many cases will be an organized database system. This does not, however, exclude other forms of communication.

The third and last element described for each system module is the method. Only an outline of the method is given because the nature of the shipyard will, in any implementation process, determine the precise details. Some methods will probably always remain manual, while a great majority will be achieved by the use of computers, especially where accuracy and rapid operation on or transfer of data is required. This concept of presentation, together with the connectivity diagram, is illustrated in Figures 4 and 5.

The concept of defining groups of operations or tasks as 'work units' and referring to the same units for planning, material status checking, progress monitoring and cost monitoring is a common theme in several of the system modules. The work unit concept is already widely applied for steelwork fabrication and outfitting where typically one or more steel blocks and their outfit elements are treated as work units. The definition of work units will vary from one shipyard to another and from one ship type to another depending on the way the work is organized. The general definition of work unit may be stated as:

A set of production operations or tasks grouped together for cost-efficient production and assigned to be so, for the purposes of planning and control

There must be a recognizable and definitive start and finish for every work unit to facilitate progress monitoring and there must be clear responsibility for each work unit at 'shop floor or trade management level

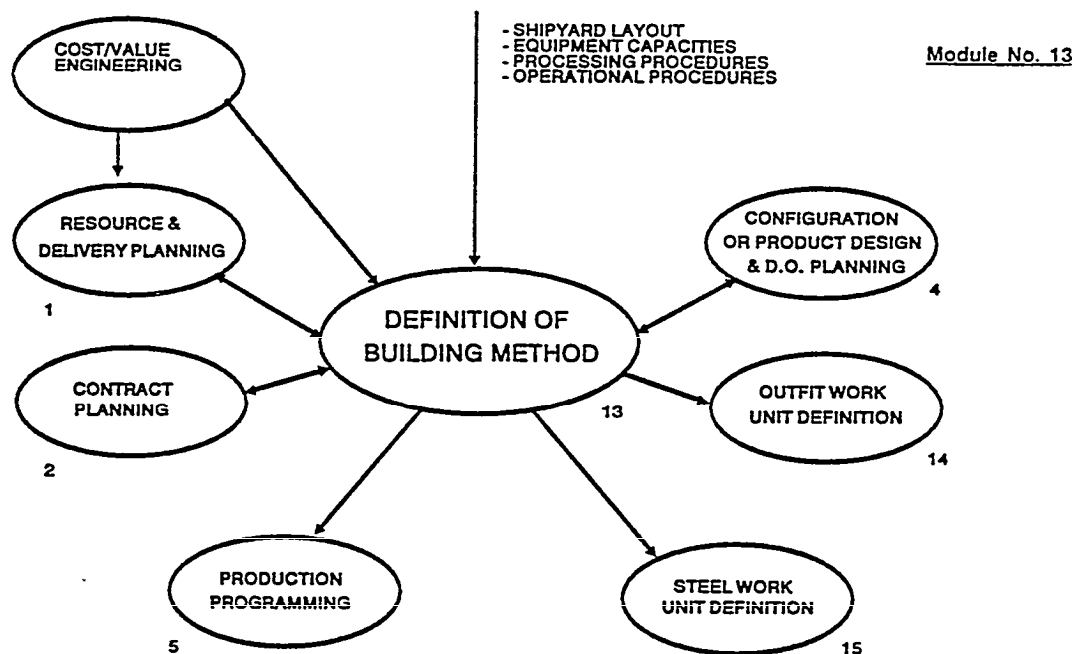


FIGURE - 4. AN EXAMPLE MODULE CONNECTIVITY DIAGRAM

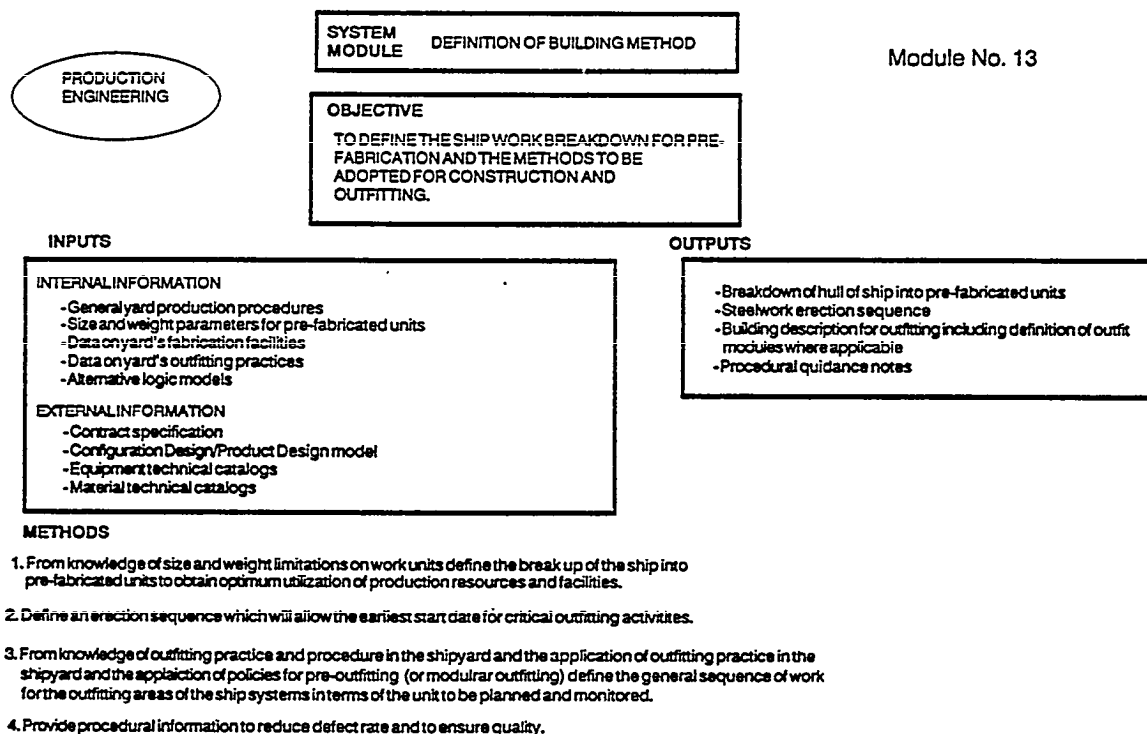


FIGURE - 5. AN EXAMPLE OF MODULE DESCRIPTION

4. RELATIONSHIP BETWEEN DESIGN AND PRODUCTION

Historically, many shipyards employed a compartmentalized approach to design and production, segregating these functions from each other. In fact, in some shipyards drawing production and design are considered to be the same thing. In the present era of rationalization and integration one of the very first issues to be settled is to define the function and interrelationship of each activity to ensure cost effective operation. Within the context of shipbuilding design refers to the generation of a configuration and product, satisfying all the functionality requirements in a cost efficient manner. Here, configuration design refers to the top-down stage of the design where each component or system is defined and analyzed to satisfy the functionality requirements, just like defining the main bone structure and organs of human body. Product design then operates on configuration design to add the necessary details and information, and reduces it to an assembly of elements, each in a producible or procurable state.

During the configuration and product design, a large number of production decisions are implicitly or explicitly made. Historical data on cost saving potential vs. cost to change indicate that earlier consideration of the cost and producibility provides the maximum gain, as depicted in Figure 6. However, achieving this end requires development and establishment of a cost effectiveness analysis.

Cost effectiveness within the context of this paper includes value analysis and value engineering. Value, for definition purposes, is the fair equivalent in services or commodities that an owner/buyer receives in

exchange for money. "Value Engineering (VE) is a creative, organized approach whose objective is to optimize cost and/or performance of a facility or system. The VE approach is directed toward analysis of functions. It is concerned with elimination or modification of anything that adds cost to an item without contributing to its required functions. During the process all the expenditures relating to design, construction, maintenance, operation, replacement etc. are considered (see Figure 7). Such an

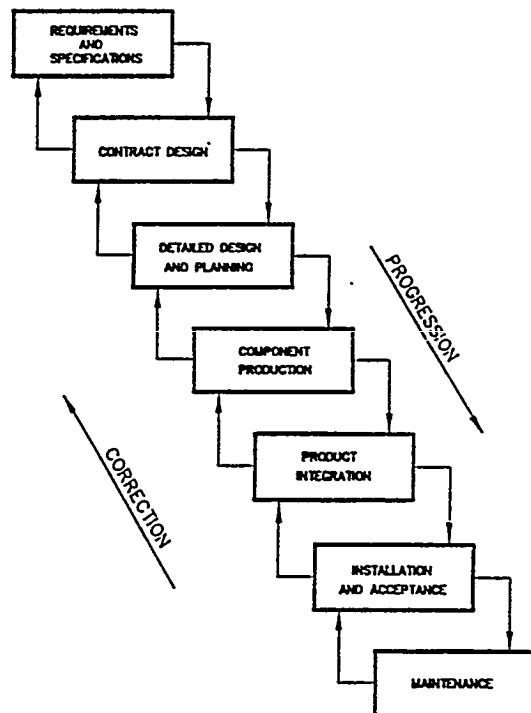


FIGURE - 7. THE WATERFALL MODEL OF THE PRODUCT LIFE CYCLE.

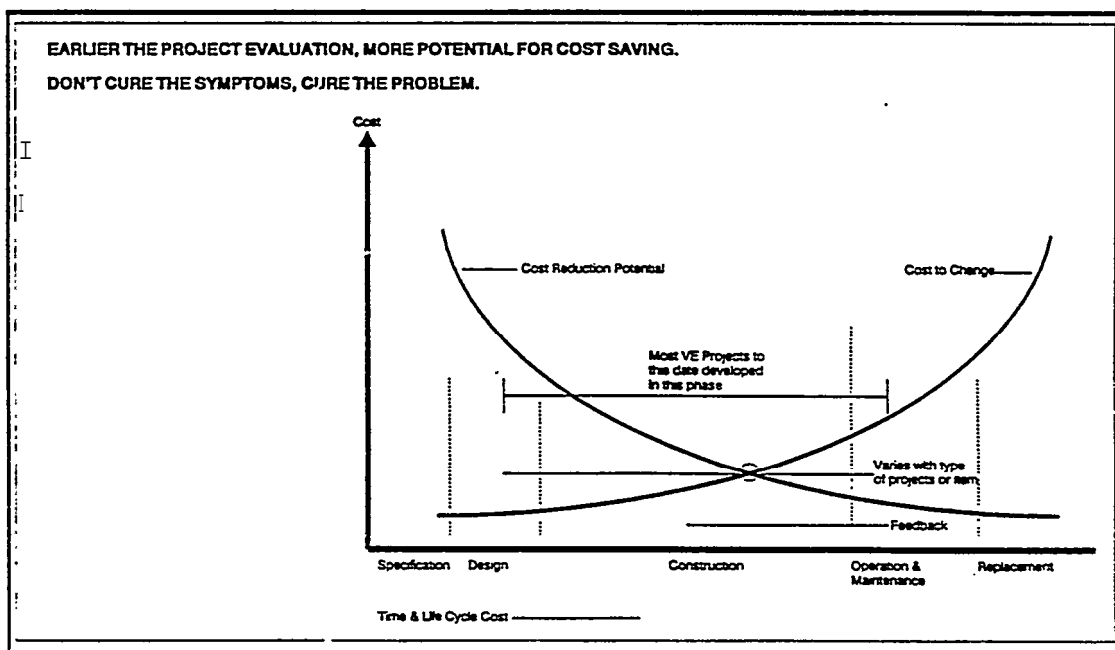


FIGURE - 6. COST REDUCTION POTENTIAL DURING THE PRODUCT EVOLUTION

evaluation relates to the life cycle considerations which represent continual activities involving design, evacuation, production, comparison and modification.

Through the use of creative techniques and the latest technical information regarding new methods, strategies, materials and processes, alternate solutions are developed for the specific functions.

Cost effectiveness aims at the efficient identification and removal of unnecessary costs, i.e. costs which provide neither quality, use, life, appearance, nor customer required features. It improves the effectiveness of work that has been conventionally performed over the years, by filling in blind spots. Once a high cost area has been isolated, quite commonly 15 to 25 per cent, and very often more, costs can be removed. As such, it is not:

just eliminating the "gold plating"

cutting costs by substituting items, processes, materials, and systems which do not meet the requirements

cutting costs by degrading performance, maintainability, or reliability below the requirements

reflecting adversely on the professional competence of the designer.

the techniques employed in value analysis are not new when taken on an individual basis (in fact we have been overwhelmed by fragments of knowledge but have had no way to structure this knowledge). What is new is the systematic and structured approach which converts observations and data into information and knowledge to be used in the analyses to be performed. Cost effectiveness is concerned with both the economic and the use values. Use value, or the properties and qualities which satisfactorily and reliably accomplish a use, is closely related to function. Performing a function based value analysis is to determine the usefulness of any item or element whereas traditional cost reduction efforts give little thought to functional considerations of the user's need and attempts to perform an item-oriented cost reduction.

To facilitate a functional analysis, the function of any item, component or design is defined literally by two words: a verb and a noun. For example, the basic function of a hatch cover is to 'control access' - control is the verb, access the noun. Similarly the function of a wire is to 'conduct current'; that of an elevator to 'convey weights. Here, the verb answers the question, What does it do? This question focuses attention on the function rather than on the particular design and the subsequent function analysis involves thinking about why an item is necessary, rather than thinking about the item itself (see Figure 8).

Since a specific monetary value may have to be assigned later during the process of relating cost to function the type of noun to be used is important. A measurable noun together with a verb provides a description of a work function (e.g. transmit load, support deck, store waste). Function definitions containing a verb and a nonmeasurable noun are classified as 'sell' functions. They establish qualitative statements, e.g. satisfy code, provide symmetry, assure convenience.

The technique of stating function using a verb-noun helps to reduce a problem to its fundamentals. The advantage of the approach are

Forces conciseness. If one cannot define a function in two words, either there is not enough information or one is trying to define too large a segment of the problem.

Avoids combining different functions and ensures that only one function will be defined at one time.

Facilitates the task of distinguishing between primary and secondary functions.

Aids in achieving the broadest level of disassociation from specific design or previous solutions.

Once the function-item relationship is established, functional analysis can be performed. The first step in any functional analysis is to classify the verb-noun function as either prime or secondary. The objective is to use an organization methodology to determine if there are functions that are unnecessary, overly expensive, or can be combined. The purpose is to simplify the logic in design, leading to making items less expensive.

Item-oriented cost reduction involves looking at item A and asking the question - "How can item A be made at a lower cost?" The result is item A', a modified version of item A, as shown below:

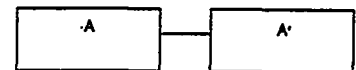


FIGURE - 8. FUNCTION-ORIENTED VS. ITEM-ORIENTED COST REDUCTION

'Prime function' is the performance feature(s) which must be attained if art item or design is to work or to meet the owner's requirements. The item may be a facility, a system, piece of hardware or software, service, method or procedure. Art item may possess more than one basic function. For example, a superstructure bulkhead cart be functionalized as "enclose space" and "support load". If the bulkhead is for an internal subdivision its 'support load' function can be fulfilled by other means, hence its prime function is to "enclose space", the other being a secondary function. "Secondary function" is any characteristic of an item which is not essential to the user for the desired application of the item and does not contribute directly to the accomplishment of a prime function. In some cases secondary function performing items may result from honest wrong beliefs and assumptions, or the Perpetuation of obsolete requirements.

Unless an item in question has also a prime function, for function analysis purposes, most secondary functions have zero use value. Secondary functions are support functions and usually result from the particular design configuration. Generally, secondary functions contribute greatly to cost. Where secondary functions are essential to the performance of the prime function, or required by codes, they have value.

Functional Analysis System Technique (FAST). As a rule functional analysis in design is performed from the top down. The relative position of an item in the total design is tailed its 'level of indentation'. If the function of the total design is dependant upon the indented item, the function is prime, - otherwise secondary. Functional analysis may be applied to all indented items, regardless of their function.

For study purposes, functions of secondary indented items are potential candidates for saving. However, when looking at the overall design and life-cycle costs, many secondary indented items may have essential functions in terms of maintenance, operations, safety or environment.

Level of indentation is derived by the ladder of abstraction method which has been developed as a thought-forcing process. Asking the question, Why? drives one's thinking up the ladder into higher order functions. Asking the question How? forces the thought process down the ladder of abstraction into lower order functions. A formal process of generating level in indentation through the use of level of abstraction is known as Functional Analysis System Technique (FAST). Use of FAST involves a function block diagram based on the answers to What? Why? How? The result is a hierarchy of functions showing their logical relationship. Within a FAST diagram the answer to the "How" question should lie to the immediate right of the function, and the answer to the "Why" question should lie to the

immediate left, about which the question was asked. In this way a chain of verb-noun function description is obtained which links the prime function to sequential supporting prime functions. However, for these functions to exist, a number of support functions need to be performed. If those support functions are required at the same time (i.e. concurrent) they are listed below that function, connected with a vertical line, forming a vertical chain of functions. Some support functions happen all the time and they are placed above the main horizontal function chain. Design Criteria and Codes are treated as all the time support functions. Scope lines determine the limits of the study, and the prime function under study always lies to the immediate right of the higher order scope line (see Figure 9).

Through the use of FAST diagrams one can identify all the prime functions, required and other secondary functions, and the analytical cost effectiveness procedures may then be applied.

Analytical Evacuation Procedure. The basic procedure of a cost effectiveness study is the function-worth-cost approach. For each major prime function all the related items and their functions are listed and identified as prime, required secondary and secondary. Cost of each item is calculated and added together to determine the cost. Then the worth of each item is determined and added together to calculate the worth. Worth is defined as the lowest cost to perform the prime function and required secondary functions in the most elementary level feasible, within the state of the present technology. Other secondary items are assigned to zero worth. In general, worth can be established from an analysis of historical costs, using collected costs for items performing similar functions. Worth may or may not be equal to cost for the same function can be performed more cheaply by other means.

Functional analysis item list is then completed, and estimated cost and worth for the function are determined. The cost/worth ratio provides an indication of the efficiency of a design or item. Experience gained in the fields of process and civil engineering suggest that when the cost/worth ratio is greater than two, there may be a fair potential for improvement.

Once a function is a candidate for potential savings, alternative ideas are generated and evaluated in the same manner. In the generation of new ideas the aim is to reduce the deficit between the cost and the worth. Some of these ideas may be impractical and eliminated on various grounds. The final decisions, however, are made by considering the life cycle costs.

Life Cycle Cost Methodology. Life cycle costing (LCC) is an economic assessment of an item, area, system or facility considering all the significant costs of ownership over an economic life, expressed in terms of

equivalent money. Life cycle cost analysis is defined as LCC plus use of a non-economic adjustment of results using utility evaluation techniques. Non-economic considerations include performance, safety, environment, etc. Because the expenditures are spread across different points in time, a 'baseline' time reference must be established and all the costs should be brought back to the baseline using proper economic procedures to develop equivalent costs.

To perform a LCC analysis information regarding the facility economic life, the anticipated return on investment, cost of money, and operation modes, as well as non-economic requirements such as performance, safety, etc, must be determined. With this information one can carry an analysis of several criteria, including economic and non-economic factors, each carrying a given degree of importance (weight) depending upon the circumstances of the project. Within this context decision making becomes a utility assessment process. At present a large body of knowledge and techniques are available for use. Because of its simplicity and other advantages, especially least dependence on data availability, makes simple ranking methods (weight assignment) the most preferable approach to be adopted.

Weight evaluation provides the tools for complex decision making through a formally organized process for the selection of optimum solutions in areas involving several criteria. In the process, criteria are assigned differing weight values according to their potential impact on a project. The alternative designs are then evaluated against the criteria. During the evaluation process, it is important to consider and weigh the following issues:

needs vs. desires
important vs. unimportant
trade-off vs. non-trade-off

The procedure for weighted evaluation consists of two stages: the criteria weighting process and the analysis process. The criteria weighting process (Figure 10) is designed to isolate important criteria and establish their weights or relative importance. In the analysis phase, performed through a matrix analysis (Figure 11), each alternative is listed and ranked against each criteria. The rank and weight of each constraint are multiplied and totalled. The alternatives are then scored for recommended implementation.

In criteria weighting, only those criteria which have significant impact in comparing alternatives should be listed. In addition, criteria should be unique and not overlapped by other criteria of similar properties. For example, reliability, maintainability, and proven quality have too many overlapping properties: only one should be listed.

Having determined the criteria to be used, the next action is to compare them and establish their relative significance. The degrees of significance are ranked as slight, minor, medium, and major preference. When a decision of importance cannot be made between two criteria, the two criteria can be indicated as equal by using both fetters in scoring the matrix and by scoring each at one point.

To standardize the weighted evaluation process, the raw scores are converted to a scale of 0 to 10 as the normalized weights, ten being the criteria receiving the highest raw score.

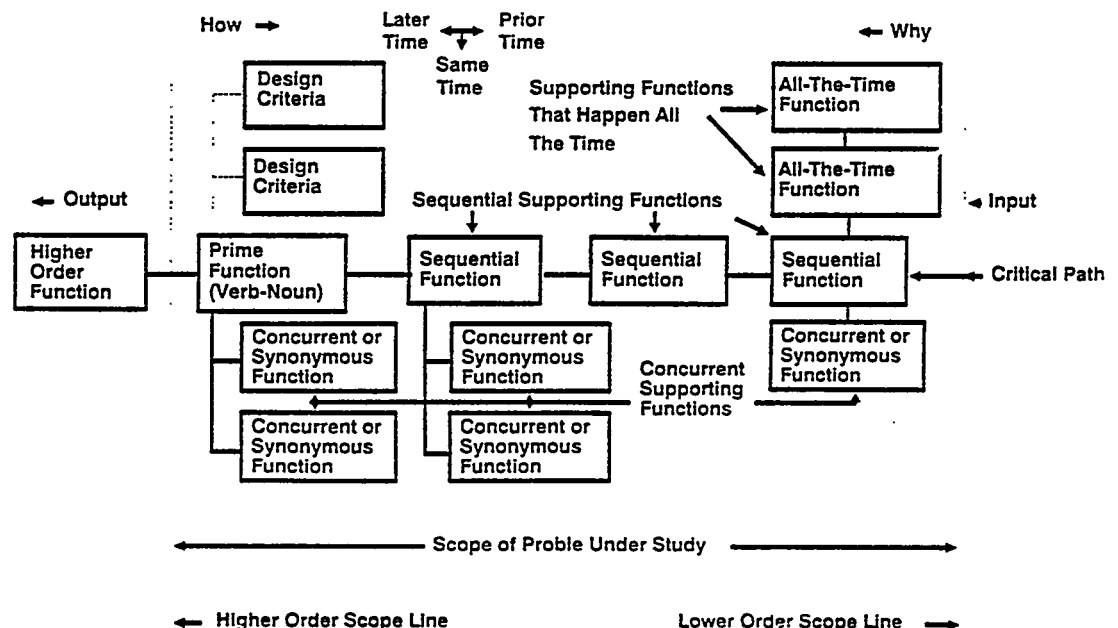


FIGURE 9. - FUNCTION ANALYSIS SYSTEM TECHNIQUES (FAST) DIAGRAM PROCEDURE

The matrix analysis is designed to take the criteria and weights developed and to establish a format for evaluation of the response of various alternatives against the criteria. Total weighted evaluation scores aid the decision-maker in the selection of best alternative. The input data consist of the criteria weighting process results and the alternatives under consideration.

LCC - Criteria Weighting Process

Project _____ Item _____

Team _____ Date _____

Criteria	Weight	Raw Score
A		
B		
C		
D		
E		
F		
G		
H		
I		

Criteria Scoring Matrix

How Important

4 - Most Preference
3 - Medium Preference
2 - More Preference
1 - Same No Preference
One point each (Latter/Lesser)

	B	C	D	E	F	G	H	I
A								
B								
C								
D								
E								
F								
G								
H								
I								

FIGURE 10. - FORMAT FOR CRITERIA WEIGHTING PROCESS

LCC - Matrix Analysis

Analytical Phase _____

Prime Function _____

	Desired Criteria	Weight of Importance (0-10)							Total
		a	b	c	d	e	f	g	
1.									
2.									
3.									
4.									
5.									
6.									
7.									
8.									
9.									
10.									

Excellent - 5 Very Good - 4 Good - 3 Fair - 2 Poor - 1

Seek The Best - Not Perfection

FIGURE 11. - FORMAT FOR ANALYSIS MATRIX

5. COST ENGINEERING

Cost Structure. Since costs are the whole foundation of a cost effectiveness study, cost modeling and cost estimating form one of the most important part of the study. Estimation depends on the available design information and it has to follow the same stages with the engineering design; i.e. concept, preliminary, contract and detailed stages. Cost estimating is the rational application of quantitative methods to problems of estimating designs. The modifier rational suggest the establishment of correct cause-effect relationship as well as the satisfaction of accuracy requirement with due account for the difficulty in obtaining accurate and useable data

Two essential elements of cost estimating are a rational cost breakdown structure and rational cost models for cost elements. Rational cost breakdown is an integral part of the overall technical database management system. The most critical element in cost breakdown is the presence of a logical structure in the form of hierarchies such that as the design progresses lower levels of the hierarchical structure are introduced into the estimation process. Such an approach necessarily leads to a direct reference to basic items in their lowest level and require the establishment of a knowledge base.

Cost Models. Cost estimates may be used for two purposes; to serve as a tool of the cost effectiveness analysis (as a guide for choosing amongst alternative designs), and to determine an actual budgeting requirement. The aim is to use the same cost models to serve both purposes, however in practice, different cost models are used for each of these purposes. The need to include value and cost considerations for the entire life cycle also demands consistency of cost models employed in different stages of design and construction, such that trends predicted in concept design level will not be contradicted in the later stages of the design and construction.

Although various classifications are always possible, based on their logical structure three major types of cost medals can be distinguished: (1) intuitive models, (2) correlative models, and (3) causal models.

Intuitive cost models employ simple design characteristics to apply quantitative reasoning. A typical cost model of this type is costing by weight groups, using past data. Correlative cost models interrelate several variables on the basis of past information, generally by means of a multi-variable regression. As such, these models are mathematically more complex than the intuitive models. They may produce more accurate cost estimates, but they are not necessarily any more insightful. Causal models are designed to represent the effects of some variables caused by changes in the others through a cause-effect analysis. Therefore causal models cannot be obtained

solely by a mathematical manipulation of data like a regression analysis. Their development requires a deliberate causal structuring, based upon either a formal theory (i.e. system identification), or at least some plausibility arguments and a strict validation process.

The major difference between the causal and other models is its ability to forecast as well as predict, i.e. incorporation of changes in technology, materials, methods and environment to anticipate how these changes may affect the future.

One feasible way of achieving a causal model is to define product, process, size and complexity metrics to reduce subjectivity and arbitrariness. Metrics are objective and algorithmic elements for the measurement and quantitative estimation of product features in relation to a product model. As such they can be used in estimation of cost, size, quality, complexity etc. For example, complexity of a hull system can be expressed using "Cyclomatic Complexity Number (CCN)" employing a decision flow graph (see Figure 12).

1 1 This definition has been borrowed by cybernetics.

CCN = e - n + p
e = number of operations in a unit
n = number of element
p = number of connections with other units

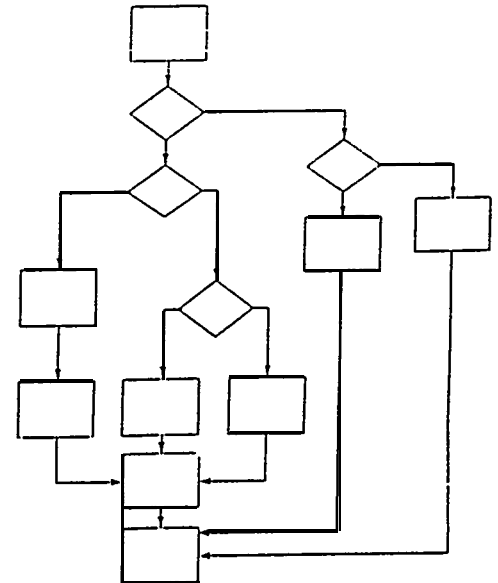


FIGURE 12. - COMPLEXITY ANALYSIS FROM A WORK SCHEDULE FLOW GRAPH

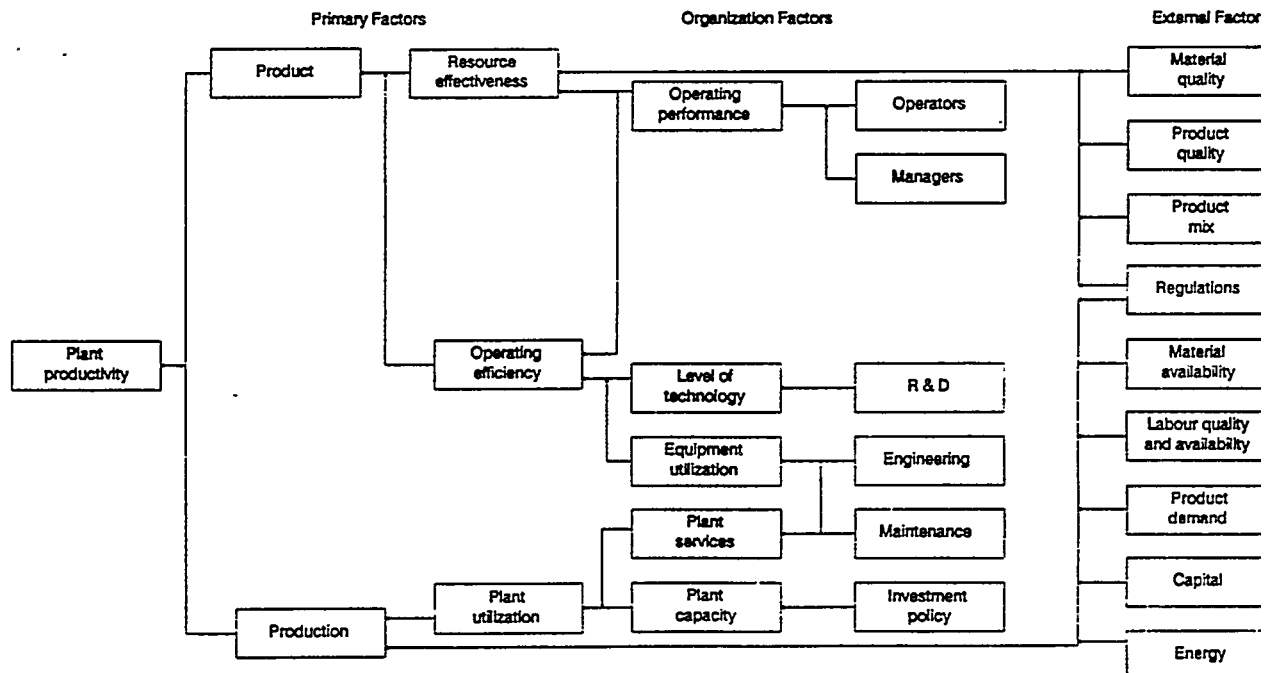


Figure 13 - FACTORS THAT INFLUENCE PRODUCTIVITY

6, RELATIONSHIP BETWEEN
SHIPYARD MANAGEMENT
STRATEGY AND INFORMATION
SYSTEMS STRUCTURE

Since the early days of industrial resolution the method of shipbuilding and its management have undergone considerable changes. Until the end of the Second World War artisan mode of operation and hands on personal leadership, based on the know-how of the master, were the basic principles of operation and management. This structure was replaced by graduate managers and strong central control, which largely led to the downfall of Western manufacturing industries by stifling innovation and by creating top heavy organizations. Since early 1980's a number of manufacturing industries have moved to a new style known as the 'learning organization', by studying and adopting (not copying) the approach adopted by the successful Japanese manufacturing companies. Table -1 displays a comparison of the two approaches, the major differences being the adoption of a graduated control system and worker participation.

Adoption of a graduated control system require the implementation of a distributive information system where the operational data is collected and analyzed locally on the shop floor to provide immediate information and to determine the necessary action. In such a system information needs to travel both upwards and downwards, necessitating flexibility and extendibility as the worker participation will tend to improve evolving tasks and alter the information requirements.

Within this context definition of productilvity and its measurement require special attention. In the first place it is to be understood that total productivity evolves from the amalgamation of a number of factors (see Figure - 13); some of these factors are outside the direct control of the shipyard, some others are dependent on the organization end operation of the shipyard, and yet the most important factors relate to the ship design and shipyard facilities and production technology. It is incorrect to assume that workers are only elements to measure productivity.

A meaningful approach for the measurement of productivity is the introduction of single factor and total factor productivity indices, [5]. Here, single factor productivity (SFP) refers to the ratio of output of a product and the input of resource, e.g.

$SFP = \frac{\text{Output of A}}{\text{Input of Resource 2}}$

It is important to note that here both A and Resource 2 are in raw variables. In the definition of total factor productivity (TFP) inflation adjusted percentage contribution to cost appears as a weighting factor, i.e.

$TFP = (\text{Inflation Adjusted Percentage Contribution to Cost}) \cdot SFP$
Change in SFP and TFP provides a realistic vehicle for the evaluation of performance and for the diagnosis of problems. Figure 14 illustrates four of many potential trends which can be detected from such an analysis.

A shipyard information system designed to capture and analyze this level of productivity data will not only assist in the achievement of performance improvement

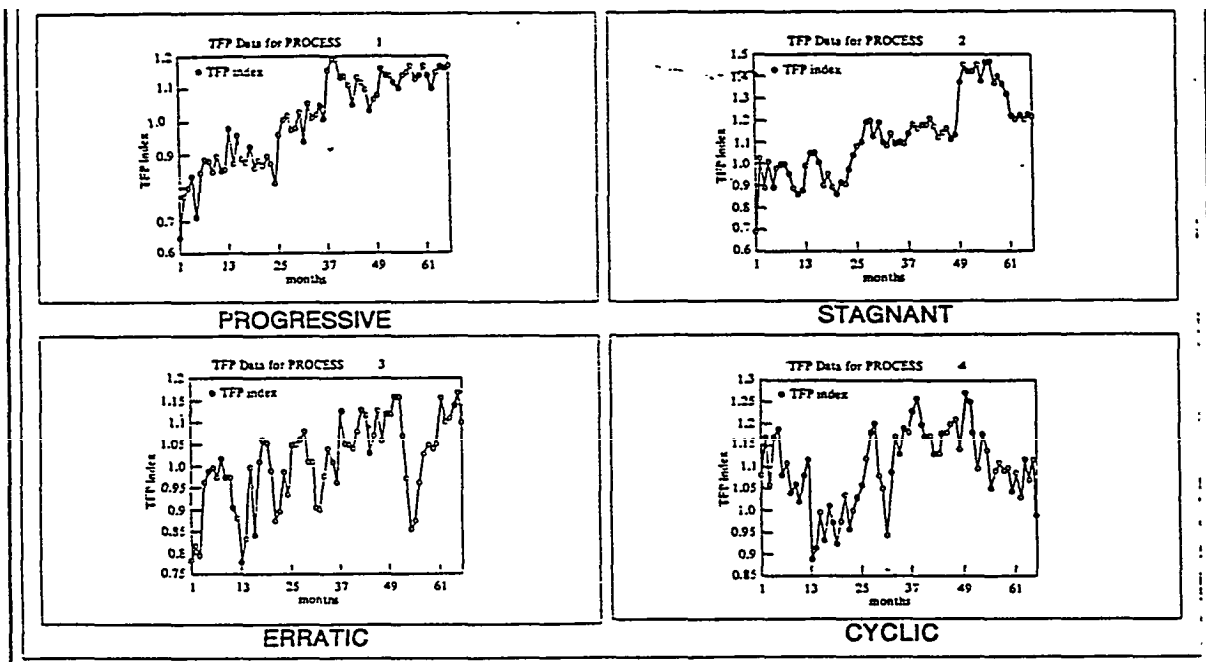


Figure 14 - DIAGNOSTIC ANALYSIS USING TOTAL FACTOR PRODUCTIVITY

but also be able to capture and predict the effect of learning (both capital and non-capital related) on productivity improvement. Such a knowledge base will help the corporate management in the planning and justification of further capital investment. In a large number of investment planning studies this effect is totally ignored as a consequence of the generally acceptable accounting practices (GAAP). Figure -15. displays the total factor productivity improvement in a fabrication plant over a period of ten years, where nearly half of the improvement is due to the capital related learning effect.

Information management starts with the premise that the key information in an organization can be identified and cataloged. Converting the data "into information is the main aim of capturing and retaining data. Increased use of computer applications increases the amount of data in such a way, if it is not managed in a meaningful manner, it can quickly turn into a liability. Therefore it becomes necessary to create information about the data in the organization, known as "metadata". An efficient method of organizing the metadata is the use of data dictionaries.

The data dictionary system can be viewed as a postcode system, knowing where all the data are, their cross-relationships anti hierarchy, and the methods of access and updating. It constitutes the constitution of shipyards' data processing environment. The main functions of a data dictionary are:

- 1 Identification of entities that enter into the system, and the association of these entities.
- 1 Establishment of naming standards and guidelines
- 1 Provision of information on the availability of data for shared use.

Overall planning for applications so that data duplication is avoided wherever possible.

Provision and enforcement of security procedures.

Provision and implementation of procedures to maintain the integrity of databases.

Success of data dictionary system in a shipyard largely depends on its relevance to the activities of the shipyard, consisting of two main tasks. The first task consist of establishing a comprehensive list of agreed

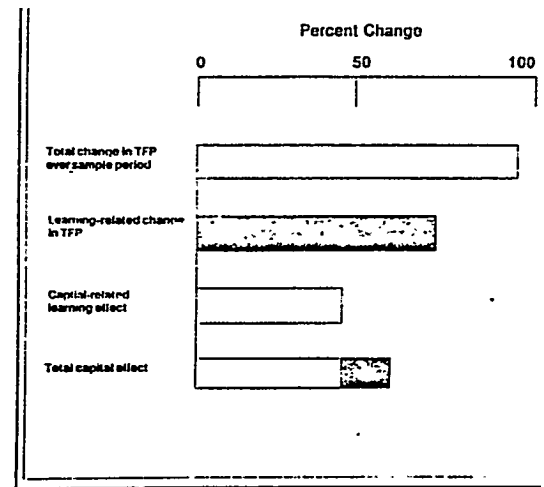


Figure 15 - • TOTAL FACTOR PRODUCTIVITY (T

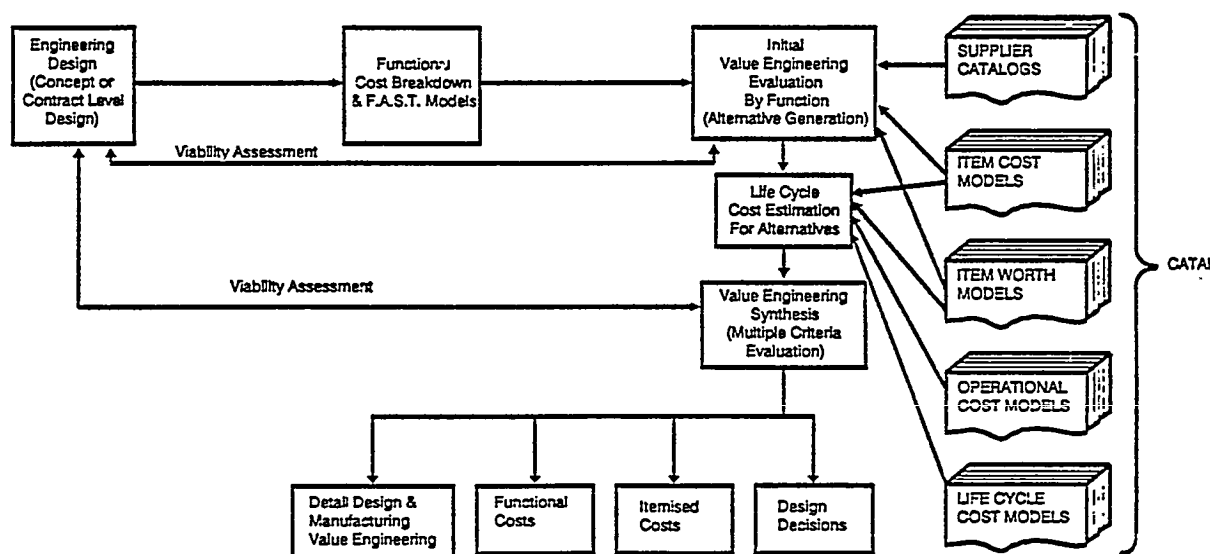


Figure 16 - DECISION INTEGRATION - COST & VALUE ANALYSIS DURING THE DESIGN CYCLE

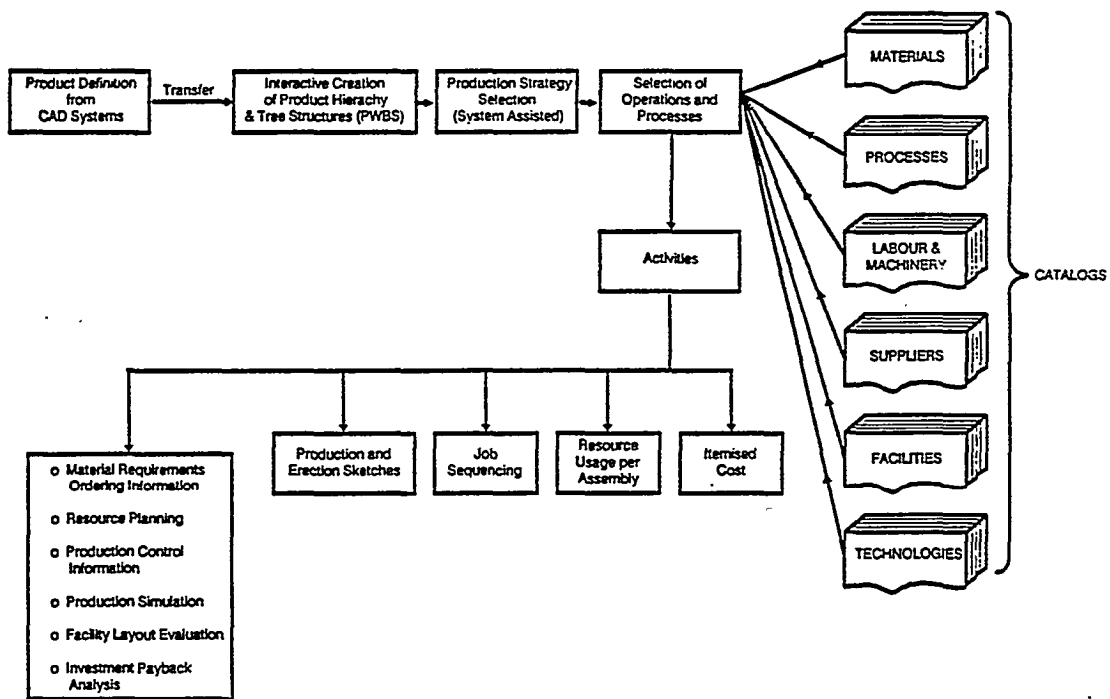


Figure 17- DECISION INTEGRATION - COST & VALUE ANALYSIS FOR MANUFACTURE PLANNING

	<i>Conventional Organization</i>	<i>Learning Organization</i>
Assumptions underlying the operating principles	Optimize defined tasks	Improve evolving tasks
	Productivity; adherence to best practice	Productivity; develop better practices
	Decisions deferred to higher levels	Decisions where needed
	Narrow job definitions	Broad job definitions
Role of the work	Physical effort	Mental & Physical Effort
	Minimize skills (deskilling)	Maximize worker's skills (both technical and problem solving)
	Process should be worker independent	Worker can add value to the process by improving it
Information needs	Coordination (what & when) and control	Process improvement is everybody's job
	Fixed responses to problems through standard operating procedures	Flexible responses to problems as they arise
Management control	Direct control (variance analysis, direct supervision, and inflexible procedures)	Performance evaluation based on success of the business
	Boss knows the answer	Second-order (systems & procedures) and third-order (norms & values) control
	Strict hierarchy and status	Boss supports and helps
		Peers working as a team

TABLE 1. - CONTRASTING VIEWS OF WORKERS' ROLE IN TECHNOLOGY ORGANIZATIONS

definitions of data. The result is analogous to an ordinary dictionary. The second task, coding and classification, is complementary to the first and consists of establishing an overall organization of the data items (classification) and then providing effective means of identifying the place of each item within an overall indentation structure (coding). A close analogy here can be made with that of setting up bibliographic system, such as Dewey Decimal System used in many libraries. U.S. Navy's extended PWBS provide a reasonably comprehensive list of ship items. It however does neither contain the purpose of use, e.g. costing, standards, specification, design, etc., nor does it relate to production related activities and processes. An alternative is the BMT coding and classification system, which satisfy these additional requirements but require further updating.

The major advantages of employing such a coding and classification system are the ability to link up with the design and production processes, work content and building logic, group technology and sorted bill of materials. This system also allows for embedding standards and procedures into the database system and make the design, production, installation, quality and acceptance as standard/procedure driven actions.

7. POTENTIAL APPLICATION IN U.S. SHIPYARDS

Each shipyard has certain characteristics in their use of information systems that are unique to that shipyard. Their future development of systems will be governed to some extent by the nature of the shipbuilding market they are operating in. Each shipbuilder can make an assessment of their systems relative to the requirements and desirable presented in this paper, and identify those aspects that are significantly at variance with the logic and the approach. It is hoped that the issues raised in this paper will be assistful in the adoption of information technology models within the U.S. shipbuilding industry. A typical logic of such an application is illustrated in Figures 16 and 17.

Achievement of a satisfactory and economically beneficial information system demands investment and takes time to be functional. As such, it requires the commitment of the highest level. Taking shortcuts and development of disjointed elements are the biggest dangers on the road to success. Involvement of workforce in the design, development, consolidation, and operation of the information system is a critical factor to make the system workable and acceptable.

It is the belief of the present authors that successful resolution of this issue is one of the key elements in the revival and growth of the U.S. Naval and Commercial Shipbuilding industries.

Acknowledgement

The authors wish to thank the members of the BMT Group Executive for the permission to publish this paper. Thanks are also due to a large number of past and present BMT staff who contributed to the evolution of this study.

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Total Quality Management (TQM)

Gerry A. Damon, Visitor,
Pearl Harbor Naval Shipyard, Pearl Harbor, HI

PURPOSE

The purpose of this paper is four folded: (1) To provide a follow-up report to the article "Implementing Total Quality Management (TQM) at Pearl Harbor Naval Shipyard" published in 1988; (2) to document Pearl Harbor Naval Shipyard's TQM strategies after approximately three years of effort; (3) to be used as a vehicle to continuously define, communicate, and improve Pearl Harbor's TQM Roadmap; (4) most importantly, to solicit feedback from inside and outside the Shipyard; this feedback will not only solidify and reinforce ideas and concepts but will also cause reexamination and possible replacement of other TQM elements. Bob King of GOAL/QPC states, "Most organizations do not know where they are going or how they will get there [1]." The challenge is to continuously define, improve, communicate and effectively execute the TQM roadmap.

INTRODUCTION/OVERVIEW

Pearl Harbor Naval Shipyard began implementing TQM in 1986. The initial effort focused on the Deming management method, Statistical Process Control (SPC), and the training of 50 internal SPC Specialists, 800 managers and supervisors, and 5,400 hourly employees. In the last three years, 340 Improvement Teams have been established; which has resulted in a documented savings of 24 million dollars. Consultant costs and training and project-meeting time costs for that same time frame was 18.2 million for a net savings of 5.8 million. In 1989-1990, training costs are expected to decrease, and the number of improvement teams will increase along with net savings. In 1988, with a change of command, the TQM effort continued to grow and expand with the addition of an essential TQM element, Strategic Planning which is a very powerful and essential methodology.

This paper discusses the application of the Deming philosophy and how the ideas of the Japanese Total Quality Control (TQC) concept have been integrated into the Shipyard's TQM effort. Pearl Harbor provides a quality product at the end of overhaul. Quality is a given. The customer will always get a quality product. The problem is at what expense of cost, schedule, and safety. Our challenge is to continuously improve shipyard processes so that we do the right thing right the first time; cost and schedule follow, are predictable, and in control.

TOTAL QUALITY

"Total Quality" includes quality, cost, schedule and safety. "Quality" is defined as meeting the needs of our customers, both internal and external. Quality must always come first. If we cannot hold the gains on quality, cost and schedule will not follow. As Dr. Deming says, "If quality improves, productivity increases and cost decreases [2]." Therefore, areas of opportunity are identified by finding variance with quality, cost, schedule and safety. "Total" means that every department, office, and shop is involved as well as every organizational level and every employee in improving the quality of shipyard processes.

To satisfy the needs of our external customers, the Fleet, operators, and NAVSEA, we must meet the requirements of quality, cost, and schedule. Pearl Harbor's TQM strategy is to meet those needs through continuous improvement of shipyard processes. Each Department/Office/Shop must identify its critical processes, internal customers, quality requirements and then constantly improve the steps in the process. This means reducing rework, waste, errors, time, inspection, redundancy, scrap, etc.

Total Quality Management (TQM) Shipyard Organization Chart

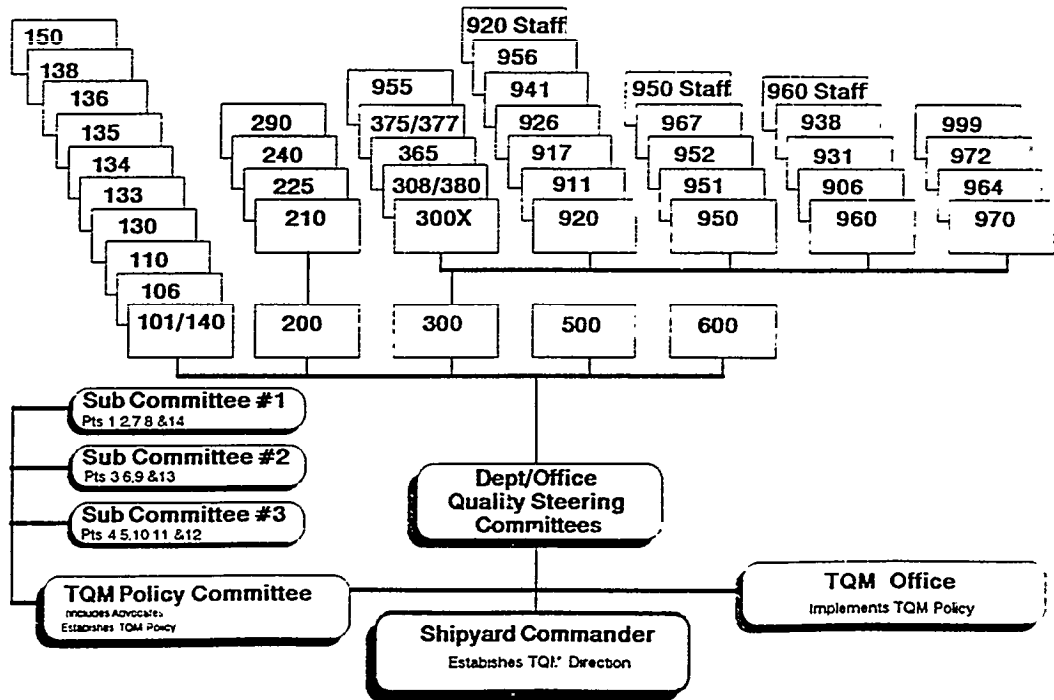


Figure 1. TQM ORGANIZATION STRUCTURE

MAJOR INFLUENCES

Two philosophies have impacted Pearl Harbor's TQM effort, Dr. Deming and the Japanese concept of TQC. Dr. Deming's philosophy has two components, the Task side and the People side. The Task side is reflected through Principles #3 and #5. Principle #3 states, "Reduce mass inspection by building quality into service and product [3]." A quality service/product comes from a quality process. Therefore, quality improvement comes from process improvement. This expands the focus of problem solving to looking at the entire process that creates the service/product from the design phase all the way to usability of the service/product in the customer's hands.

Principle #5 states, "Constantly and forever improve the quality of product and service [3]." This principle introduces the concept of continuous improvement through the use

of statistical methods and the application of the PDCA (Plan-Do-Check-Act) Cycle. PDCA is what Deming gave Japan, the relentless and continuous improvement of product and service. Those that stand still will be surpassed by the competition. The Shipyard's goal is to create an environment where every employee is constantly thinking of ways to improve the way the Shipyard does its business and is actively involved in creating the improvement. TQC promotes Daily, Cross Frictional, and Policy Management. Daily Management focuses on department or vertical quality improvement activities. At Pearl Harbor this is accomplished through the 44 Quality Steering Committees (QSCs) which steer and drive quality improvement efforts in each Department, Office and Shop as shown in Figure 1. Cross-functional activities can occur in three ways. First, Department Heads working in conjunction with their QSC may identify a critical process that needs improvement. Critical processes are selected based on their inability

to meet quality, cost, and schedule requirements and usually cross department boundaries. In this case, a Cross Functional Team is selected to work on these types of processes. Team members are assigned from the Trades and Codes involved in the process. Second, the TQM Policy Committee, under the chairmanship of the Shipyard Commander, may identify critical Shipyard processes that are adversely affecting ship overhaul. These processes have high pay back potential and also include numerous trades and codes. Team members are formed to work on these processes. Third, Cross Functional projects are a part of the many goals and objectives of the Shipyard Operations Plan.

TQM STRATEGIC OBJECTIVES

The following strategic objectives are firmly embedded in the TQM implementation process:

Customer focus.

The concept of customer is at the center of all quality improvement. The customer determines the quality requirements. The external customer's needs of quality, cost, and schedule are met by improving Shipyard processes and meeting the needs of internal customers. In Dr. Ishikawa's words, "The next process is the customer [4]".

Everyone is involved.

For TQM to work, all Departments, all organizational levels and all employees participate. If everyone is involved in improving quality, quality will, in fact, improve. If quality improves, cost decreases and productivity increases.

Leadership and respect for people.

Leaders coach, actively listen, use consensus when appropriate, remove barriers so employees can develop pride of workmanship, promote two way communication, build trust, and provide training, proper tools, equipment, materials, and software.

Making decisions based on facts.

The foundation of quality improvement is based on the use of statistical methods to improve shipyard processes. The Quality Control (QC) Story process provides all improvement efforts throughout the shipyard a step-by-step process to improve quality. A team's ability to follow and learn

this process is fundamental to TQM success.

Long range planning.

In order to move away from "crisis management" as an everyday occurrence, the Shipyard must get its many complicated processes in control. This begins by establishing a 5-7 Year Plan. The next step is to develop a 1 Year Plan that includes all the key goals and objectives that are to be met in the coming year.

Finally, to work every day to achieve those goals.

ORGANIZATIONAL STRUCTURE (See Fig. 1)

The following organizational structure provides a framework that decentralizes the quality improvement effort:

Shipyard commander.

Provides top down leadership and serves as a role model, chairs TQM Policy Committee, kicks-off every TQM training class, reviews process improvement presentations twice weekly, makes TQM presentations to outside customers/activities and reviews progress on the 1 Year Goals and Objectives (Shipyard Operations Plan) on a weekly basis.

TQM Policy Committee.

Steers and drives the shipyard TQM effort, develops policy, members are Advocates for the 14 Quality Management Principles, and meets weekly. Continually applies the QC Story process to improve the four TQM components of Policy, Process, Principle and Daily Management.

TQM Office.

Develops, schedules, and contracts for TQM training, works with Code 180 (Training) to coordinate TQM training, schedules, facilitates Process Improvement Team (PIT) presentations to the Shipyard Commander twice weekly, reports quarterly on PIT activity and progress, administers and publishes Shipyard operations Plan (1 Year Goals and Objectives), administers and tracks progress on specific shipyard goal of "Implementing TQM", and promotes and publicizes TQM activities/successes.

Total Quality Management

Strategic Objectives

- Customer Focus
- Long Range Planning
- Use of Statistical Methods
- Leadership and Respect
- Everyone Involved

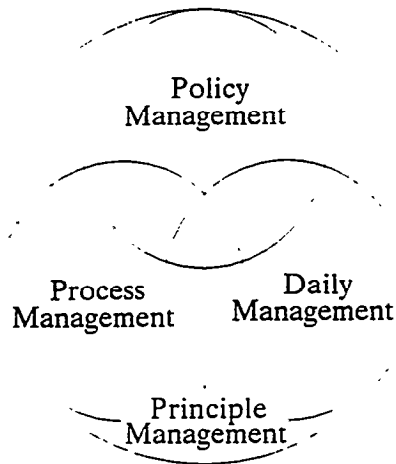


Figure 2. TQM COMPONENTS

Subcommittees (three).

Identify and remove barriers to Deming's 14 Principles. These Principles provide the organizational values necessary for a successful quality driven organization. Each Subcommittee is assigned 4-5 Principles. Subcommittees work directly with the TQM Policy Committee Advocate responsible for each Principle and develop recommendations and POAMS to remove the barriers.

Quality Steering Committees (QSCs).

The line organization is responsible for implementing and institutionalizing TQM. Quality Steering Committees are the most important element in making TQM work in each Department/Office/Shop. There are 44 QSCs in the shipyard at present that steer and make TQM a reality. There are three levels in the Production Department and two levels in the Planning Department. All other Departments/Offices have one level as shown in Figure 1. They make sure their people get TQM training, identify critical processes and establish teams

to improve these processes, establish internal suggestion systems and assist their Department/Office Head in making sure Shipyard Operations Plan actions are tracked and completed.

THE FOUR COMPONENTS OF TQM (Figures 2 and 3).

After three years of defining and implementing TQM, four components have evolved. They are Policy, Process, Daily and Principle Management

All four components overlap, are interwoven, and are interdependent with one another.

Policy Management.

Policy Management is the component of TQM that develops constancy of purpose. It establishes long and short range plans that are not affected by managers that come and go. It creates a structure that aligns departments to move together in the same direction to achieve common Shipyard goals that will

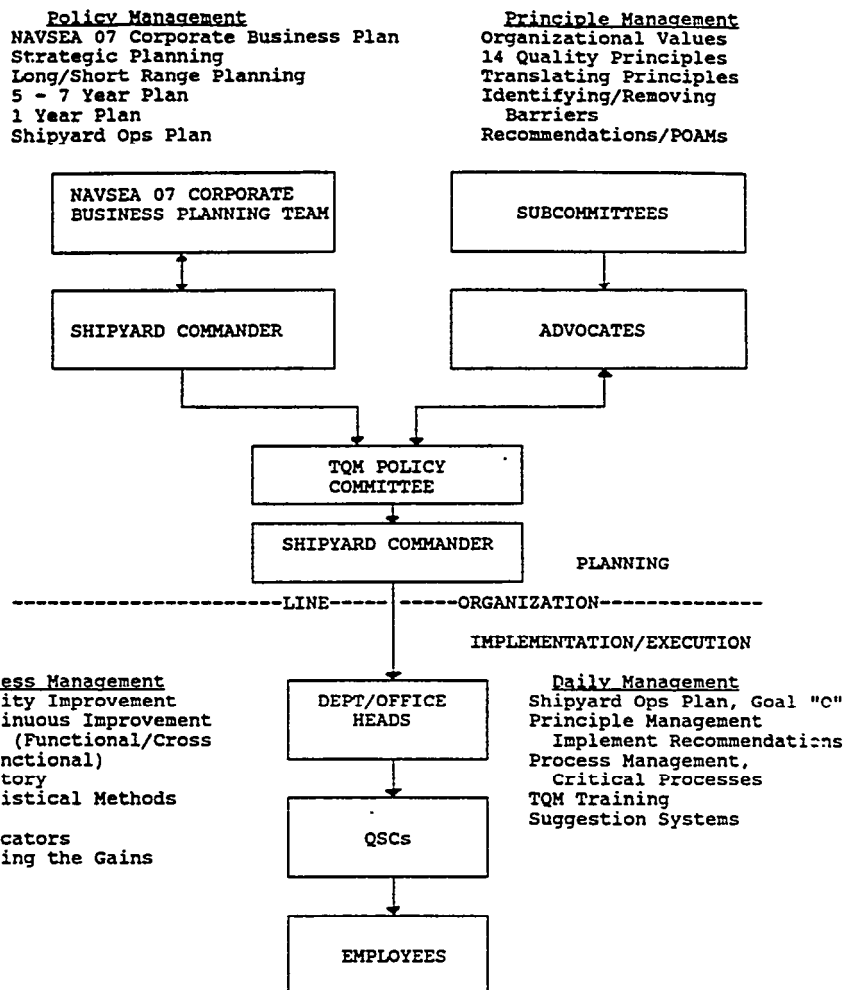


Figure 3. TQM COMPONENT FLOW/INTERACTION

shape the Shipyard of tomorrow. Policy Management incorporates the following methodologies and plans:

NAVSEA 07 Corporate Business Plan
 Long Range Planning
 Strategic Planning
 5-7 Year Plan
 1 Year Plan
 Policy Deployment
 Catchball
 Shipyard Operations Plan

The following groups and individuals are involved and responsible for Policy Management as shown:

NAVSEA 07 Corporate Business Planning Team. Develops NAVSEA Strategic Business Plan via environmental scan, identification of key issues, strategies, goals, objectives and contingencies.

Shipyard Retreat Group [Includes TOM Policy Committee). Twenty-one Department/Office Heads, Union Representatives and an outside consultant meet on 4 separate Saturdays during the summer of 1989 to define the 5-7 year and 1 year plan.

Shipyard Commander. Initiates the Policy Management cycle. Conducts weekly, monthly, and quarterly meetings and reviews, as necessary, with Goal Managers. Initiates "catchball" process during deployment phase. Negotiates changes to Shipyard Operations Plan with Goal Managers during review/implementation phase and records those changes for future review meetings. Is a member of the NAVSEA 07 Business Planning Team.

TOM Office. Issues/provides the final Shipyard Operations Plan for each fiscal year. Schedules review meetings, as required with Shipyard Commander approval and distributes schedule.

Goal Managers. Manage their assigned goal. Promote "catchball" process during deployment phase. Negotiate changes with Shipyard Commander and assigned action groups during implementation phase. Track and maintain changes/updates to their goal. Provide copies of changes/updates to shipyard Commander, TQM Office, and action groups involved. Apply QC Story process, i.e., 5 step approach and the use of statistical methods and indicators to achieve goals.

Department/Office/Shop Heads. Work with Goal Manager to achieve goals. Promote "catchball" process during deployment phase. Provides monthly progress reports on all cognizant goal assignments to Goal Manager. Provides quarterly progress reports to Goal Managers and TQM office. Ensure application of QC Story methodology in all aspects of quality improvement, i.e., Shipyard Operations Plan, PITs, QSCS, Daily Management, etc.

Shipyard Operations Plan Action Codes/Shops. Manage and complete actions assigned. Enter into "catchball" process to develop ownership for the actions proposed to achieve the established goals/objectives. Use QC story approach, i.e., 5 steps, statistical methods, and indicators to improve processes and hold the gains.

The Phases of Policy Management include:

5-7 Year Plan. The process to define this plan includes the identification of:

- Key Issue Areas
- Vision Statement (Direction)
- Key Accomplishments (What)
- Strategy (How)
- Goals (1-3 years)

Establish Policy Phase (Starts April 1). This phase begins by reviewing and updating the 5-7 year plan and follows by reviewing the progress of last year's Shipyard Operations Plan. The next step is to define the 1 year goals and objectives that support each strategy. Objectives are more specific than the goals. Goal Managers are assigned followed by the identification of action Department/Offices/Shops/Codes. When and where possible indicators are established. This phase results in the development of the first draft of what will become the Shipyard Operations Plan.

Deploy Policy Phase (Starts July 1). This phase begins by deploying the goals and objectives down through the various organizational levels. Each level defines the tasks, subtasks, and actions that support the achievement of the goals and objectives. This initiates the "catchball" process which involves operationally defining all the actions required to achieve the goals and objectives. Action Codes/Shops develop ownership in this process by developing actions they believe will best achieve the goals/objectives. It is important in this process that ownership is developed up and down the organization chain and includes negotiation between the various levels involved. Indicators should be finalized at this stage. This phase is completed with the final issue of the Shipyard Operation Plan.

Implement Policy Phase (Starts October 1). Action Departments/Offices/Shops/Codes have already started preparing to complete their assigned actions as they got involved in the deployment phase. The next step is the review process. Depending on the need, reviews can be held on a weekly, monthly or quarterly basis. The frequency of review is a function of the urgency of the goal and the degree of actions/indicators required to achieve the goal/objective not being clearly defined. The review process is an important managerial discipline that ensures that impediments are removed and that the goals/objectives are achieved.

Process Management.

Process Management involves improving the quality of our Shipyard products and services by improving the processes that create those products and services. Improving quality requires we understand the needs of our customers, both internal and external. It is our customers that determine the quality requirements we want to meet. Two very important methodologies to do this are the QC Story and the Plan-Do-Check-Act cycle. Process Management includes the following methodologies and concepts:

Quality Improvement
Continuous Process Improvement
Critical Processes
Statistical Methods
QC Story
Plan-Do-Check-Act
Focus on Customers
Measurements and Indicators
Holding the Gains

Process Improvement Teams (PITs).

Process Improvement Teams provide a structured environment for employees to work together toward: (1) improving the quality of products and services; (2) developing the skills and abilities of employees; and (3) promoting communication and teamwork. Process Improvement Teams are the basic building blocks of TQM. They consist of three major kinds of teams:

1. Functional Teams. Includes employees from a single functional area or work unit.

2. Cross - Functional Teams. Includes people from more than one functional area to work on improvement opportunities that cut across functional lines.

3. Task Teams. Include members from one or more functional areas, formed to solve a specific problem or group of problems, and then disband. It is a team to which members are selected because of background and experience and are usually tasked by the Shipyard Commander or at the Department Head level.

Critical Processes. Critical processes are defined as those that are critical to the Department/Office/Shop mission and have major variances from total quality. These are the processes that every level of every Department/Office/Shop have identified and are working to improve and have a high potential payoff.

QC Story. The QC Story is a standardized structure/process to be used by all those involved in TQM to improve processes. It is a standard way of communicating team progress and a form to help illustrate the steps to be taken by a team in the improvement process. It is used by teams to organize, collect and analyze information, and to monitor how they are doing.

Principle Management.

The 14 Quality Management Principles are the organizational values required to make the quality improvement effort at the Shipyard successful. The principles are divided into two categories; the Task Side and the People Side. The Task Side is focused on quality/process improvement and the use of the QC Story, the PDCA Cycle and statistical methods. The People Side is focused on TQM leadership, respect for people, coaching, communication, teamwork, trust, and cooperation. The consultant

has stated that only 20% of the total potential quality improvement possible is attainable from just the Task Side. Therefore, the Shipyard must develop its leadership. The Shipyard has made good progress on the Task Side. The area of opportunity is on the People Side.

As shown in Figure 1, there is an organizational structure established to remove the barriers to the 14 principles. This structure includes:

TOM Policy Committee. The TQM Policy Committee has overall responsibility for managing the institutionalization of the principles. They must ensure that the subcommittees get the support they need and that progress is being made. Further, they must ensure the integration of the efforts to remove barriers by the line organization and the subcommittees.

Advocates. The Advocates are members of the TQM Policy Committee and are assigned specific principles. They are responsible to champion these principles and their translation into the Shipyard. They work closely with the subcommittees and provide the communication link between the subcommittees and the TQM Policy Committee.

Subcommittees. The three subcommittees are staff functions. Each is assigned 4-5 principles and is responsible for the identification of barriers to these principles. They prioritize principles, barriers, and causes and provide recommendations for the removal of barriers through the appropriate Advocate to the TQM Policy Committee. The recommendations become the Shipyard strategies for institutionalizing the barriers.

Line Organization. The Line Organization is responsible for implementing the recommendations passed down from the TQM Policy Committee. Actions taken on these recommendations must be tracked and monitored to ensure improvement is taking place.

This process has been in effect for 2 years and has moved somewhat slowly. The process is under review at the present time to strengthen the communication between the committees and individuals involved.

Daily Management.

Daily Management involves the line or functional organization in the implementation of TQM. This is where the rubber meets the road. You can have all the strategies, methodologies, plans, concepts, and good ideas in the world but they must be put into action by the line organization. Just as the Shipyard Commander and the TQM Policy Committee steer and drive the quality improvement effort at the Shipyard level so does each Department/Office/Shop Head and their QSC steer and drive quality in their area. This is the last frontier of the TQM implementation process. This is where getting everyone involved takes place. The Quality Steering Committees play a major role in this process and may be established at several levels within the department. Daily Management involves the following activities and responsibilities:

Training. Employees must receive TQM training which includes PH 101, PH 201, PH 401, Leadership, First Line Supervisory and Refresher Training.

Process Management. Critical processes must be identified, improved and monitored. Application of the QC Story and the PDCA Cycle is required. Indicators are to be identified and the gains held. Establishing Functional Teams at the workforce level is the next area of opportunity for the Shipyard.

Policy Management. Shipyard operations Plan actions must be identified and tracked. Indicators must be established and actions completed.

Principle Management. Department/Office/Shop Heads are responsible for removing the barriers to the 14 Quality Management Principles in their areas. They work closely with their QSC and the TQM Policy Committee and the Subcommittees to ensure all recommendations get implemented. They are encouraged to initiate additional actions to remove barriers that will further the TQM effort.

SPC Specialists. A sufficient number of SPC Specialists must be trained to support the process improvement effort. SPC Specialists assist their department and the Improvement Teams in the proper application of statistical methods. To date, 72 SPC Specialists have been trained over the last 3 years.

Suggest System. Internal suggestion systems are to be put in place in each area. Vital to the success of this effort is to provide timely feedback to the originators of suggestions and to implement suggestions at the lowest level and in a timely manner.

LABOR AND MANAGEMENT AS EQUAL PARTNERS

It wasn't until mid 1987 that top management initiated action to include the Union (Metal Trades Council) as equal partners in the TQM effort. This effort was strongly encouraged by the consulting firm, Process Management Institute (PMI), who had been contracted to assist the Shipyard implement TQM. The Union was invited to attend TQM training which included a two day course, "The New Management Philosophy," and a six day course, "Statistical Methods for Process Improvement." The Union has been encouraged to apply this training in managing their own activities. The Union also sent two representatives to the 1988 GOAL/QPC Conference in Plymouth, Mass. The Union participates on all TQM Committees; this includes the forty-four QSCS, the TQM Policy Committee, the three Subcommittees, and the Ops Plan review process. Weekly Ad Hoc meetings are held between 3 Union and 3 Management representatives to discuss and resolve Union TQM concerns/issues. The Shipyard Commander has issued a letter to all Department Heads stating emphatically that Management and the Union are equal partners in TQM and that all effort must be taken to work with the Union at Department levels. Moreover, the door is open for discussing concerns, and on going dialogue exists between Management and the Union.

CRITICAL MASS

When the TQM consultant, Process Management Institute, arrived in June of 1987 there was considerable dialogue about when the shipyard would achieve critical mass. Critical mass is defined as having institutionalized TQM to the degree that no new Shipyard Commander could come in and eliminate it. Managers and supervisors would be practicing TQM on a daily basis and would understand and have seen the benefits. As this occurs in most organizations the realization becomes that they have only scratched the surface and an even deeper quest for quality improvement results. New incoming Shipyard Commanders would see the results of continuous improvement working and would not want to change this successful trend. Critical mass

was estimated to take 3 to 5 years. The shipyard has still not achieved critical mass. However, critical mass is no longer the issue it once was. There has been acceptance of TQM at the DOD and DON level. The shipyard has spent millions of dollars on TQM training and by the time this paper is published the shipyard will have maintained a continuous TQM trust forward under the leadership of three different Shipyard Commanders. Maintaining momentum and consistency of TQM from one Shipyard Commander to another has become routine. One strong reason for this is that the last two Shipyard Commanders have come from within the shipyard and both have been members of the TQM Policy Committee for at least one to two years previously. They understood the value of TQM and maintained strong leadership in the same direction. The bad news is that Shipyard Commanders have been changing about every year and a half. However, at this point there is so much TQM activity both inside and outside the shipyard that it seems unlikely that the TQM effort will be stopped. The question is at what rate and how effectively will we continue the implementation process?

CONCLUSION

The die is being cast. After three years, the TQM Policy Committee understands the major elements and methodologies necessary to make TQM work in the Shipyard. The implementation process at this juncture is one of execution and continuing to improve and refine that process. There has been good progress in the area of training and the use of statistical methods to improve shipyard and departmental processes. Through the Process Improvement Teams and the Quality Steering Committees most managers have seen and believe in the concept of continuous improvement. Strategic Planning and the Shipyard Operations Plan has become a powerful tool. It has helped the shipyard develop a constancy of purpose, make inroads on long range planning and focus on the right problems. The hardest area is that of leadership. There have been significant positive changes in top managers closest to the implementation process. However, for the most part, middle managers fail to see leadership change or begin to exhibit the managerial behaviors desired.

THE FUTURE

Areas of opportunity for the Shipyard in the coming year include:

- Getting TQM to the waterfront.

Improvement Teams properly applying the QC Story process.

- Making decisions based on facts.

- Functional Teams increasing in number and proficiency.

Instituting leadership and respect for people.

Continuing TQM leadership training and developing indicators to verify improvement is taking place.

- Completing the second cycle of the Strategic Planning process.

- TQM training for First Line Supervisors defined and ongoing. Less mass training and more Just-in-Time training, i.e., putting the "use it or lose it" concept into practice.

- Measurements and indicators defined and used as a regular part of the PDCA Cycle and process improvement efforts.

- Departmental process improvement efforts start to show progress on improving the quality, cost and schedule of ship DMPs and overhauls.

- The Naval Shipyards working together with NAVSEA, networking, exchanging information, and collectively making TQM a reality.

Continuing to look beyond everyday frustration, the resistance to change, blaming those above us for not practicing what they preach, and realizing every incremental step is a step closer to our common goal.

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C o m b i n i n g W e l d i n g E x p e r t S y s t e m s w i t h
W e l d i n g D a t a b a s e s t o I m p r o v e S h i p b u i l d i n g
P r o d u c t i o n

Hans H. Vandetverldt, Visitor, Sterling Johnston, Visitor and Jerald E. Jones, Visitor, American Welding Institute, Knoxville, TN, Dawn White, Visitor, and B. Cleveland, Visitor, MTS Systems, Inc. Eden Prairie, MN

ABSTRACT

Construction of a large ship requires many thousands of feet of welding. Whenever the welding process can be streamlined or automated, tremendous cost savings can be obtained. The WELDEXCELL system is a WELDing EXpert manufacturing CELL that provides computerized technical support information, off-line weld planning, and an integrated welding robot/welding system/vision system controller. The first of two subsystems, the Welding Job Planner (WJP) accomplishes off-line intelligent weld planning for both automated and manual welding processes. The second subsystem, the Welding Job Controller (WJC) provides a fully integrated hardware control environment with associated software for combined control of a welding robot, welding equipment and a robotic vision system. In the WELDEXCELL system, a series of expert systems and databases have been combined in a new type of computer software environment called a blackboard. There are as many as 19 separate components of the Welding Job Planner subsystem of WELDEXCELL which fall into five interrelated functional groups. WELDEXCELL will be used by design engineers, welding engineers, mechanical engineers, and NDT engineers for both manual welding and to interface to automated and robotic welding systems and vision systems. WELDEXCELL also includes the control system hardware and software to provide off-line intelligent adaptive control of the welding process itself.

The development of WELDEXCELL is a multi-year effort involving a partnership of government, industry, university research, and technology transfer. The project has already generated new concepts with potential for future spin-off benefits. The ultimate payback in productivity will be large for the American welding, fabrication, manufacturing, and construction industries.

OVERVIEW

The American Welding Institute (AWI), together with the other WELDEXCELL team members, the Colorado School of Mines (CSM), and MTS Systems, Incorporated (MTS), is developing an intelligent weld process planner for flexible welded fabrication known as the WELDing EXpert manufacturing CELL (WELDEXCELL). This project entails the development of a computerized blackboard with a series of linked expert systems acting as a welding engineers' assistant, and software to download welding procedures from the weld designer to a welding workcell for automatic execution of the planned welds. The system will also employ sensors to record actual weld process parameters and a postweld analysis capability to examine these parameters and update the welding procedure between passes. These sensors include a seam tracker which will provide path corrections to the welding robot during a weld.

Many parts of the system software have already been developed, and some of the software is commercially available as in-

dividual expert systems and databases. But, the heart of WELDEXCELL is a new computer architecture called a "blackboard". This blackboard system allows the interconnection of multiple expert systems and databases with a central goal. WELDEXCELL will be one of the first commercial computerized application blackboards ever developed.

BACKGROUND

The joining of metals into fabricated components and structures is a difficult task. The most common method of joining metals is welding, but the welding process is complex and requires several important steps to be performed in a carefully integrated manner. Although the process may seem simple to an experienced welding engineer, when analyzed in sufficient detail, the engineering/planning processes are extremely complex. Such an analysis was performed in developing the task description for the WELDEXCELL Welding Job Planner (WJP). The weld joint is first designed and engineered properly, then that design must be correctly communicated to the fabrication facility. The appropriate welding consumables, including filler metal and protective flux or inert gas, are chosen. Then the welding procedure is specified, including preheating schedules; welding variables such as voltage, current and travel speed and postweld heat treating. Finally, the weld must be performed under highly skilled human guidance and control. A minor error in any of these steps, if undetected, can create an unsuitable welded component, which in later use may result in a catastrophic failure and perhaps loss of life.

An extremely complex and interrelated system of codes, specifications, tests, and inspections ensures that the vast majority of welds will never fail in service. Fortunately, a large number of engineers, designers, and welders work within the system of codes and specifications to ensure the high quality of welded joints, but this system is very expensive and requires the careful attention of many human experts. Consequently, welding is an ideal application

for computerized expert system technology. However, no single expert system could be expected to perform the myriad of tasks required to make a welded joint. For example, there are over 100 welding processes ranging from simple flame heating to exotic laser welding; there are several hundred welding filler metals – from plain carbon steel to elaborate chemical mixtures of alloying ingredients; and there are over 1000 different grades of weldable steels classified by the American Society for Testing and Materials (ASTM). The possible combinations of welding process, filler metal, and steel base metal would number into the millions.

The expert systems needed for welding include materials selection, joint design, welding process and procedure selection, and a CAD system interface to draw the design and communicate that design to the welder. The ultimate goal also includes an intelligent system to instruct a complex welding workcell to perform the weld; and a workcell simulator to allow off-line automated weld planning.

WELDEXCELL SYSTEM BLACKBOARD

It is clear that the type of distributed problem-solving in multiple knowledge domains involved in this multidisciplinary engineering problem cannot be addressed using a single knowledge source (KS). Rather, multiple knowledge sources and humans will cooperate to solve a broad problem. The technique to be applied to this data and knowledge-integration problem is the computer blackboard architecture.

The concept of blackboard architectures was discussed in the literature as early as 1962; however, no applications were built until the 1970s. A blackboard is being used for this expert integration environment because it possesses capabilities to support problem solving while accounting for diverse types of information, methods for combining various types of data while resolving conflicts, and the ability to

accommodate different program modules without requiring a complex interface.

The problem solving technique which has been applied to the blackboard model is to divide the problem into loosely coupled sub-tasks which are then operated on by specialized programs with access to various information sources. The information sources consist of knowledge bases, expert systems, databases, and interfaces to human experts. The advantage of such a system is that much larger quantities of information can be used in a fully integrated manner to solve the problem and develop the weld plan. The human experts supply the external information about the required welding task and then review the intermediate and final plans. The system also includes facilities to query a human expert in the event that conflicts outside of the system's domain of expertise occur. The time required by a human expert will be substantially reduced, thus allowing more design and planning to be accomplished with higher overall quality and reliability by the same number of human experts. Also, the system will reduce the time required to test qualify, and practice automated welds. This will substantially reduce the problem of small batch size automated welding.

The blackboard software architecture is analogous to a group of experts seated before a blackboard, with only one expert allowed to approach the blackboard at a time. A monitor is empowered to call on the experts individually to modify the blackboard's contents. Following each contribution, the monitor evaluates the state of the blackboard's contents and, based on its planning algorithms, considers which expert to call on next. If the "experts" described in this scenario are replaced by knowledge sources (KS's), which include expert systems, databases, knowledge bases, human users, graphical data and information, etc., a blackboard system results. The monitoring and control functions are performed by what is essentially another expert system with planning algorithms designed to move the expert system toward a problem solution.

The blackboard's purpose is to provide a framework for the interaction of the multiple independent knowledge sources and to respond opportunistically to the changing contents of the blackboard to achieve a solution. There are eight behavioral goals for the intelligent blackboard control system to accomplish this task. They are as follows:

1. Make explicit control decisions that solve the control problem of multiple independent knowledge sources.
2. Decide what actions to perform by determining what actions are desirable and what actions are feasible.
3. Adopt variable task size control heuristics.
4. Adopt control heuristics that focus on action attributes which are useful in the current problem solving situation.
5. Adopt retain, and discard individual control heuristics in response to dynamic problem solving situations.
6. Decide how to integrate multiple control heuristics of varying importance.
7. Dynamically plan strategic sequences of actions.
8. Reason about the relative priorities of domain and control actions.

The blackboard controller controls the blackboard, monitoring the activities of the knowledge sources attempting to find a solution to the weld design problem. At various levels ranging from abstract to very detailed, decisions are made such as which problem to solve next, whether forward or backward chaining reasoning is to be used and which knowledge source to activate. While building a master expert system to control the problem solving blackboard is a complex solution, it provides the

flexibility to solve both broad planning problems and perform detailed scheduling.

The blackboard control system contains more explicit support for meta-level facilities. The blackboard is divided into multiple partitions which contain classes. The classes contain objects. The objects, which contain the data used by the KS's to solve a problem are placed in the blackboard by KS's or by external processes such as human interactions or interaction with the databases.

Another concept for organizing problem solving with multiple, diverse cooperating sources of knowledge is being applied to the blackboard. A hypothesize-and-test paradigm is a mechanism which can provide a high degree of cooperation among the knowledge sources. Thus, the solution finding is an iterative process, which involves two steps:

1. Create a hypothesis (an educated guess about some aspect of the problem)

2. Test the plausibility of the hypothesis

As the blackboard proceeds toward a solution, the system will build on the knowledge about the problem contained in its knowledge sources and the changes in the state of the system knowledge (i.e., in the contents of the blackboard) produced by previous hypothesis. This iterative process ends when the contents of the blackboard form a consistent hypothesis which satisfies the requirements of an overall weld design solution.

WELDEXCELL SYSTEM DESCRIPTION

WELDEXCELL is logically divided into two major subsystems: the Welding Job Planner (WJP) and the Welding Job Controller (WJC). A high level block diagram is shown in Figure 1.

Welding Job Planner

The WJP will use various expert system: knowledge/databases, and user input to solve welding engineering design problems. The user will interact with the computerized knowledge resources and the computerized "blackboard" to design the joint and then locate or assist in developing an appropriate welding path and procedure.

The WJP configures this information in the form of a Job Description (weld schedule) which is in turn passed to the WJC for the actual execution of the weld. The user interface for the WJP is primarily the blackboard output file which is represented as a Welding Procedure Specification (WPS) and displayed on the screen. As information is determined by the expert systems and other systems, the onscreen WPS will be updated. The display shows initial information (such as material type and joint geometry) and the evolution of the WPS as it is developed, including the joint design, robot path planning, and simulation information.

Welding Job Controller

The WJC is responsible for ensuring that the various equipment used for the weld, including the welding power supply, the manipulator, the vision system, and other support equipment are coordinated as appropriate to execute the weld schedule from the WJP. During the course of a weld, the WJC will record several weld process parameters (such as voltage, current, wire feed rate, gas flow, travel speed, and temperature as appropriate to the type of welding taking place) as well as any offsets between the planned path and the actual seam location. This data is saved for later inter-pass analysis by the WJP, but the seam offsets will also be used in real time by the controller for adjustments to the robot's planned trajectory (i.e., seam tracking). At the end of a weld pass, a weld results file containing the recorded weld process parameters and seam offsets is prepared by the WJC and passed back to the WJP for

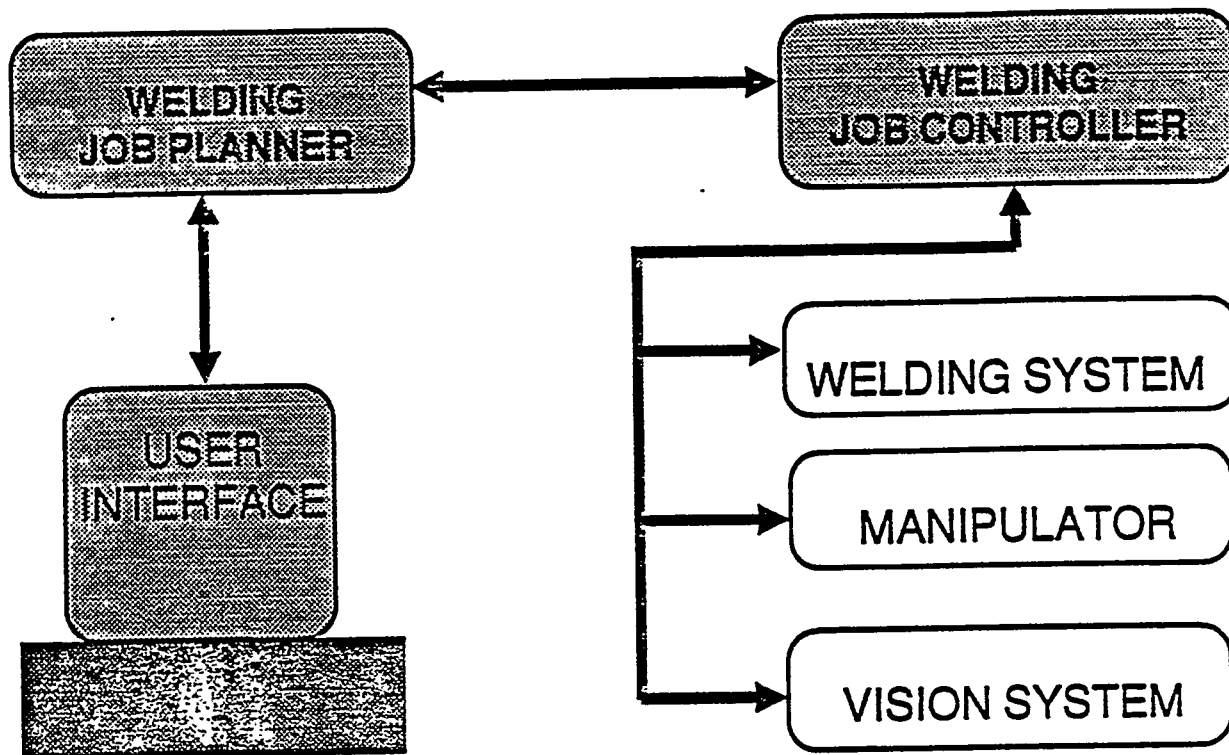


Figure 1. High level block diagram of the WELDEXCELL System

analysis and possible modification to the job description for the next pass.

WELDING JOB PLANNER

The traditional method of creating a new weld procedure specification is similar to the following scenario. First, given a specific metal to be welded, the welding filler metal or electrode is chosen, then the joint design and welding procedure are selected. Finally, the information must be communicated to the fabrication facility in the form of a joint design drawing with a welding symbol. Each of these tasks is not completely independent and, in the existing manual mode of operation, they are often done in an iterative manner. Thus, the

WJP must be able to do distributed problem solving in multiple simultaneous knowledge domains.

The WELDEXCELL blackboard is functionally organized into a frame-based structure of sub-blackboards. Each of the sub-blackboards has a specific functional use in the overall system. These sub-blackboards are described by a series of attribute (i.e. specific goal parameters) values which are determined, through operation of the system, to the greatest extent possible whenever that sub-blackboard is instantiated during a consultation. Each sub-blackboard also inherits the attribute values of the parent (main) blackboard. The blackboard structure has the ability to go through a scenario repeatedly with minor changes so that engineer-

ing iterative solutions ("what-iffhg") techniques can be applied.

The major components (sub-blackboards and other routines) of the WJP are the Joint Designer, the Structural Integrity Analyzer, the Material Analyzer, the Procedure Specifier, the Path Planner and the Main Blackboard. Each of the sub-blackboards are made up of several cooperating expert systems and databases. Each of these major components is described below in greater detail.

Most of the expert systems and databases have been previously developed or prototyped by AWI and the Colorado School of Mines (CSM) as individual modules. In development of these expert systems, it was important to use recognized standards, codes, and existing tested procedures in the operation of the expert system. Two principal organizations in the United States are primarily responsible for the technical standards and procedures of welding (besides the United States government): the American Welding Society (AWS), and the Welding Research Council (WRC). Selected committees of each organization were approached to enlist their cooperation and input with respect to the development of the expert systems. These committees have supplied expert knowledge, evaluation, and beta test sites for the prototype expert systems. Future beta testing will also be performed by U. S. Navy shipyards.

Wherever possible, expert systems which already existed, or which had been prototype by AWI/CSM are being used in WELDEX-CELL. AWI and CSM, as part of the Welding Information Network (W.I.N.[™]) system, have previously developed, and in some cases AWI is commercially marketing, a full range of expert systems for use in welding engineering decision support. In addition to the expert systems, several technical databases are used by the Welding Job Planner. Each database is structured as summarized in Table I. Figure 2 illustrates the overall breakdown of the WJP.

Weld Joint Designer

The JointDesigner Sub-blackboard (JDS) functions to prepare a welding joint design and communicate the joint design information in a graphical format to the engineer, as well as to the shop floor. Standard joint design formats (consistent with the AWS standard graphical description) are being employed for the basic joint design. Also, the welding symbol prepared by JDS conforms to AWS/ANS standard A2.4-86.

WELDSYMPLE. A large amount of information is needed to describe a weld procedure on a mechanical drawing. The welding technique and testing must be specified as well as the joint design and machining requirements. A shorthand way of describing a weld, known as a welding symbol, is used on a mechanical drawing to describe the specified weld. The technique for developing a weld symbol is like that of constructing a word in the English language. A set of symbol elements (the alphabet for the word construction analogy) is available. By choosing appropriate symbol elements and assembling them in an appropriate manner, a symbol (a word in the English analogy) can be constructed. There is a nearly unlimited number of symbol element combinations which could be used to generate welding symbols, so generating a CAD library of symbols is, for general application, not practical. The appropriate weld symbol must be generated each time it is to be used.

The expert system WELDSYMPLE is designed to use a symbol base (database of graphic welding symbol information) and input from a human user or the blackboard regarding the weld joint design application to draw the appropriate welding symbol using a CAD system. WELDSYMPLE uses the same logic processes which would be applied by a welding engineer to develop a welding symbol. The symbol is generated according to the rules established by AWS in documentation reflecting the standardized use of welding symbols (AWS A2.4-86 "Standard Symbols for Welding, Braz-

Welding Procedure Database (WPS)

The welding procedure database consists of process, material, and parameter information for the weld. This database is structured in accordance with the proposed AWS/ANSI Standard A6.1-90 for welding procedure specifications.

Procedure Qualification Record Database (PQRDB)

This database consists of information similar to WPSDB, but includes test results. Full PQRs are stored in this database conforming to the proposed AWS/ANSI Standard A6.1-90.

Electrode Database (ELDB)

Contains data about welding electrodes and filler metals. The information includes not only the designated AWS A.5 standards but also manufacturer published data. The records include typical/recommended usage, composition, operating parameter ranges, etc.

Steels Database (MATDB)

Contains ASTM, AISI, ACI, and UNS weldable steel information, including composition and mechanical properties. Recommended electrode/filler metal usage data is also incorporated.

Heat Treatment Database (HEATDB)

Contains pre- and postweld heating schedule information. Includes data for carbon equivalent (CE), Pcm, and PHa analysis, as well as WRC-published recommend temperatures/times.

Joints Database (JOINTDB)

Contains welding joint design detail information, including data for root opening, included angle(s), tolerances, etc. Curmtly, the data is not CAD compatible but if necessary for system operation, the data will be converted.

Welding Symbols Database (SYMDB)

Contains AWS/ANSI D2.4-86 standard welding symbol information for developing standard welding symbols on mechanical drawings. This data is already CAD compatible and will be maintained in Navy CALS compatible format.

Table I. Welding Databases

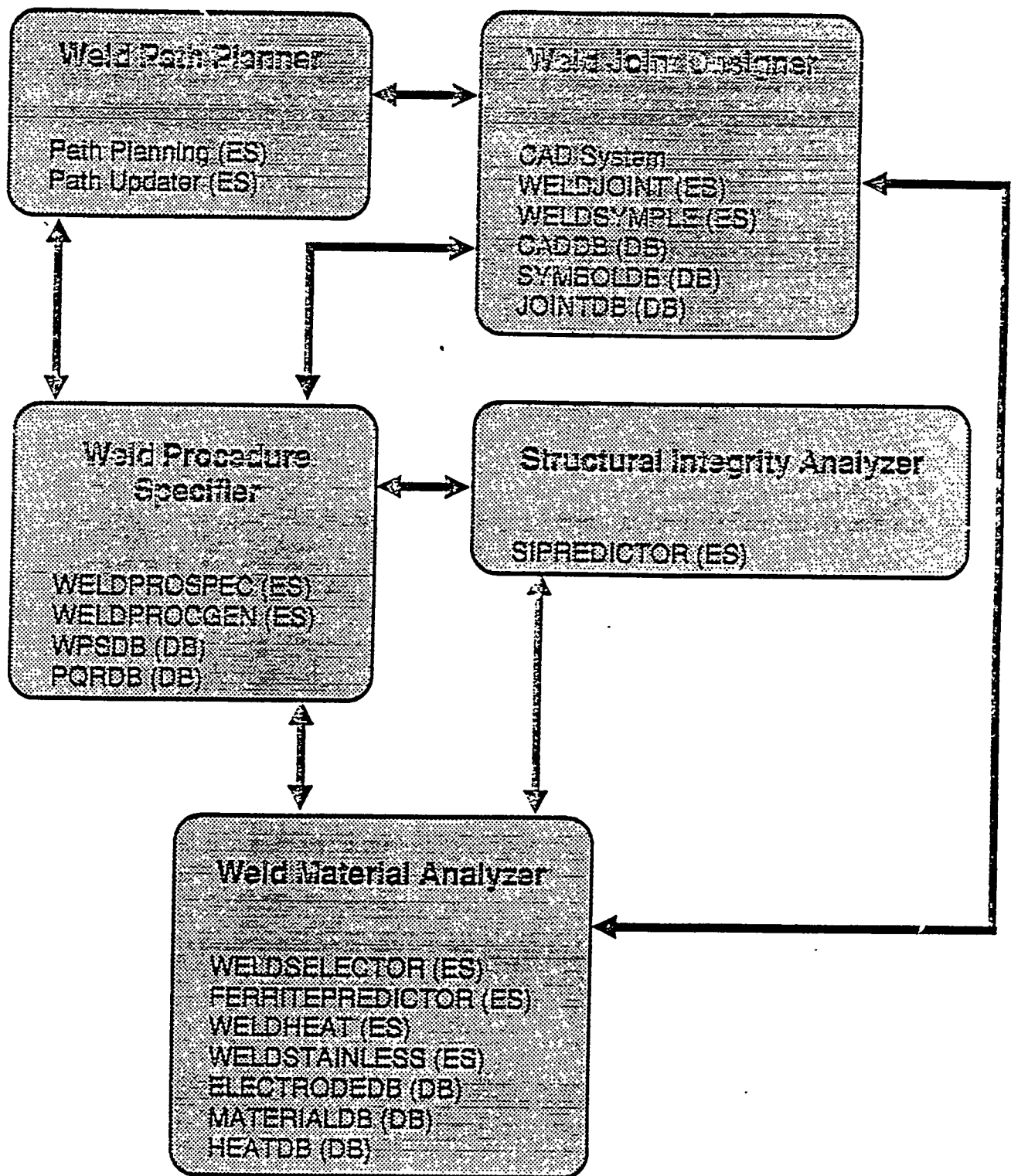


Figure 2. Overall Breakdown of the Welding Job Planner Sub-system

ing, and Nondestructive Examination"). This expert system is currently available as a stand alone system and was tested by AWS prior to its commercial release.

WELDJOINT. The design of a welded joint is, as with many engineering decisions, a delicate balance of compromises. The joint design attempts to combine several criteria simultaneously, some of which may conflict. The joint must be machined to allow sufficient clearance for the welding operation, but with a minimum of open space to fill with the expensive filler metal and time consuming welding operations. The design must accommodate the configuration of the structural shapes to be joined, but also minimize the stresses which occur on the joint in service and the residual stresses that develop as the weld shrinks due to non-uniform temperature distribution during solidification and cooling.

The WELDJOINT expert system interacts with a graphics-based data system to produce a drawing of the weldjoint. In addition, the expert system provides much of the output information so that the welding symbol can be produced for the mechanical drawing. The data and graphical layout of the figure are in accordance with AWS/ANSI standard joint design, as described in AWS D1.1, "Structural Welding Code."

Structural Integrity Analyzer

The Structural Integrity Analyzer Sub-blackboard (SIS) will function to provide the design engineer with basic structural integrity information and help to set the NDE criteria. The system utilizes the basic Linear Elastic Fracture Mechanics (LEFM) criteria for defect size limit setting. However, the SIS will have provisions to include more complex analyses in future implementations.

SI-PREDICTOR A structural integrity analysis is a necessary part of the overall system. The SI-PREDICTOR expert system provides a fracture mechanics approach to the

analysis of structural safety. The system utilizes basic information about the structural geometry type, mode of loading, and structural dimensions, and also about the material being used (tensile properties and fracture toughness). SI-PREDICTOR is currently based upon a LEFM approach; consequently, solutions are checked to see whether the limits of linear elasticity are violated. SI-PREDICTOR determines a critical defect size for a structural component geometry. Six component geometries are available: Vessel, Truss, Plate, Beam, Girder, and Pipe.

The SI-PREDICTOR expert system program calculations have been verified independently for numerous test cases to ensure that the program is error free. The accuracy of the critical defect sizes calculated are dependent only upon the accuracy of the input; component dimensions, applied loading, and material properties.

Material Analyzer

The Material Analyzer Sub-blackboard (MAS) will enable the design engineer to perform optimum selection of welding consumables and to set pre- and postweld heat treatment (PWHT) to optimize the weld properties. This system utilizes all applicable Mil. Spec's. and standards, and AWS welding electrode and filler metal specifications are included in the databases. The weld preheat and PWHT will be based on Mil. Spec's. and Welding Research Council (WRC) published guidelines. In addition, the MAS will provide the user with the latest state-of-the-art technology for analysis of special nonstandard materials, or universal weld heating requirements.

WELDSELECTOR. The selection Of a welding electrode or filler metal is a complex task requiring detailed information about the base metal to be welded and the properties of the electrode and filler metal. In addition, several aspects of the welding operation must be examined and decisions made regarding the specific application in order to narrow the list

of possible electrode choices. A weld, which is a small bit of solidified metal, is expected to have the same (or perhaps better) properties as the base metal that it joins. The base metal may have undergone hours of careful and expensive heat treating and processing, yet the weld metal must be as corrosion resistant, as strong, as ductile, and as fracture resistant as that base metal.

The WELDSELECTOR expert system is able to access data about the welding materials through the use of extensive databases which contain information about base metals and electrodes. The base metals database currently contains over 1,000 grades of steel identified by ASTM classification. Navy-used steels are being added to the database, including the HY and HSLA steels commonly used in shipbuilding. The electrode database contains all of the AWS classified welding electrodes which are used in the United States for three welding processes: Shielded Metal Arc Welding (SMAW), Gas Metal Arc Welding (GMAW) and Flux-Cored Arc Welding (FCAW). The various military qualified electrodes are currently being added to the cross-reference listing.

WELDSELECTOR follows the logic processes which are used by a human expert to determine an appropriate filler metal. Given basic information regarding the material to be welded and using the databases of the base metals and electrode properties, an initial feasible list of electrodes is produced. The list is then ranked based on decision factors about the required weld. Examples of the type of decision factors include: (1) the type of welding equipment to be used, AC or DC (to partially determine the chemical design of the welding flux); (2) the degree of hydrogen contamination coupled with the sensitivity of the base metal to hydrogen damage; and (3) the position in which the weld is to be made (e.g., flat, vertical, or overhead).

WELDSELECTOR only uses decision factor data as necessary. The system can prompt the human user for more details when needed.

As with any decision making process, conflicting input must be weighed and evaluated based on its resulting impact. This is accomplished in WELDSELECTOR with the use of a numerical rating system of certainty factors (CFS). WELDSELECTOR produces a CF-ranked list of electrodes from which the top choices are selected. These top choices can then be used in the design of an overall welding procedure.

WELDHEAT. The arc welding process often requires additional heat treatment in the form of applying external heat to the weld area before interpass and during and following the welding process. This external application of heat treatment is referred to as interpass heating, preheating, and postweld heat treatment respectively. By minimizing the temperature differential during and after welding, the welded area will have lower residual stresses and is less susceptible to cracking and other metallurgical problems such as hydrogen damage.

The WELDHEAT system uses the same decision making procedure that an expert metallurgical engineer uses to establish weld heating schedules. However WELDHEAT provides a fast and efficient procedure to evaluate the heating requirements using several different methods. The system will interact with the user to choose the best analysis method (WRC recommendation, carbon equivalent, Pcm, or PHa) to use for preheating determination. Then the expert system will be called upon to assist with generation of a WPS and to verify that a standard or a developed WPS has the appropriate choice of heating schedules.

The database system incorporated with WELDHEAT contains "typical" composition values for over 500 ASTM classified steels. WELDHEAT will include in the decision process one or more of several important parameters, depending on the specific situation: cooling rate, potential hydrogen content, joint type, plate thickness, energy input, and electrode choice. The various methods can run in parallel. Based on the user's selection, one or

more of the methods can be used to provide a "best estimate" of the preheat and interpass temperature, as well as the recommended postweld heat treatment. If the user or the blackboard does not have information about all of these parameters, WELDHEAT will use all of the available information to provide a "best estimate" of the preheat and interpass temperature as well as the recommended postweld heat treatment.

Weld Procedure Specifier

The objective of the Procedure Specifier Sub-blackboard (PSS) is to obtain a Welding procedure which can be used to develop a weld schedule. That weld schedule is then passed to the welding job controller. There are three options which are available within PSS. First if an applicable welding procedure specification (WPS) is available in the database which meets the requirements of the weld to be performed, then that WPS(s) is extracted. If there is more than one, the list is ranked in order of applicability and presented to the human user. Second, if no WPS is already available, then pre-existing welding procedure qualification records (PQRs) are extracted from the database which are applicable to the weld to be performed. Then a WPS is generated from these PQRs. Finally, if no applicable PQRs can be found, a PQR plan is developed which can be tested to produce PQRs in an actual weld testing operation.

WELDPRO-* Expert Systems. This suite of expert systems is an important part of the WELDEXCELL WJP. Each expert system in the suite deals with weld procedure data. They work together to select an appropriate procedure (WPS) or to generate one, and then to develop a welding schedule based on the welding procedure data. The schedule is then used to direct the welding tasks to be performed.

The WELDPROSPEC expert system chooses a previously tested WPS from a database. If a WPS is not found which will meet the specific application needs, then

WELDPROSPEC selects all of the PQRs from the database which are applicable to the weld to be performed. The PQRs which are selected are used to backup a WPS to be generated from the PQRs by WELDPROGEN. Additional rules are being added to the existing WELDPROSPEC system to include Mil. Spec. requirements; currently, it is based on the AWS D1.1 Code guidelines for WPS generation. PQRs are currently selected so that the WPS data specified falls within the allowed variance of the PQR essential variables as specified by AWS D1.1 code. The selected PQR data is passed to the WELDPROGEN expert system which is then called upon to generate a WPS. If appropriate PQRs cannot be located, the WELDPROPLAN expert system is called upon to develop a PQR test plan. WELDPROGEN will generate a WPS which conforms to the appropriate rules or guidelines from the set of PQRs which were selected by WELDPROSPEC. The expert system produces a WPS which contains all of the necessary data required to develop a weld schedule and which conforms to the applicable code or Mil. Spec. and which is adequately "backed up" by PQR's.

WELDPROSCHED develops a suitable welding schedule which is supplied to a manual welder, an automatic welder, or to the robotic welding system. Specific values and allowable ranges are supplied to define machine settings during the welding operation. The schedule considers position, thickness, and joint design changes and is able to adjust for multiple passes.

Weld Path Planner

The Path Planner System (PPS) includes the basic design implementation of a welding path from a CAD-based design of the part to be produced. The three aspects of the system are (1) the CAD system which will be compatible with many commercial CAD systems including the Navy CAD system; (2) the path planner which takes the CAD drawing and plans the welding path; and (3) a robot welding graphic

simulator which includes collision avoidance assistance.

A computer-aided design (CAD) system is used that works in the specific hardware and software environment defined by this project. Currently the system uses AutoCAD. Drawings of the assembly pieces are created in three dimensions, and details of the joining of these pieces will be included. The CAD system must have the ability to allow the engineer to select the path to be followed by the welding torch/end effector of the welding robot. In addition, CAD code is being developed which allows the human user to identify objects in the CAD drawing. The three types of objects to be identified are (1) the weld line, (2) the objects to be joined, and (3) other objects which are potential collision objects or are important to the weld process (e.g. fixturing).

A separate system to be operated with the Welding Job Planner blackboard is available to do the path planning so that the path will be able to be associated with welding schedule data provided by the WELDPROSCHED system. Considerations are made for part accessibility, and/or possible obstructions on the part itself. It will also be necessary to simulate the robot movement relative to the parts to be welded. The simulation assists in path planning and collision avoidance.

A robot simulator has been developed for an articulated arm and for gantry robot system. The simulator is capable of reproducing all of the robot motions including operating envelope limitations. The robot end effector world coordinates, and joint positions are displayed in real-time on the graphics screen. A specially designed collision avoidance system was developed by the Colorado School of Mines to operate in parallel with the real-time robot simulator.

WELDING JOB CONTROLLER

Functional Description

The Welding Job Controller (WJC) is responsible for all real time activities within the WELDEXCELL system. The WJC can accept a weld description from the Weld Job Planner (WJP) and accordingly control the welding hardware. The WJC will also collect data during the welding process for analysis on the WJP workstation. Figure 3 shows the top level organization of the WJC software components.

The WJC operator interface supports direct interaction between the end user and the welding system. Animated graphical control panels allow the operator to configure the hardware, adjust system parameters, load weld descriptions, and monitor the real time welding process. The WJC system is currently under development by the WELDEXCELL team at the MTS Systems facility in Minneapolis.

Operator Interface

The operator interface will allow the welding hardware operator to perform the following functions:

- Load, limited edit, and execute a Weld Job Planner description
- Configure the hardware interface components
- 1 Perform sensor and transducer calibration
- Monitor execution of the welding plan
- Monitor real time welding process variables
- Monitor and adjust the robot motion control system

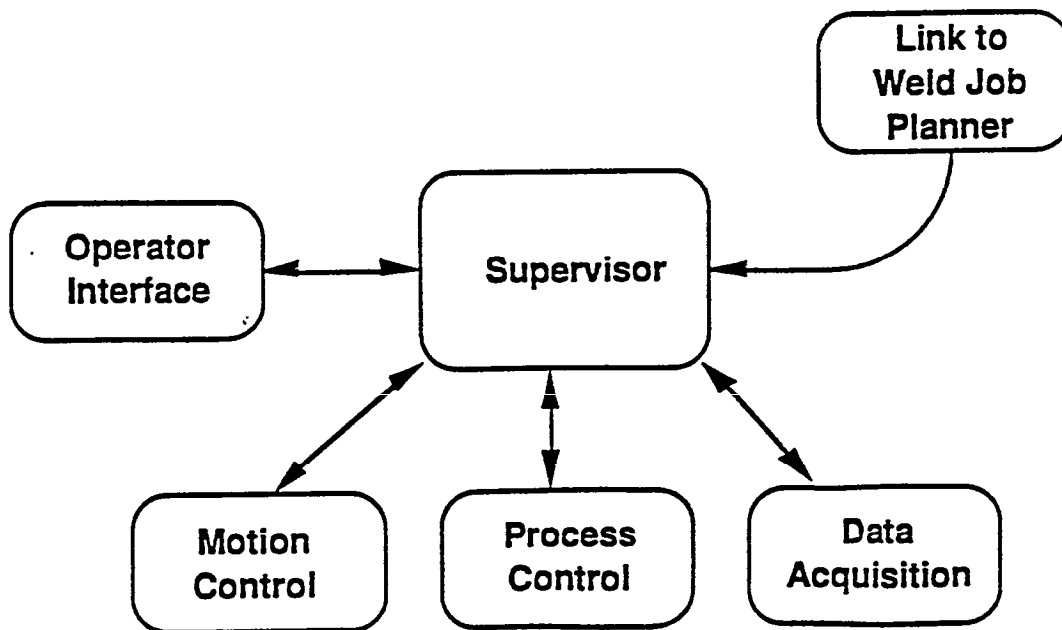


Figure 3. Overall Welding Job Controller Software Breakdown

1 Configure and display the data acquisition processes

The operator interface will present a set of animated control panels to the end user. These panels will be displayed in workstation windows. The user will manipulate a picture of electronic controls using a pointing device. Input components will include push buttons, toggle switches, slide controls and radio button clusters. Animated displays will show the state of the welding process and provide immediate feedback when the controls are adjusted. Displays will include virtual graphic representations of indicator lamps, digital readouts, oscilloscopes and chart recorders.

The organization of the operator interface will follow object oriented design principles: Each major hardware subsystem will have an associated graphical control panel. The panel allows the welding specialist to adjust and monitor familiar welding process parameters. The operator will be able to control which panels are displayed and interact with any con-

trol panel at any time. All visible displays will be continuously updated to reflect the current state of the welding process. All active input controls will provide immediate feedback to the operator when their values are changed.

The Real-Time System

As described above, the real time system will consist of a supervisor module and three major real time processes:

- Motion control system
- 1 Welding process control system
- Data acquisition system

The supervisor module will handle the interface between these three subsystems, the operator interface and the Weld Job Planner. The supervisor will be the main control program within the WJC although the user interface will

be reactive: consequently, the operator will at all times be able to adjust or even override the execution of the welding plan;

The Supervisor will implement the following major functions:

- 1 Download weld job descriptions from the Weld Job Planner using a LAN interface.
- 1 Interpret the weld job description as a program by sending commands to the other real time system modules.
- 1 Monitor the execution of the Weld Job Description and support operator interventions such as pause/resume and single stepping.
- 1 Monitor the status of other major components of the WJC for display on the Operator Interface.
- 1 Implement commands from the Operator Interface for system configuration, adjustment and control.

Motion Control

The motion controller will move the welding torch along a programmed path using a robot arm. Figure 4 is a signal flow diagram showing the top level organization of the motion controller.

The motion controller will work with three coordinate systems. The world system will be used to specify points in a fixed Cartesian coordinate system. The part coordinate system will be aligned with the part to be welded. The tool system will be aligned with the welding torch tip. During the welding process the motion controller will keep one axis of the tool coordinate system aligned with the seam.

The signal flow diagram shows three coordinate conversion modules. The world to joint module will take a vector signal of world coordinates and convert it to a vector signal of joint angles. The part to world module will take a part relative vector signal and convert it to the joint system. The tool to joint module will convert a tool relative vector signal to the joint system.

The Path Generators will be responsible for providing a position command to the robot arm that moves the welding torch. The supervisor will provide a sparse sequence of gauge points in either part or world coordinates at the desired tool velocity along the seam. The world path generator will receive the gauge points specified in world coordinates while the part path generator will receive gauge points specified in part coordinates. In either case, the path generator will interpolate additional points along the trajectory uniformly spaced in time (i.e. upsamples the position signal).

The joint controller command will be the sum of three input signals: the desired trajectory from the supervisor, the correction from the seam finder and the feedback from the robot joint resolvers. The joint controller will calculate a new command for the joint servos based on these values.

The robot interface will accept a stream of joint angle vectors and use this to apply a proportional signal to the joint actuators. The output of the robot interface will be a vector signal of actual (measured) angles taken from the joint resolvers.

The seam finder will send adjustments to the joint controller based on real time visual information about the seam location.

The seam finder will be responsible for updating the path of the robot in real time (actual update rates will be approximately 10Hz) by analyzing the gray scale or laser imaging data to determine an offset in the coordinate system of the torch (i.e. tool coordinates). This relative

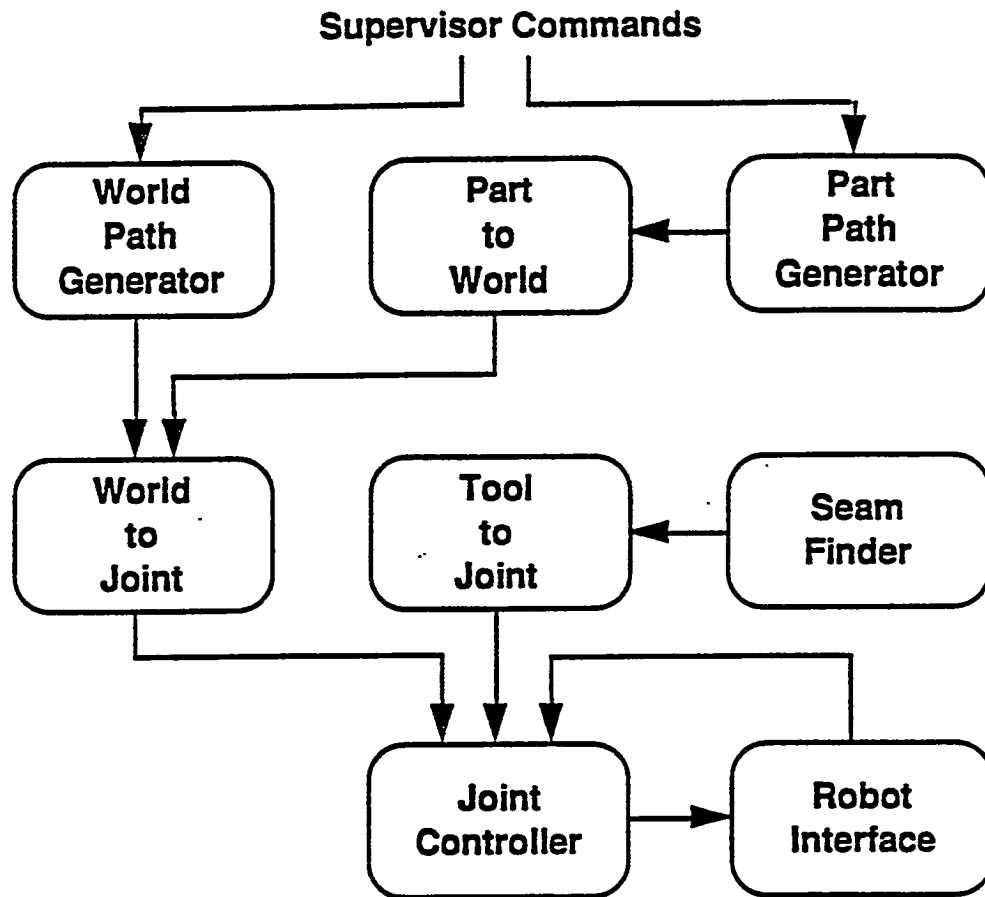


Figure 4. Signal Flow Diagram for the Motion Controller

offset will be passed to the joint controller via the tool to joint converter.

The data acquisition system preprocesses and record weld process parameter data such as weld travel speed, wire feed rate, gas flow, current velocity and temperature. The raw results may be examined from the operator interface and/or sent back to the Weld Job Planner workstation for further analysis. The data acquisition system has several modules specifically designed to capture data from the different types of sensors and perform preliminary sampling and filtering operations as shown in Figure 5 below.

USER INTERFACE

The objective is to develop a user interface which makes maximum use of advanced interface design technology. Extensive use of windows, mouse active screen elements, icons, and object-oriented interface philosophy. Occasionally, the user may be asked to type in a response but in most interactions, the user will be presented with a list of parameter values or icons from which to choose.

The user interface will be designed for a variety of potential users. These users will include mechanical engineers (ME), NDE engineering personnel (NDE), welding engineers (WE), welding system operators (WO), and

data system operators (DO). The major functions of the interface and anticipated users are as follows

- Welding Procedure Specification (WE)
- Materials Analysis (WE, ME)
- Structural Integrity Analysis (ME, NDE)
- Weld Schedule Specification (WE, WO)
- Data Systems Interaction (WE, ME, DO)

- Knowledge Systems Interface (ME)

- CAD System (WE, ME)

Interface System Components

The interface will consist of several virtual components. Most of the functions required of the WJP system require that the system acquire information from the user at each step in the analysis. For example, when determining the welding consumables for operation, the user should only need to specify the gas type after the process has been determined to be GMAW or shielded FCAW. The main technique to be employed will be one

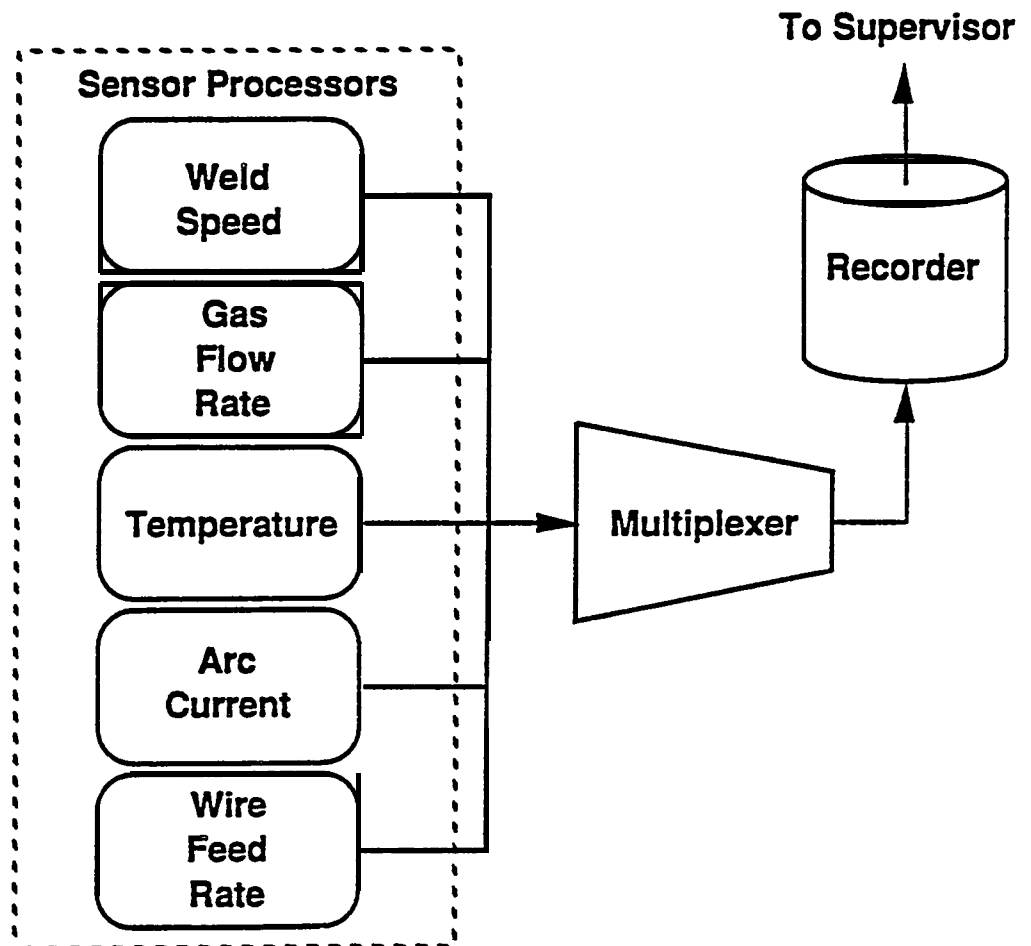


Figure 5. Welding Job Controller Data Acquisition System

overlapping windows in a layered hierarchical frame-type knowledge representation schema.

Whenever possible, the user will have available a series of icons which represent the necessary and/or system-required information needed from the user. For example, a small icon of a gas cylinder would be used which the user could manipulate with a mouse and open a window which would allow the user to provide information or get back information relative to shielding gas decision making.

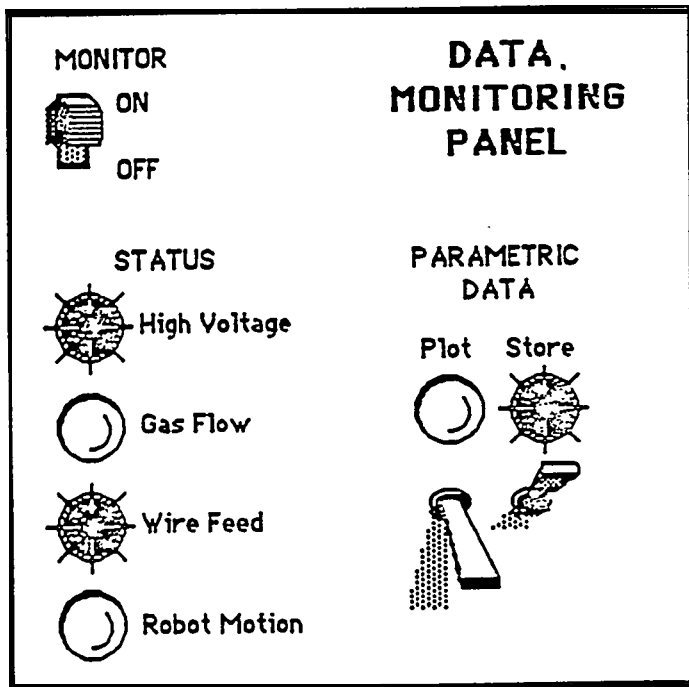


Figure 6. A Graphical representation of an example control panel.

COMPUTER SYSTEM

The WJP will be implemented on a Texas Instruments Explorer Artificial Intelligence Workstation, which is an ideal choice for fast execution of the various expert systems and databases which make up the WJP. An Ethernet link will be used for transferring files to and from the WJC. The WJC will be implemented on a VME-based Unix system consisting of several Motorola 680X0 microprocessors. This architecture is a proven platform for real-time welding workcell control and provides the

openness which will be required to interface to different manipulators, welding equipment and process parameters.

Welding Job Controller/Planner Interface

The interface between the WJC and WJP has specific requirements that are primarily driven by the needs of the WJC. This interface is exclusively one of file transfer through a TCP/IP protocol LAN. The two primary activities of the interface are to pass weld schedule data from the WJP to the WJC and second to provide interpass weld history data to the WJP for interpass intelligent update of the process variables.

In order to provide maximum flexibility and modularity, the system was divided into two component subsystems at a point where minimum communication was necessary. This design provides for enhanced throughput and autonomy of operation. It also lends itself to a simple broad band LAN rather than to a bus structure. Finally, by subdividing the problem at this point, the engineering workstation can be remote to the actual workcell environment.

Artificial Neural System Based Vision System

An Artificial Neural System (ANS) simulation of a robot tracking a welding seam in the presence of a large amount of noise has been developed by the Colorado School of Mines. It consists of an image input subsystem, a neural network subsystem, an output robot control signal subsystem, and an interactive display interface. The software for the simulation is a 3-layer, back propagation network. The number of input nodes is equal to the number of pixels in the input image. Connection strengths are determined by the training of the network for the specific welding problem. The output nodes provide the guidance information to the welding robot.

During a weld, the Artificial Neural system on the WJC (i.e. the Seam Finder) will be run in a "feed forward", or non-learning mode

where images are processed into control signals without any adjustments to the strengths of the connections between processing elements. A detailed description of this ANS based vision system can be found in the literature (A. Rock, 1988; A. Rock, 1989)

Real-Time System Implementation Strategy

The real-time processing components of the Weld Job Controller will be implemented using HOSE, a tool for programming industrial control systems. HOSE allows the designer/implementer to draw data flow diagrams that are automatically implemented on the real time hardware. The diagrams may be used for system design, simulation, implementation and diagnostics.

HOSE is used for both rapid prototyping and final implementation of industrial control systems at MTS. The graphical interactive nature of HOSE allows client feedback to be incorporated in the control system design process. Most of the diagrams used to illustrate the WJC real time systems in the previous sections are suitable for direct representation in HOSE. In many cases, the top level diagrams in a HOSE program are the design documentation.

Welding Control

The welding control system is designed to provide two capabilities. First, the system can set and hold a constant welding parameter schedule as specified by the WJP Subsystem. Second, the controller can ramp the welding parameters between physical set points in the welding path -- also as specified by the WJP. The welding control system provides the welding operator with the capability to view and, to a limited extent, to edit the weld schedule.

WJP User Interface Implementation Strategy

The interface will be developed through the use of the windowing facility in the

Knowledge Engineering Environment (KEE) software and will interact with the X-windows software interface to provide easy accessibility to the user. If appropriate, the AllTalk language software, from MTS Systems, will be utilized. In addition, a significant effort is being made to unify the basic "feel" of the WJC and WJP user interfaces. This is not always possible, however, since the two interfaces require significantly different functions for different classes of users.

CONCLUSION

Based on the development of the prototype blackboard, expert systems, and databases for this project, it can be concluded that the ability to combine welding expert systems and databases is technologically very feasible. It has been estimated that the potential savings for the shipbuilding industry alone could be quite substantial if this technology is integrated into the welding activities of shipyards. Finally, it is the intent of the AWI/MTS/CSM team to complete the development of this system and to transfer this technology both to the shipbuilding industry as well as other welding intensive industries in the United States.

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No. 24

Designing the Future U.S. Naval Surface Fleet for Effectiveness and Producibility

CAPT Clark Graham, USN, Member, Commanding Officer, and
LCDR Michael Bosworth, USN, Life Member, Project Officer,
David Taylor Research Center, Carderock, MD

Abstract: David Taylor Research Center is just commencing investigations into a new manner of defining future fleet architectures. The cost of current performance-driven ship designs has increased at a rapid rate. While it is true that a warship designed with insufficient performance is of meager utility, it is also true that the best performing warship design is of no utility if never built. Both performance and affordability are required if sufficient numbers of ships are to be built to counter the threat. By designing a future fleet architecture with producibility as a major requirement from the start, we hope to impact the acquisition cost significantly. One battle force concept titled "Distribute, Disperse, Disguise and Sustain" suggests two fundamental surface ship types; the Carrier of Large Objects (CLO) and the Scout Fighter. A CLO feasibility design in progress, Carrier Dock Multimission, is outlined to inform shipbuilding researchers of an initiative that promises to have significant impact on naval ship procurement and provide increased visibility within the U.S. Navy on producibility issues.

Before attempting to conceptualize a future United States naval surface fleet, to help create a vision of the U.S. Navy for the year 2030 and beyond, the shortcomings of the current surface Navy must be addressed first. An honest assessment of where we are now is a must for us to determine where we need to be in the future and how to get there.

"CURRENT SHORTCOMINGS

The shortcomings of greatest significance in the current surface Navy that are related to Hull, Mechanical and Electrical technologies are:

- Highly observable ship signatures
- Easily discriminable ship signatures
- Concentration of operating functions
- Logistically demanding
- Programmatically inefficient and expensive to acquire.

The ships of the surface navy are highly observable by radar, acoustic, infrared, magnetic, and electro-optical sensors. As the enemy's surveillance,

tracking, and classification capabilities increase with time, the advantage will continue to shift more and more to the enemy. The result is that the enemy can, in most cases, engage our surface forces outside the battle space of our own weapon systems. This forces us into a defensive posture that requires us to shoot down the "arrows" (cruise missiles) rather than the "archers" (aircraft, submarine and surface ship launch platforms).

Forty-two classes of surface ships currently operate in our carrier battle groups, surface action groups, amphibious task forces, logistic support groups, and convoy escort groups. Each of these ship classes (and, indeed, most of the ships within a particular class) has unique signatures that allow the enemy to discriminate ships within a surface force. This plays to the enemy's strength of massing fire power on whatever type of ship their strategy calls for.

We have generally concentrated required operating functions on large ships. This platform architecture, coupled with the high observability and discriminability results in an inherently vulnerable force structure, requiring extensive investment in long range, layered defense. The enemy can target the ships that carry our tactical aviation assets, our projection of power amphibious assets, our logistic support train, and our defensive area anti-air warfare (AAW), anti-submarine warfare (ASW), and anti-surface warfare (ASUW) assets. The recent move to distribute our cruise missile strike capability among a wide range of surface and submarine assets is a sound move away from the inherent shortcomings of the concentration of functions architecture.

The surface forces are extremely demanding of logistics support. With probable future closings of oversea bases and increasing host country restrictions on use of those bases retained, the demand for long-distance, high-volume, prompt logistic support will be compounded. Fuel represents the most immediate demand of our surface forces while underway. With the exception of our few nuclear surface ships, the surface Navy has ignored fuel efficiency. Our ships are manpower intensive, and human support requirements are logistically demanding. Because

there are so many ship classes with little attention to standardization, underway and overseas maintenance requires extensive logistic support. Finally, and most important in times of war, U.S. Naval surface forces require the transfer of huge volumes of ordnance at sea. With the introduction of larger cruise missiles and extended range AAW and ASW missiles, this transfer has become a serious problem.

Over the last ten years the surface Navy has acquired eleven ships per year of nine different ship classes. These ships were constructed in seven shipyards. The number of different major contracts for government furnished material and contractor (shipbuilder) furnished material is in the tens of thousands. The current platform architecture of many classes of specialized ships with minimum standardization is programmatically demanding. The demand on the Navy's technical and programmatic infrastructure now exceeds the Navy's billet allowances. The United States' shipbuilding industry, along with the supporting marine industry, has become weakened and vulnerable now that the U.S. Navy is the only major customer.

A possible root cause of these five problems is the lack of a master architecture and supporting technical and programmatic strategy for the surface Navy. A coherent vision and a road map for the future needs to be formulated.

MISSION REQUIREMENTS FOR THE FUTURE SURFACE NAVY

Considering the above current shortcomings, is there a viable role for the surface Navy in the future? We believe there is because the inherent strengths of the surface Navy include:

- Real-time force direction and control enabled by command, control and communications (C³) continuity,
- Efficient bulk lift capacity
- Flexible and visible overseas presence
- Relatively low acquisition cost for a presence at the interface between undersea and air
- Unique ability to project and protect power ashore when that power includes combined land and tactical air combat forces of any significant size

It is certainly appropriate for the Navy to investigate entirely new force architectures consisting of different schemes for distributing required operating functions on alternative platform types. In the future there may be some shift towards a greater dependence on submerged ships; land-based aircraft with greatly extended endurance, and other concepts not even conceived at this time. Our current vision of the future indicates there will be a substantial surface Navy because of the inherent strengths of this type of warfare platform.

The projected roles and future missions of the surface ships must be conceptualized in coordination with the projected mission requirements of other elements of the navy, notably the submarine force. There are other elements of the surface navy not addressed in this paper, such as mine warfare, combat/forward area repair and special operations. "Surface Navy" in this paper refers to the battle force structured elements.

A PROPOSED PLATFORM ARCHITECTURE FOR A FUTURE SURFACE NAVY

A platform architecture describes how the required operating functions assigned to the surface navy are distributed among the many types of platforms and how these required operating functions are integrated. One must also address the architecture of the surface Navy to realize the complete perspective. This section addresses the platform aspects of a postulated architecture.

The current architecture of the surface Navy is much as it has been during and since World War II. There are discrete force compositions:

- Carrier Battle Group
- Surface Action Group (Battleship Battle Groups)
- Amphibious Task Forces
- Underway Replenishment Groups
- Convoy Escort Groups (Protection of Shipping)

Within each of these forces, the capital ships transport and support the principal commodity

- Aircraft Carrier - tactical aviation aircraft
- Battleship - large caliber guns and cruise missiles
- Amphibious Transports - Marine amphibious forces
- Logistics Transports - logistic (direct support) material
- Merchant Ships - resupply material

Within each of the forces, the defensive AAW and ASW combat systems are located in the escorts - cruisers, destroyers, frigates. The C³ functions are distributed between the capital ships and the escorts. With the introduction of Tomahawk cruise missiles, Strike and ASUW capability is contained in the larger surface combatants as well as the air wing of the the aircraft carrier.

In an earlier section of this paper, the inherent shortcomings of the surface Navy were discussed. Whatever future architecture the United States Navy adopts for its surface Navy, this architecture should be designed to minimize these shortcomings. The brute force approach which results when problems are masked (rather than the source of problems removed or at a minimum mitigated) could eventually be unaffordable. Continuing the current architecture, which is inherently vulnerable and days to the strength of our principle adversary, the Soviet Navy,

will require a never-ending expansion of our battle space and continued, ever-increasing investment in expensive combat systems to provide the required defense in depth.

In order to overcome existing shortcomings and exploit new technology implications in G, space and weapon systems, the Navy should explore new architectures for its surface forces. The David Taylor Research Center has been studying an architectural option which is designed to reduce each of the five fundamental shortcomings previously discussed. This architecture has been a product of the Round Table strategic planning process developed at DTRC as well as extensive participation in recent war games held at the Naval War College in July 1988.

The architecture option is called "D³ + S" from the key attributes achieved, namely:

- Distribute
- Disperse
- Disguise &
- Sustain

Distribute. The architecture emphasizes distributing the surface Navy's required operating functions into a wider range of platforms. In addition, the concept would discourage concentrating critical functions on single purpose ships. A capital ship would carry two or perhaps three functions. The primary motivation for this greater distribution of functions is to make it more difficult for an enemy to target and then mass its firepower on a single high value unit. The loss of a capital ship would result in the loss of one third of three critical functions rather than all of one function.

Disperse. The surface assets would also be dispersed over a greater area of the ocean. This dispersion would further work against the Soviet's strength of massing firepower.

Disguise. The ships of the surface Navy would be designed with observability as low as possible consistent with a functioning, affordable surface ship. Thus the ships would strive for maximum disguise relative to the "noise" of the ocean. Additionally and equally important, the surface ships signatures would be designed to be as undiscriminable as possible. The motivation is to make it near impossible for the enemy to classify targets and determine which ship carries a particular required operating function.

The desired result of D³ (Distribute, Disperse, Disguise), is to cause the enemy to come well within US Navy battle space to detect, classify, target, and engage U.S. surface ships. This will make our existing combat systems far more lethal in defense of the surface forces. The advantage shifts to our side as we now will be shooting down the "archer" before the launch of the "arrows".

The fundamental thrust of this architecture is the removal or mitigation of inherent vulnerabilities of surface forces caused by high observability, discrimination, and concentration of functions. The expectation is that the current trend of requiring longer range, reduced reaction time combat systems will be reversed. Intuitively, we expect this to be a less expensive and more cost-effective approach. To verify the validity of this statement will require extensive systems engineering and systems analysis studies.

Sustain. The word "sustain" in the context of the D³ + S architecture refers to the requirement to substantially increase the sustainability of each of the ships of the D³ + S force. The submarine navy has emphasized the close relation between stealth and sustainability since the introduction and total commitment to nuclear submarines. It is nonsensical for a low observable ship to require frequent resupply from a highly observable logistic support ship.

A typical surface combatant ship must leave station in a carrier task force every three days in order to maintain a fuel load above the desired sixty percent. Conventional aircraft carriers require approximately the same periodicity of aircraft fuel replenishment during sustained flight operations, CVN's somewhat less frequent. In time of combat the demand for the replenishment of ordnance is expected to occur even more often. Resupply to satisfy the human support requirements can be extended beyond thirty days during normal operations. Providing for underway maintenance requirements is more difficult to predict.

The requirement for frequent replenishment at sea adds substantially to the inherent vulnerabilities of an underway surface force. The signatures of the ships increase during the high speed transit to and from station. The logistics ships themselves may very well be the Achilles' heel of the force. The ships shuttling fuel, ordnance, and stores from ports to the AOES and AOR'S are particularly vulnerable.

The D³ + S concept as an architectural option, summarized in Figs. 1 through 6, has the potential to reduce the inherent vulnerabilities of the current surface battle forces. With this hope, goals and system concepts consistent with this architecture have been developed.

Appendix A provides a category listing of the preliminary quantitative, time-phase goals that have developed through the H, M&E strategic planning process.

The setting of these goals is a mandatory first step in conceptualizing system concepts and prioritizing technology clusters.

SYSTEM CONCEPT FOR THE D³ + S ARCHITECTURE

The David Taylor Research Center has formed systems engineering teams to conceptualize system concepts building on the D³ + S architecture and goals. The most promising system concept is described.

The system concept that has the potential for meeting the requirements of the D³ + S architecture and the ensuing goals consists of a concept where the surface navy necks down to two parent types of ships, namely a Carrier of Large Objects (CLO) and a Scout Fighter (SF). Both ships would be designed with significantly reduced signatures compared to current surface practice. Furthermore, the signatures of the CLO and SF would be as indiscriminable as possible. Both ships would incorporate design features to extend their on station time considerably in excess of today's capabilities.

Carrier of Large Objects (CLO). The surface Navy carries the following large objects:

- Aircraft and their operating and support equipment and personnel
- Marines and their amphibious equipment
- Logistic material and transfer equipment
- Mobile repair equipment (i.e., tenders)
- In the future, autonomous vehicles (underwater, surface, and air).

A list of current CLOs and their cargo is contained in Table I

The system concept calls for one low-observable, highly sustainable ship class that is capable of transporting and supporting each of these categories of large objects. The variants would differ in arrangement as required by the demands of the large objects, but they would appear similar from a signature standpoint and utilize similar subsystems to the maximum extent possible.

In order to make this system concept remote reasonable, the large objects (future aircraft, amphibious equipment, logistic transfer equipment, repair equipment, and autonomous vehicles) will need to be conceptualized in parallel with the CLO. Clearly this is a concept which will require thirty to forty years to implement fleet wide.

A CLO concept which is currently designated at DTRC as Carrier Dock Multi-mission (CDM) envisions multiproduct variants, one variant for each major mission area, i.e. amphibious, direct logistics support, repair, carrier of aircraft or carrier of autonomous vehicles (manned or unmanned). The common framework consists of a conventional monohull with welldeck and flightdeck, with integrated electric drive and intercooled, regenerative gas turbine engines.

Ship concept studies are underway to size and configure a notional CDM along with its possible conceptual variants, shown in Figs. 7,8 and 9. The starting point will concentrate on, Carrier Dock Amphibious (CDA) and Carrier Dock Logistic (CDL) variants. Notional CDA and CDL requirements are shown in

**Table I. Current U.S. carriers of large objects
summary**

TYPE	NO.	LENGTH	DISPL (k LT)	SHP (KHP)	SPEED (kts)	CARGO
CVN	5+2	1092	91	260	30 +	90 + AIRCRAFT
CV	10	1046	81	280	30 +	85 AIRCRAFT
BB	4	887	58	212	35	GUNS & MISSILES
CGN	9	585	10	100	30 +	MISSILES
LCC	2	620	18	22	23	COMMAND AND COMMUNICATIONS
LHD	[1+10]	844	41	70	20 +	3 LCAC, 42 HELO, 1900 TROOPS
LHA	5	820	39	70	20 +	1 LCAC, 38 HELO, 1700 TROOPS
LPH	7	602	18	22	23	27 HELO, 1750 TROOPS
LPD	13	570	17	24	21	6 HELO, 900 TROOPS
LSD	9+10	609	16	42	20+	4 LCAC, 4 HELO, 338 TROOPS
LST	18	522	8	16	20	LVT's, TANKS, 420 TROOPS
LKA	5	575	19	19	20	HEAVY LIFT, 226 TROOPS
AE	13	564	18	22	20	ORDNANCE
AFS	7	581	18	22	20	2600 T DRY STORES, 1300 T REEFER STORES
AO	5	592	26	24	20	120,000 BARRELS OF FUEL
AO m	2	644	34	13.5	18	184,000 BARRELS. 200 T AMMO, 100 T REEFER
AO	20+	679	40	32	20	180,000 BARRELS OF FUEL
AOE	4+4	793	53	100	26	177,000 BARRELS, 2100 AMMO, 500 DRY, 200 REF
AOR	7	659	38	32	20	175,000 BARRELS, 600 AMMO, 400 DRY, 100 REF

Source: Jane's Fighting Ships; not official U.S. Navy figures

Table II. A ship of between 30,000 and 40,000 tons full load has been used as a starting point and an early conceptual drawing is included as Fig. 10. Other features of the CDM concept are summarized in Fig. 11.

Scout Fighter (SF). The scout fighter would share the functions of command and control, surveillance, offensive, and defensive combat capability. The scout fighter is envisioned to be a far smaller, more mobile and less expensive ship than the Carrier of Large Objects.

The distribution of functions between the CLO and SF has many possibilities. On one extreme the SF could be a relatively independent, fully capable, multi-warfare capable ship much like the cruisers of

example, both ships would use the same type of propulsor and prime mover. The two ships could be designed with the same basic topside configuration and materials. Active signature control techniques would also be required.

This battle force system concept based around only two parent ship classes with a large degree of ship design commonality has the potential for significant programmatic cost savings in areas of both acquisition and operating and support costs. Longer production runs will permit the shipbuilding industry to more aggressively adopt modern shipbuilding techniques, such as more extensive use of process flow lanes, preoutfitting, and modularity. Capital investments would become more attractive to shipbuilders,

Table II. Notional CDA and CDL design requirements

Feature	CDA	CDL
Signature	low observable	same low observable
Cargo fuel	185,000 gals	120,000 barrels
Cargo ammo		150,000 Cu ft
Cargo dry stores		830 tons
Cargo reefer stores		350 tons
Containers (8' x 8' x 20')	2 (minimum)	150
Troops	950 men	
Square footage	21,000 Sq ft	
Cubic footage	37,000 cu ft	
LCAC's/barges	2	
Boats (LCM 6 equivalent)	9	2
Aviation Facilities		
helos/planes	10 helos/planes	4 helo
hanger & repair	yes	yes
UNREP suite		
CONREP	3 fuel, 1 cargo	5 fuel, 1 cargo
VERTREP	3	3
Sustained speed	20 knots	20 knots
Endurance (min)	10,000 nm @ 20 kts	10,000 nm @ 20 kts
ship stability	< common >	
Habitability standard	< common: Navy standard >	
Manning	c as per goals >	
Combat System	< corn-mom TBD >	
Margins	< common >	
Survivability	< common low signature, SRBOC, collective protection, doublesteel hull >	
Propulsion Machinery	< common: integrated electric gas turbine/LCR >	

today. On the other extreme the SF could be an unmanned autonomous vehicle supported by the mother ship. There is a wide range of differences in SF capabilities between these two extremes. Current scout fighters (cruisers, destroyers, frigates) are summarized in Table III.

Even though the SF would be a smaller, more mobile ship as compared to the CLO, the SF would be designed with similar low signatures. This would be accomplished by incorporating the same subsystem and component concepts that are the source of the emissions which result in ship signatures. As an

and various producibility concepts become more economic. Commonality would greatly lessen fleet introduction, training infrastructure and other logistic support costs.

This two ship concept could have major ramifications on the shipbuilding and marine industrial base. Careful planning would be required to architect the "Distributed industrial base consistent with the D + S platform architecture. There will be far less variety of materials, components, and standards in this system concept. This could result in a considerable neck down in the number and diversity of marine

Table III. Current scout fighters.

TYPE	NO.	LENGTH	DISPL (k LT)	SHP (kHP)	SPEED (kts)	PAYLOAD
BB	4	667	58	212	35	Large guns, missiles, flag facilities
CGN	9	585	10	100	30+	Missiles, guns
CG	32	567	9.6	80	30+	Missiles, AEGIS on half of them
DDG	37	437	4.8	70	30	Missiles, guns
DD	31	563	7.6	80	33	Guns, ASW helos
FFG	46	445	3.6	40	29	Missiles, ASW helos
FF	49	438	3.9	35	27	large sonar. ASW helo

Source: Jane's Fighting Ships not official U.S. Navy figures

suppliers. It is likely that the Navy shipbuilding and repair business will be concentrated in a smaller number of shipyards. A specific shipbuilder or supplier may specialize in a particular process flow lane to provide preoutfitted subsystems, which are then shipped to assembly yards.

The two ship system concept could greatly alleviate the current severe problem of a size-constrained government technical and program support infrastructure being unable to provide the ship design and fleet technical support for the highly diverse surface force of today. A far more streamlined and disciplined support organization would result from this neck down of ship classes.

The size of these two concepts relative to today's missions and ship types are shown in Fig. 7. The specifics of the size variation of the SF will greatly depend on the distribution of functions between the CLO and the SF, affordability constraints, and projected weapon system characteristics.

TECHNOLOGY CLUSTERS

The concept of clustering technologies that have synergistic and programmatic linkages has merit for any platform architecture. It has particular merit when coupled with the D³ + S architecture and the resulting two ship system concept.

Technology clusters have been identified at the David Taylor Research Center which serve as building blocks for ship concepts which meet the specified goals. As of the writing of this chapter, five technology clusters have been identified and are in the process of system definition. These five clusters are:

- Cluster A - Advanced Machinery Systems
- Cluster B - Advanced Hull Technologies
- Cluster C - Advanced Topsides Technologies
- Cluster D - Manning and Human Support
- Cluster E - Propulsion Powered Combat Systems

These five technology clusters vary significantly in maturity and definition and the systems analysis completeness explaining the cost benefit of

each of these clusters in the context of the D³ + S architecture, the goals, and the CLO/SF system concept also varies.

TRANSITION PLAN TOWARDS THE D³ + S ARCHITECTURE

The Navy will have rebuilt itself by the year 2030. By that date the ships and systems of the current Navy will have been retired or very nearly so. In this context ships and systems actually in the fleet plus those under construction are considered to be part of today's Navy. One must reach out beyond this forty year time frame to be able to conceptualize a Navy unencumbered by current force architecture, current systems, and current government and industrial infrastructure.

The transition Navy is the forty year period of time between today and the future (2030+), see Fig. 12. The first twenty years can be considered as near term and the next twenty years as mid term. The Navy must have a vision of the future architecture, system concepts, and support infrastructure to be able to lay out a road map towards that vision. Far too many technology investment decisions are influenced by today's constrained perspective. This leads to a replacement in kind system solution, an evolutionary upgrade that may not address the fundamental source of shortcomings. It encourages the maintaining of paradigms no longer valid.

Both the neck down in the number of ship classes as well as the change in the design philosophy and acquisition strategies of all near term ship building programs should begin as soon as possible. One concept of future surface battle force composition (approximately one-half of the entire Navy) is shown in Fig. 13. A postulated timeline for CDM and SF technology and procurement is shown in Fig. 14. A conjectured 2030 CDM/SF fleet makeup is described in Fig. 15.

EFFECTIVENESS AND COST ASSESSMENT

A key element of the Strategic Planning procedure is to evaluate the military worth of projected future ship concepts and assess the cost to implement them. for an overall evaluation of cost effective-

ness. At DTRC, this is done by an independent assessment group. Much work remains to validate existing assessment models, increase their flexibility to assess more far-reaching technology concepts, and to develop assessment models in additional mission areas.

PRODUCIBILITY

Producibility is not presently considered a major element in the naval ship design process for several reasons.

1 There exist a myriad of other elements that are considered more critical.

1 There has been a decided lack of visibility and external pressure to increase the producibility of the ship design. Producibility is not as patently obvious as a hydrostatic problem which results in severe list, or a naval gun that cannot fire. Lack of producibility in design is more insidious but no less important.

1 There is a preception that the design community does address producibility through weight minimization or cost constraints. While these are related to producibility, they can easily create a design decision that is out of equilibrium. (Note 1)

1 A lack of awareness of the relative leverage of various ship subelements and design phases for improving producibility and thus increasing the ship's overall cost-effectiveness.

1 A lack of detailed data on specific producibility concepts.

1 A lack of any rigorous methodology for the assessment of producibility.

In the thesis "Producibility as a Design Factor in Naval Combatants" [reference 2] producibility was categorized into wartime (time oriented) and peacetime (cost oriented). Peacetime producibility was further divided for consideration into Fleet Concept, Preliminary Ship Layout, Production Details, Shipyard as Factory, and Economic Considerations. The thesis proposed a peacetime producibility evaluation methodology. The Distribute, Disperse, Disguise and

Sustain ($D^3 + S$) architecture outlined above and the Carrier Dock Multimission ship design feasibility studies getting underway are an attempt to consider producibility at the very inception of ship design, in the Fleet Concept arena.

SUMMARY

The structure of H, M&E technologies presented in this chapter is an outgrowth of an evolving strategic planning process at DTRC. It consists of (a) the definition of quantitative time-phase goals necessary to overcome the perceived shortcomings; (b) the identification of clusters of synergistic technologies that provide maximum leverage in satisfying these goals; (c) system concepts that incorporate and exploit these technologies; and d) an overall architecture in which they can be evaluated. A specific force architecture ($D^3 + S$) has been proffered to evoke discussion and further evaluation.

This discussion of R & D planning is presented in this forum because producibility has too often been an afterthought to the ship design and force architecture procedure. Only by committing some small percentage of the navy's assets to long range strategic R & D planning, and integrating the planning of inter-related portions of the navy, can the challenges of the future threat be met within increasing fiscal, manpower and industrial base constraints. The vision of the future U.S. naval surface fleet presented above is not the only possible vision, nor is it the complete vision. For instance, an examination is warranted of what synergisms this battle force vision might have with a merchant ship of the future.

The scope of the challenge can be overwhelming, but a start has been made. Between vision and reality lie years of dedicated engineering. This engineering must be tied together on the systems plane, with the producibility aspect given a strong voice in the earliest stages.

ACKNOWLEDGEMENTS

The authors wish to express appreciation to Mr. Dennis Clark and a myriad of David Taylor Research Center Strategic Planning Center participants for their significant contribution to the development of the thoughts expressed in this paper.

Note 1: The equivalence of ship weight to ship acquisition cost is a common fallacy. While it has merit in some applications, it is used for conceptual designs with technical innovations that extend the costing method far past its range of reasonableness. An extreme example of the "weight as cost" concept running afoul is the Patrol Hydrofoil Missile (PHM). The PHM-1 leadship used small, lightweight structural sections, close stiffener spacing and thin gage welded aluminum materials to save weight in the weight-critical high performance ship. While the result was low weight, excessive costs resulted from problems such as weld distortion, part fitup and poor welding accessibility. An extensive structural redesign for the follow ships resulted in a mere 5% increase in weight for a 68% reduction in typical midship bulkhead cost. [reference 1]

REFERENCES

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APPENDIX A

Initial categories of Hull, Mechanical and Electrical Goals set and prioritized in the Strategic Planning Process. These are to be interwoven with Combat System goals to give the Navy timephased and quantitative goals over the spectrum of ship design. These attributes were originally set for a surface combatant (Scout Fighter); ongoing work will modify attributes, add attributes and revise priorities as required for the Carrier of Large Objects and deployable vehicles.

1. Radar Signature
2. Acoustic Signature
3. Survivability (Vulnerability)
4. Damage Control
5. Chemical, Biological and Radiological Defense
6. Fire Protection
7. Range and Endurance
8. Acquisition Cost
9. Infrared Signature
10. Reliability, Maintainability, Availability
11. Operating and Support Costs
12. Seakeeping
13. Wake Signature
14. Speed
15. Extreme Cold Weather Operations
16. Logistics
17. Maneuverability
18. Magnetic Signature
19. Electro-Optic and Visual Signature

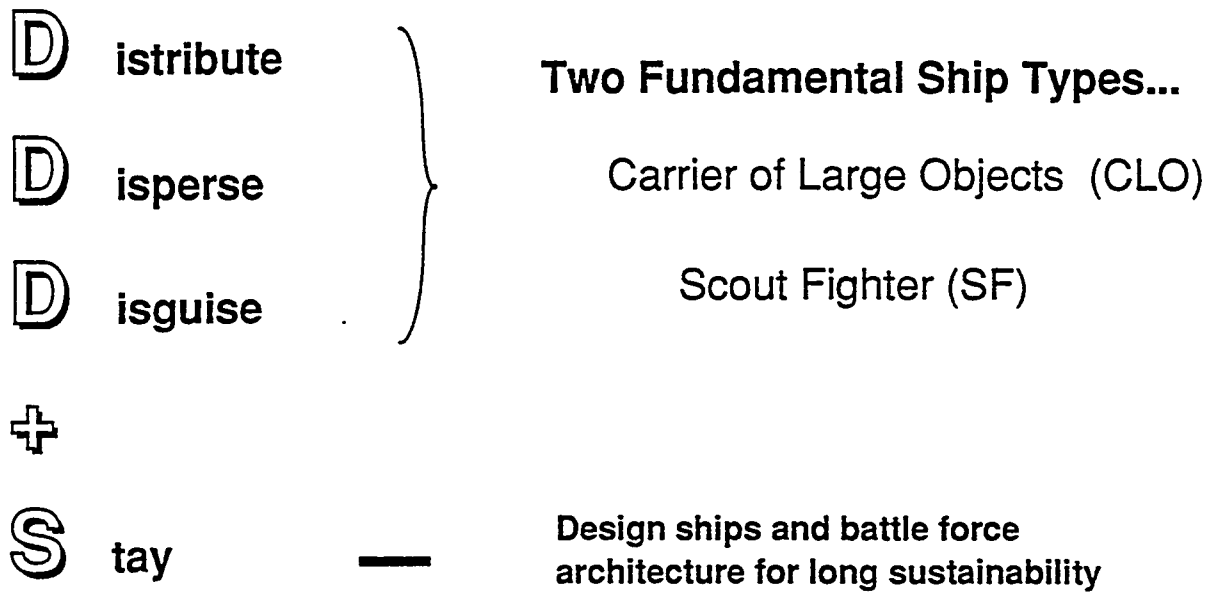


Fig. 1 – D³ + S architecture applies to ships

Large Objects

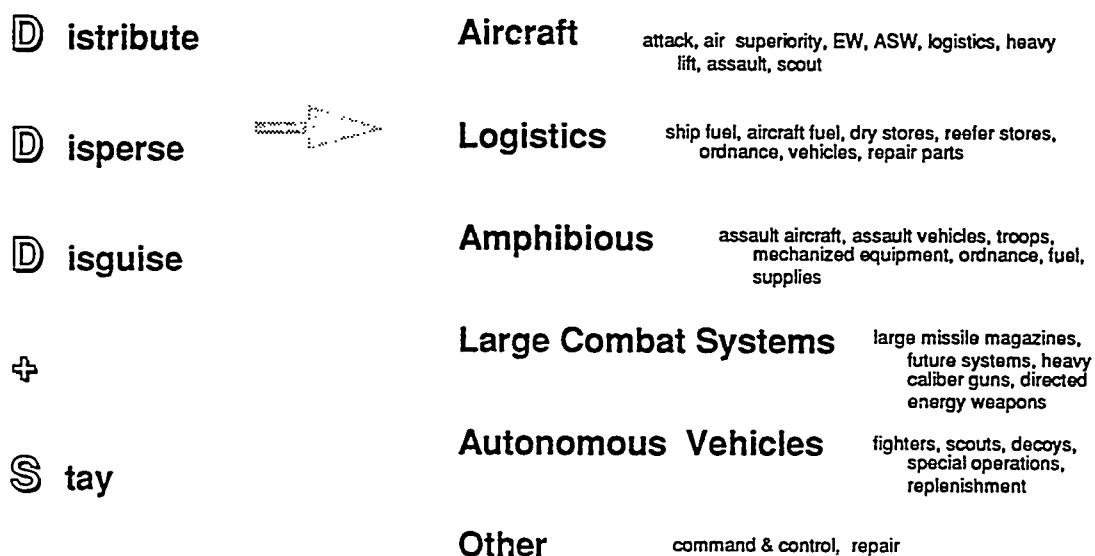


Fig. 2 – D³ + S architecture applies to large objects

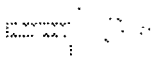
<u>Scouting / Fighting Duties</u>			
D istribute		Command & Control	
D isperse		Surveillance	air, subsurface, surface
D isguise		Offense	land, subsurface, surface
		Defense	air, subsurface, surface
+			
S tay			

Fig. 3 – D³ + S architecture applies to SF duties

Aimed at Removing the Source of Force Problems:

- | | | |
|--|---|--|
| <ul style="list-style-type: none"> ➡ Observability of Ships ➡ Signature Discriminatability | } | Allows Enemy to mass firepower beyond our own defenses |
| <ul style="list-style-type: none"> ➡ Concentration of Functions | — | Loss of one ship means loss of commodity |
| <ul style="list-style-type: none"> ➡ Logistically Demanding | — | Long, demanding logistics tail is expensive and vulnerable |
| <ul style="list-style-type: none"> ➡ Programatically Demanding | — | expensive and time consuming |

Objective: Reduce inherent vulnerability by:

Distributing, Dispersing, Disguising assets and
reducing extent and vulnerability of logistics
support by . . .

Sustain (design for staying power)

Fig. 4 – D³ + S architecture helps remove problems

today (1989)...

future (2030)...

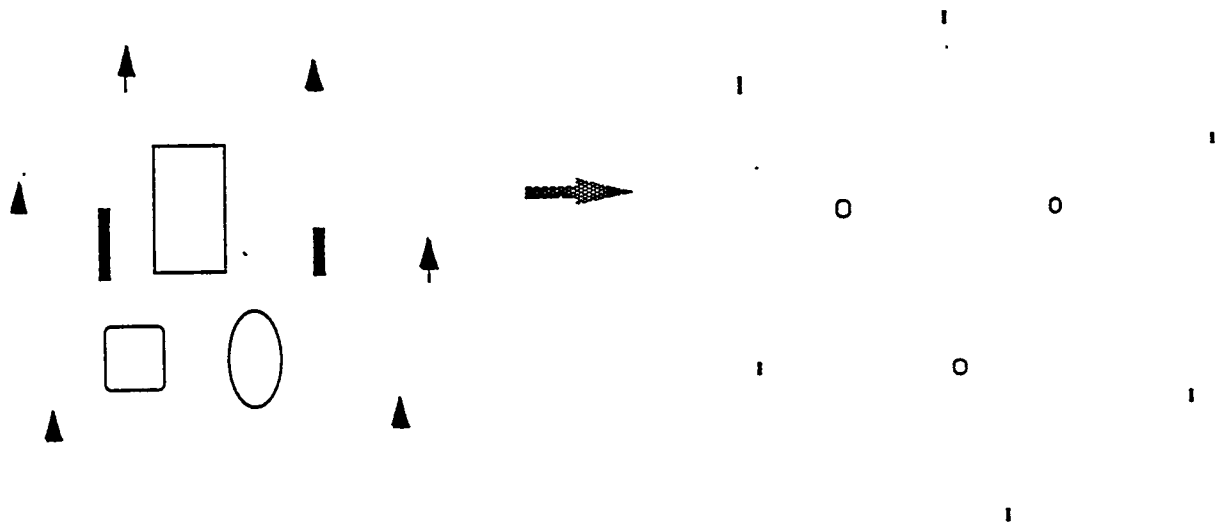


Fig. 5 – Proposed force level group change

□ Increased Military Effectiveness

- ◆ Shrinks Red's battlespace well within Blue's battlespace
- ◆ Negates Red's massing firepower on Blue's high value units
- ◆ Enhances effectiveness of Blue's decoys

○ Reduced Cost

- ◆ Reduced cost through standardization allows either more units or higher quality units

resulting in ...

Fig. 6 – Key reasons for proposed change in architecture

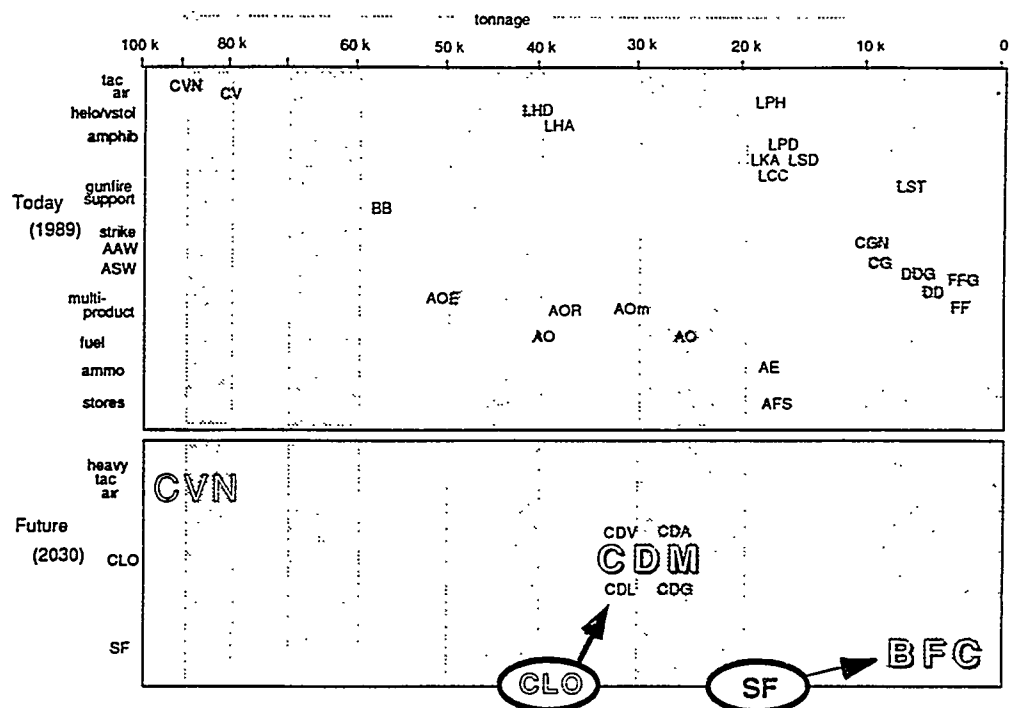


Fig. 7 – Mission and tonnage perspective

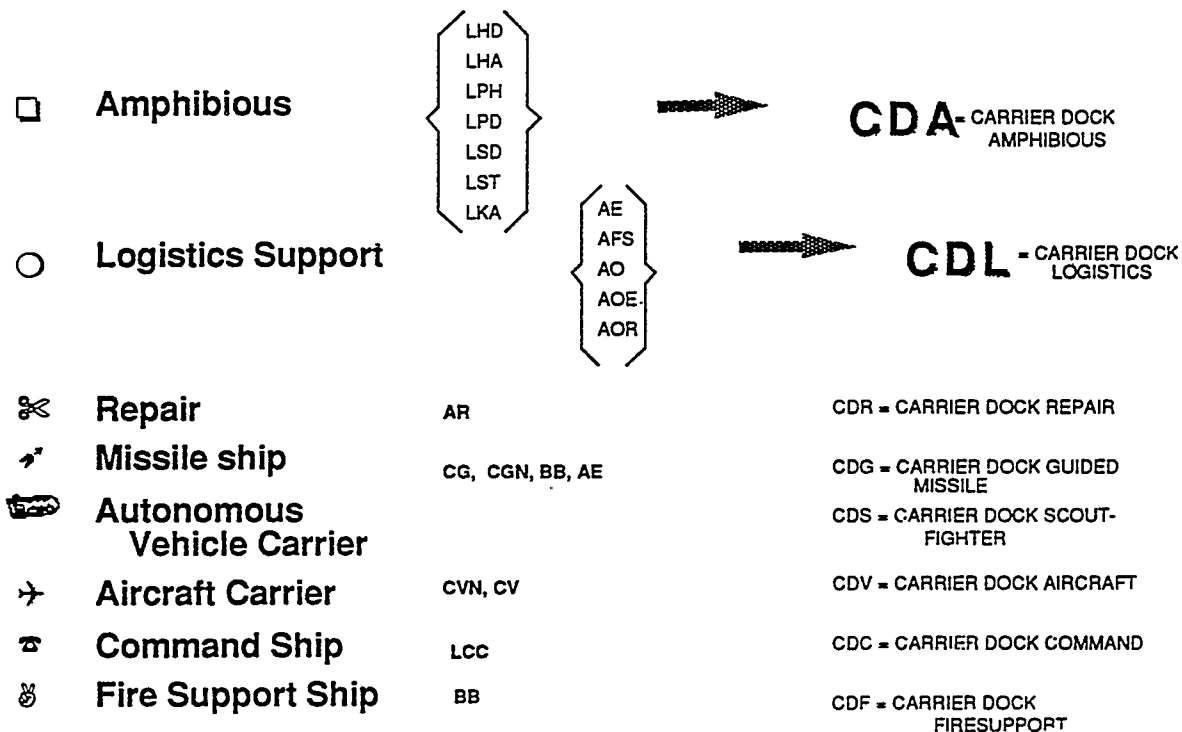


Fig. 8 – Carrier dock multimission variants

disguise which ship is which within a taskgroup/taskforce

disguise which taskgroup is which

balance the ships within a group so that the loss of one vessel (by enemy, equipment failure or tasking) does not jeopardize the mission

reduce ship design costs by commonality

reduce program costs by minimizing the number of programs and reducing overhead

reduce ship production costs by maximizing repeats

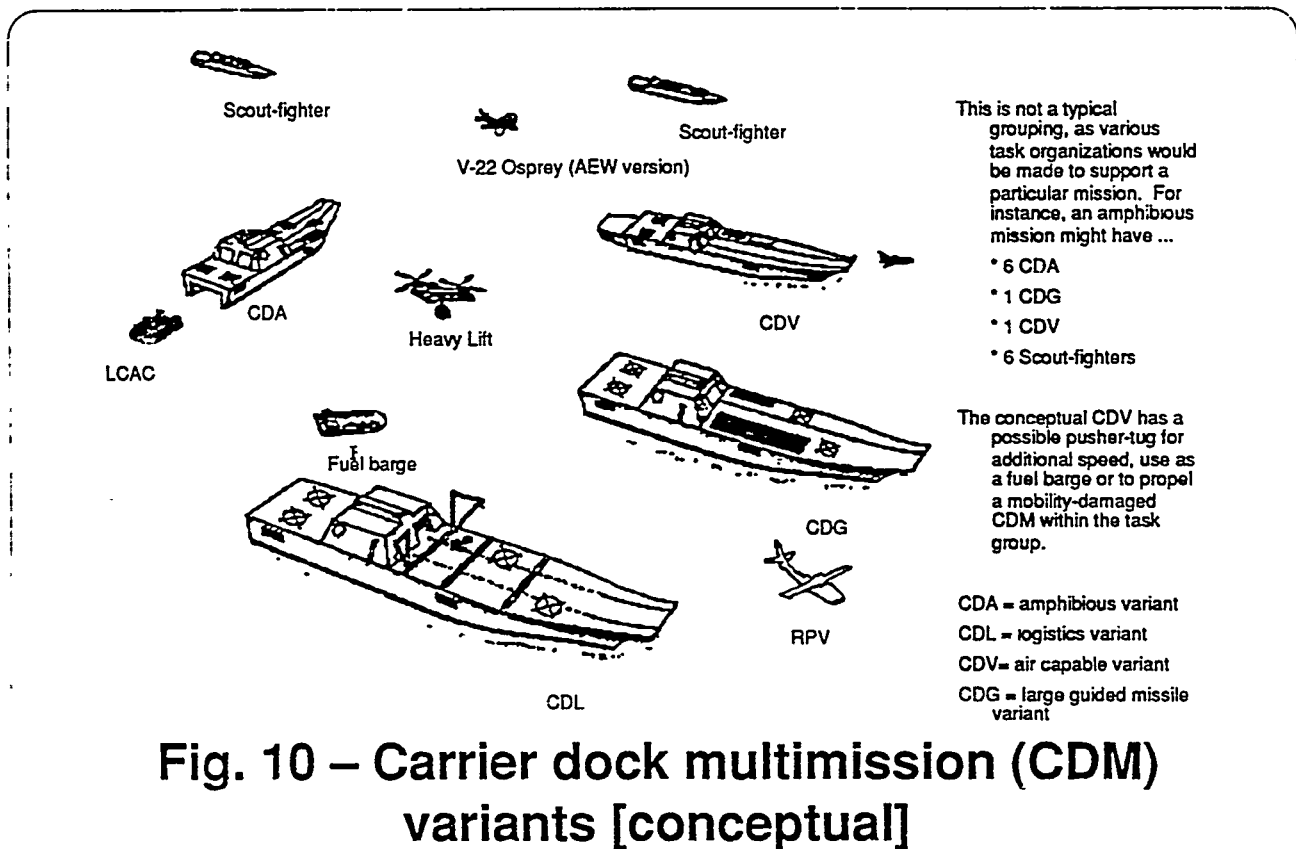
expand U.S. shipbuilding base thru repeats allowing shipyards to make significant capital improvements

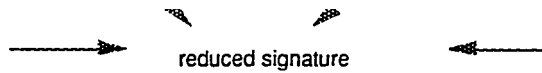
provide for improved ship availability through common subsystems

reduce logistics support through common subsystems and simplified logistics support shuttle

graceful, gradual transition from current fleet architecture to future fleet architecture as replacement ships phase in; flexibility to meet changing needs over the years

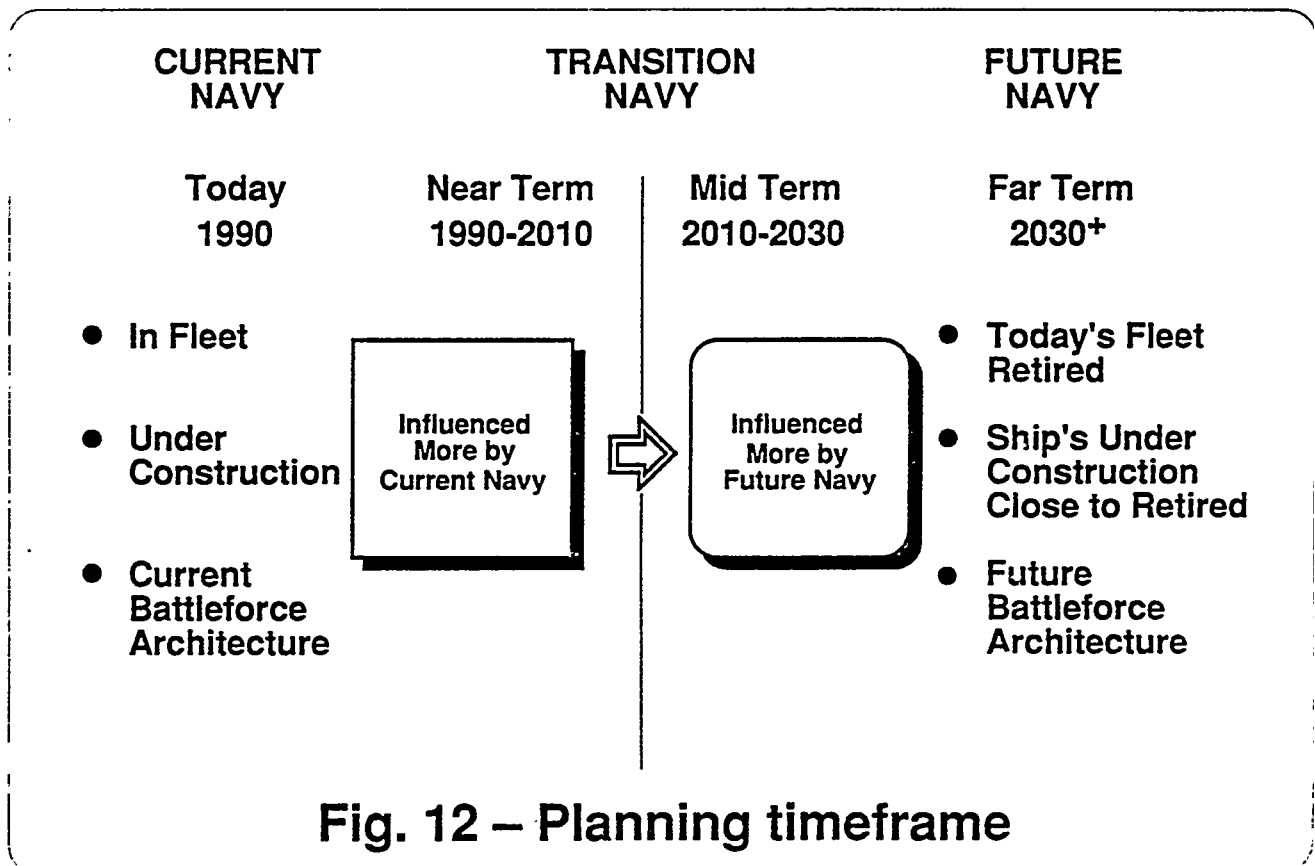
Fig, 9.- Why CDM?





- ◆ reduced discernibility
reduced discernibnility
- ◆ de-emphasize ship speed but maximize
weapon and scouting speed
- ◆ emphasize endurance and independence from external support
during mission
- ◆ well deck on all CLO's within taskforce opens alternate
replenishment schemes
- ◆ additional vertrep pads on all variants
expands operational use of VERTREP vice CONREP
- ◆ similarities of the variants permit multimission usage, ie
logistics variant for amphibious surge or amphibious variant in
logistics role

Fig. 11- Other features of CDM



Stabilized Number (+ reserves)	Class	Production Rate	Active Life (yrs)	Reserve Life (yrs)
8 (+2)	CVN	one every 5 or 6 years	45	10
8 (+2)	CGN	one every 3 or 4 years	30	10
19 (+5)	CDV	one every 1 or 2 years	35	10
42 (+12)	CDA	one or two every year	35	10
45 (+13)	CDL	one or two every year	35	10
19 (+6)	CDG	one every 1 or 2 years	30	10
2 (+1)	CDC	replacement	30	15
8 (+2)	CDF	one every 4 years	35	10
160 (+64)	SF	six or seven every year	25	10
311 (+107)				

- these numbers are CDM/SF replacements for current task force (CVBG, SAG, ATF, URG, CEG) only. Mine warfare, non-direct support logistics, repair/tender not included.

- ships with inherently hardmounted primary mission payload (CGN, CDG, CDC and SF) are assigned a shorter active life. Larger ships get a longer active life than smaller ships (notably the SF) as backfits and extensive modernizations are severely curtailed in favor of new construction. The CVN assumes SLEP at 30 yr point.
- the concept of flexible transition is used...first half of active life in highest threat environment, second half in lower threat, activated reserves to merchant escort and transport duties.

Fig. 15 – Postulated 2030 CDM/SF fleet makeup



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601 Pavonia Avenue, Jersey City, NJ 07306

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No. AP

Design Through Manufacture: A Computer Aided Advisor for the Manufacture of Submarine Hulls

Harry West, Visitor and Mike Gallo, Visitor, Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA

ABSTRACT

A computer graphics based advisory system has been developed to aid in the design and manufacture of submarine hulls. The design and manufacture advisor incorporates models of the materials (steel) and processes (bump forming, roll bending, welding, and fixturing) used for the manufacture of the hulls, and allows the user to explore the effect of different material qualities (described in terms of variances of thickness and yield strength), and different manufacturing parameters (punch penetration, punch spacing, and number of fixtures, for example) on the resulting quality (circuliuity) of the hull section. By "Designing through Manufacture" in this way the resulting design of the submarine hull section is not just a geometric representation of the desired shape of the hull, but incorporates explicit information about the materials and processes used to create the shape, and of the quality that results from the designer's choice of materials and processes.

INTRODUCTION

The design engineer is responsible not only for the fitness of the design for the function intended, but also for its cost and ease of manufacture. The designer cannot "throw the design over the wall" to manufacturing and hope that they will find a way to make the part to print, but must be responsible for designing the part to facilitate manufacture, and assembly.

Design engineers have to understand the manufacturing implications of design decisions. However, considerable experience is needed for a design engineer to gain such an understanding. Often the interaction between the design and the manufacture of the part is complex and product specific, and is a type of knowledge not generally featured in an engineering student's curriculum. Design engineers gain such knowledge on-the-job; by trial and error, and from more experienced coworkers or their supervisor. On-the-job training is expensive; there is a need for computer-aided-design tools to provide an alternative route for learning the complex details of how the design of a part affects its manufacture, and to enable less experienced designers to produce designs that are manufacturable.

There has been considerable interest in developing such manufacturing advisory systems [Jakiela and Papalambros 1985, Desa et al. 1987]. However, most of these developments have concentrated primarily on the purely geometric characteristics of the parts and their effect on the ease with which the parts can be assembled, without regard for the manufacturing process used to

produce the part itself. In this paper a Design through Manufacture (DTM) advisory system is described that provides the designer with explicit feedback of the interaction between the design of the part and the manufacturing process used to produce the part.

Design Through Manufacture

Conventional computer-aided-design tools allow the designer to create parts geometrically without explicit consideration of the manufacturing process used to produce the part. Some more recent developments in Computer-Aided Engineering (CAE) provide the designer with feedback of an estimated cost of the part based on the tolerance specified (Cognition 1988), but the costing is done after the geometric feature is designed.

The philosophical basis for Design through Manufacture is that the starting point for any design should be readily available materials, and that the designer should manufacture the part by performing a computer simulation of the manufacturing process. The designer cannot suppose the geometry of a part on the CAD screen, but must manufacture the geometry. Secondly, the models of the engineering materials and the manufacturing process should not be idealized, but be realistic representations of the materials and processes available. The computer simulation of the manufacturing process should perform the manufacturing operation on the computer with the same tolerance and 'quality' that would be expected on the factory floor. In this way the designer can visualize the effect of design decisions on the effort required to manufacture the part, and the effect of the manufacturing process on the cost and quality of the real part.

A computer model of a part designed through manufacture can include explicit descriptions of the "raw material" used in its manufacture, of how the part was manufactured, and its expected tolerances and quality. Because all information pertinent to the design and manufacture of the part is included in the description of the part, the effect of any changes in a design or manufacturing parameter on the subsequent stages of design and manufacture can be readily simulated.

There is a recognized need for incorporating interactive design aids into the design process, and many design engineers welcome intuitive tools that can aid their design process. [Zeid 1987, Grant 1987]. One of the earliest examples of a Design through Manufacture system was developed in 1975 [Gossard 1975], but the computational complexity of modelling real manufacturing processes has inhibited the continued development of such systems.

The Manufacture of a Submarine Hull Section

The example of the manufacture of a submarine hull has been chosen for the development of this Design through Manufacture system. The circular geometry simplifies the system. A simplified cartoon of the manufacturing process for a submarine hull is shown in Figure 1. The process can be divided into the following stages:

- Select steel
- Cut steel plate to size
- Bend plate into arc
- Fixture plates for assembly into circular hull section
- Assemble plates (weld)
- Fixture hull section for assembly with a second section to remove out-of-roundness
- Assemble hull sections (weld)

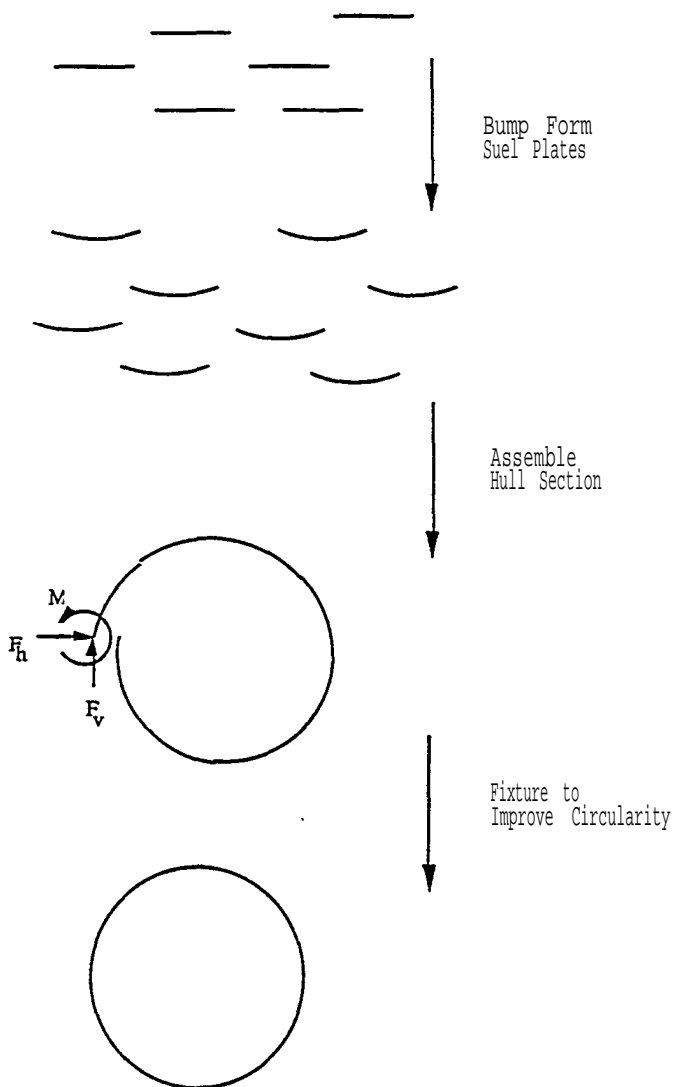


Figure 1: Sketch of Idealized Hull section ,

The hull sections are manufactured from steel plates, HY-80 Armor Plate Steel [Alloy Digest 1966], supplied directly from the steel mill. Material properties of the

input stock can vary from plate to plate, and from point to point on the same plate. Properties such as grain structure, alloy content, and yield strength will vary due to process variances in the manufacture of the steel. Localized stress can result from the rolling mills and heat treatment of the plate. Flame and plasma cutting methods are used to cut plates to size. The heat input will relieve the residual stresses in the heat affected zone and may result in workpiece distortion. The amount of distortion depends on the residual stresses present in the workpiece, the variation in the amount of heat generated by the cutting heat source, and the rate of cooling of the workpiece after cutting.

The hull section of a submarine is circular, assembled from 8 curved steel plates. The steel plates are formed into arcs by bump forming or roll bending. Strain hardening, plate thickness, maximum moment point location, and machine geometry may vary and affect the resulting curvature. Sequential bending, also called bump forming, applies a three-point bending moment at discrete intervals along the length of the workpiece. A sketch is shown in Figure 2. The plate is placed on a stationary die, with a spacing of $2a$. The punch is displaced the distance y_p , referred to as the punch penetration. When the punch is retracted, the plate will partially springback. This process is repeated at a series of points along the length of the plate and results in a finished shape that approximates a smooth curve. The mechanics of this process are discussed in [Hardt Wright and Constantine 1989].

The United States Navy imposes strict requirements for the dimensional tolerances of submarine hull contours. A typical circularity tolerance for a submarine hull is approximately $\pm 1/2$ in. on a diameter of 42 feet. Circularity measurements are required at regular intervals along the pressure hull, and each point must be within the specified tolerance. A sketch of a hull section without stiffeners, is shown in Figure 3. Methods allowed by Navy specifications to take circularity measurements include the bridge gauge method, internal swing arm, internal radii, method of optical squares, the external template, and photogrammetry [Jacobson, 1985].

In addition to the Navy specified tolerances for final configuration, there are fit-up requirements for the assembly and welding of the hull segments. Excessive mismatch at the weld joint will require additional time and expense for fitting and fairing methods to be applied to allow proper welding. Problems encountered during the manufacturing of submarine hulls due to workpiece deviation from nominal include "chasing the bubble" while assembling two hull segments. As the weld progresses, the local mismatch is corrected by fitting and fairing methods. If there is an excessive mismatch between the two hull segments being joined, an uncorrectable "bubble" will develop that must be cut out before the assembly weld can be completed. Ideal manufacturing processes result in no residual stresses in the material, and yields dimensionally perfect parts, eliminating the need for fitting and fairing. Existing manufacturing capabilities do not allow this goal to be achieved.

SYSTEM OUTLINE

The Design through Manufacture advisor is a graphics based system developed using X-windows on a UNIX based VAXstation II with a black and white monitor. The programming is written in the "C" language, and comprises approximately 3000 lines of code and comments.

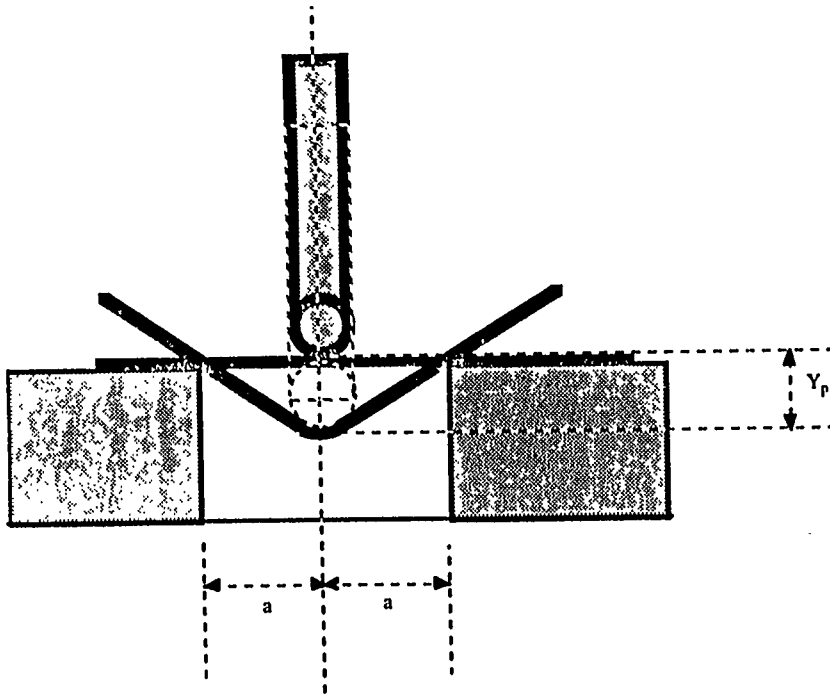


Figure 2: Bump Forming Geometry

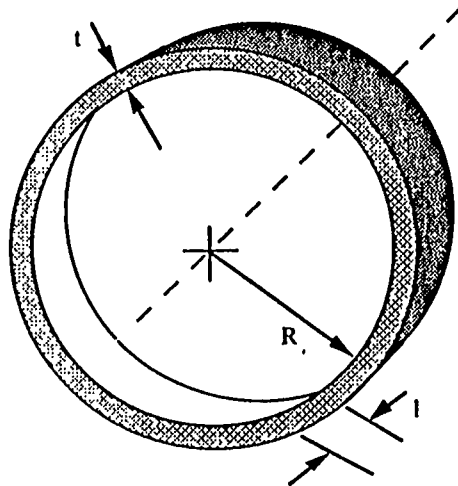


Figure 3: Sketch of a Submarine Hull Section

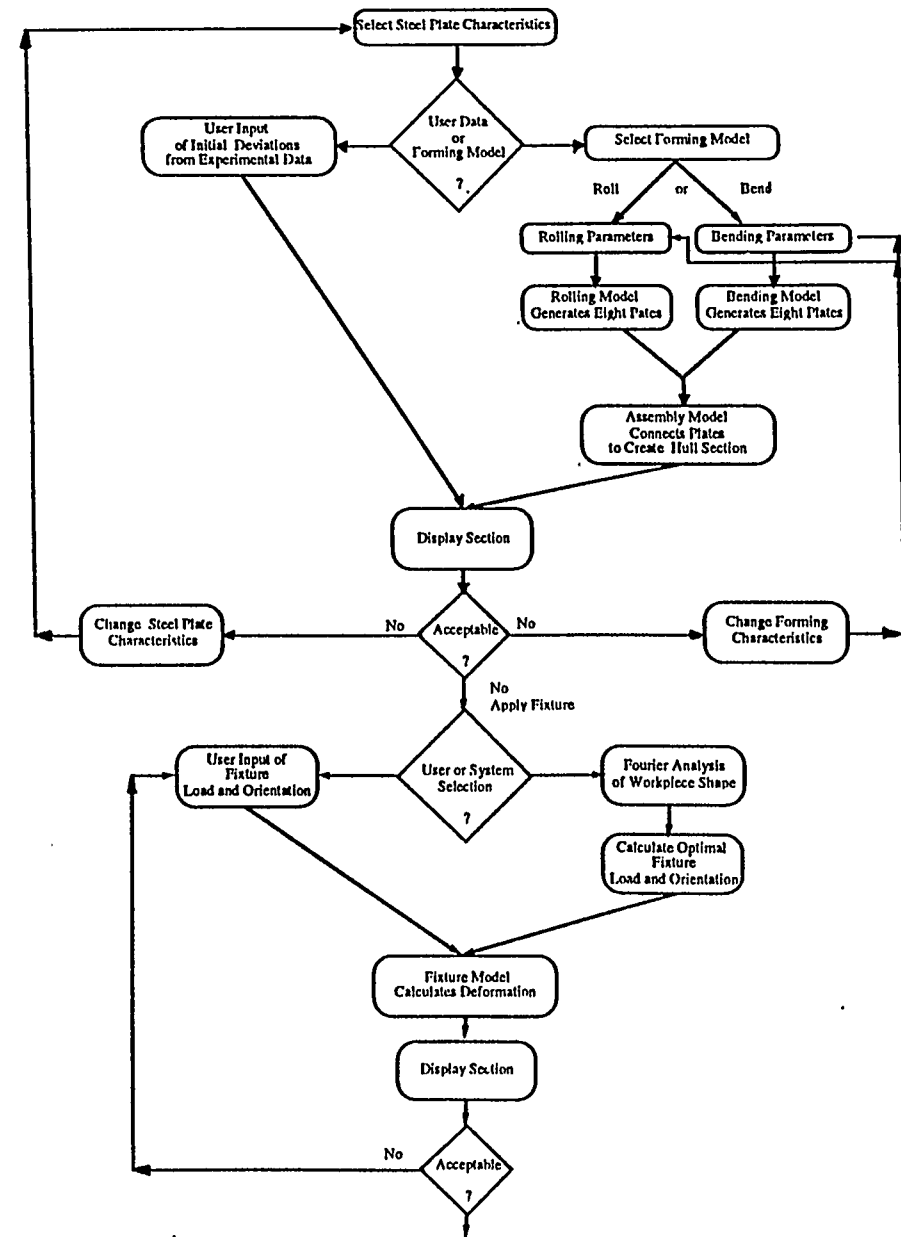


Figure 4: Overview of Manufacturing Advisor System

The system facilitates user interaction with the bending and rolling models developed by [Hardt, Wright and Constantine 1989], facilitates the display of experimental out-of-roundness data, and helps the user to design fixtures to improve the roundness of the submarine hull sections. An overview of the manufacturing advisor system is shown in Figure 4. The manufacturing advisor allows the design engineer to "experience", through computer simulations, the impact of design decisions on the manufacturing process, and to optimize manufacturing decisions based on the process models. Currently a simplified model of the hull assembly process is used that does not incorporate stiffening flanges.

The inputs to the system are the characteristics of the steel plate in terms of its geometry (thickness) and material properties (modulus of elasticity, yield strength, strain hardening behavior), and the expected tolerance in those characteristics. The geometry of a hull section can then be created either from experimental measurements or by using the rolling or bending models described in a companion paper [Hardt, Wright and Constantine 1989]. The geometry of the rolling or bending processes can be specified interactively by the user, as can the allowed variation in output (a measure of the quality control standard on the forming process). The output of the forming models is eight plates of different curvatures. The different plate shapes are generated by creating a stochastic distribution of steel plate characteristics that might be expected from the allowed tolerances in the specification of HY80, and propagating the effects of these characteristics through the forming process. Plates that exceed the quality control limits are rejected.

The eight plates are then assembled by butting them together so that their tangents match to give a smooth continuous curve, and then applying a combination of forces and moments to the last two free ends to complete a hull section. This process is sketched in Figure 1. As a result of the non-uniformity of the curvature of the eight plates the hull section is out of round.

The out-of-roundness of a hull section can be improved by changing the steel plate characteristics, by changing the forming parameters, or by applying a fixture. The steel plate specifications can be changed to allow a smaller variation in geometry or material characteristics. Alternatively, the forming processes can be modified so that variations in the steel plate characteristics result in smaller variations in the resulting curvature of the eight curved plates, or the quality control on the output of the forming process can be tightened so that only more uniform plates are assembled into hull sections.

The manufacturing advisor currently allows the user to design 2-, 3- and 4- point fixtures, or alternatively, the system will automatically generate a series of such fixtures to minimize the out-of-roundness of the hull section in the least squares sense. The out-of-roundness is described in terms of Fourier coefficients by treating it as a purely radial distortion. By matching Fourier coefficients of the out-of-round shape of the hull section to the Fourier coefficients of the deflections caused by applying different types of fixtures, the orientation and load of a set of fixtures is designed to optimize the resulting shape of the hull.

The plate assembly model and fixturing distortion models have been developed based on a simplified elastic analysis for small deflections. The models assume that the section radius is large compared to the thickness of the plates. that the deflections can be described as small

deviations from a circular geometry, negligible hoop stress, and that the maximum stress is below the yield point of the material.

The manufacturing advisor graphically displays in 2-D the hull segment's initial shape and the change in the shape due to fixturing. The design shape and allowable deviations are overlaid for comparison. An examples taken from an interactive session working with the fixturing model are shown in Figure 5.

SYSTEM DESCRIPTION

The manufacturing processes modeled are:

- 1 Bump forming of plates
- 1 Roll bending of plates
- 1 Assembly of plates into closed cylinder
- 1 Fixturing to reduce circularity errors

The design parameters that may be varied are given in Table 1

Table 1: Design Parameters

1. The physical dimensions of the segment
 - a. Radius to midplane
 - b. Thickness of plate and variance
 - c. Axial length of segment
 - d. Contour limit
2. The material Properties
 - a. Modulus of Elasticity
 - b. Yield strength and variance
 - c. Strain hardening modulus/Modulus of Elasticity ratio
3. The initial deviations from true geometry
4. The forming model parameters
 - a. Punch penetration
 - b. Machine geometry
 - c. Quality control on plate curvature
5. The fixture loading conditions
 - a. The angle relative to the vertical axis for future load application for each future
 - b. The load magnitude for each fixture

Forming of Plates

Forming models have been developed for bump forming [Hardt, Wright and Constantine 1988] and roll bending [Wright, 1988]. These models, based on given material properties, plate geometry, and machine geometry, predict the final shape of the formed plate. Statistical models of parameter variations are used as input for these models. Parameters are given a uniform probability distribution within the material specification. The resultant output is formed geometry that varies stochastically from the nominal geometry.

Assembly Model to Close Cylinder

A hull segment is assembled from 8 formed plates. The variations from desired geometry, given by the forming models, will result in deviations from a true circle after assembly. It is assumed that the plates are attached together such that the plates form a smooth, continuous curve. As shown in Figure 1, the variations in plate curvature will result in a gap between the free end of the first plate and the free end of the last plate.

To butt the two ends together tangentially, the force

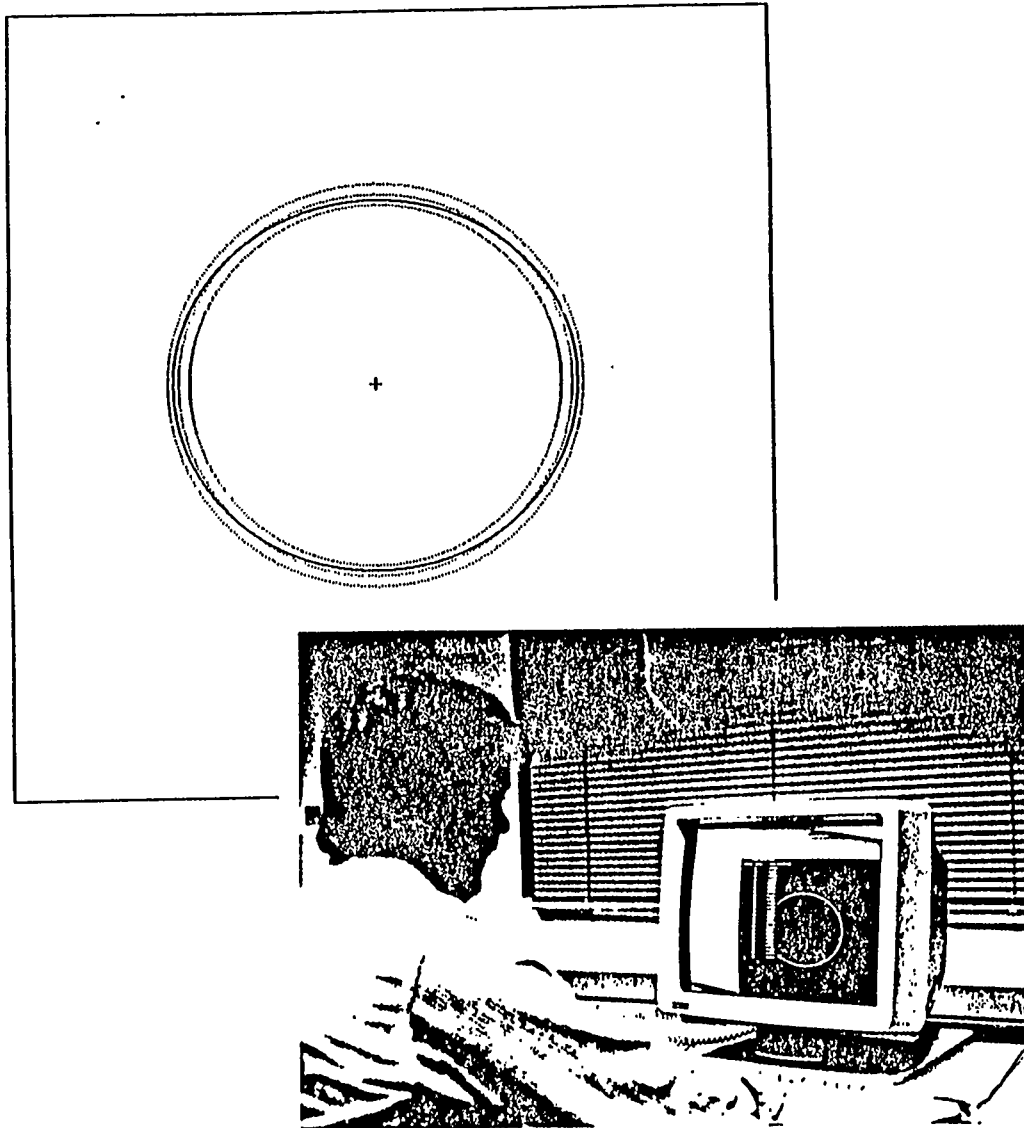


Figure 5: Examples of Interactive Session with Manufacturing Advisor

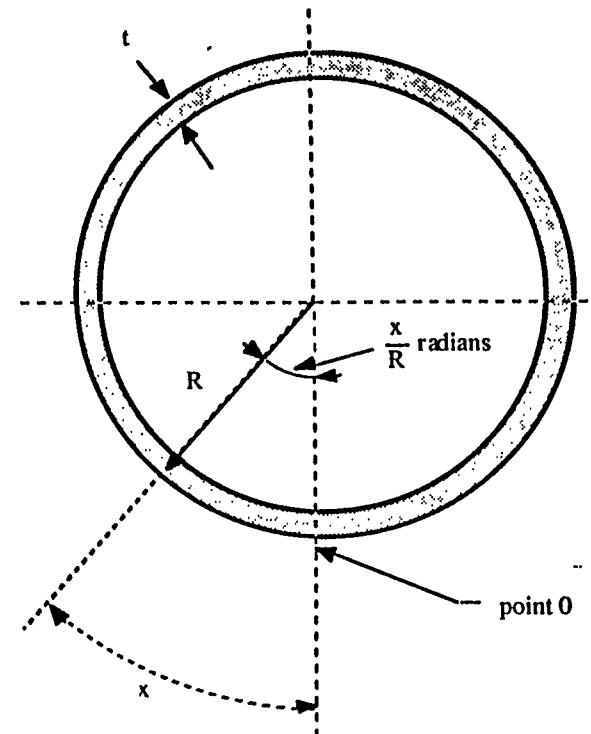


Figure: 6 Cylindrical Ring Hull Segment Model

components V and H , and the moment M_0 , shown in Figure 1, are applied to the ends. The radial gap, Δy , the tangential gap, Δx , and the angular mismatch, are derived in terms of the unknown force and moment components using Castigliano's Theorem [Roark, 1975]. These equations can then be solved for V , H , and M_0 .

The submarine hull segment is modelled as a cylindrical ring, as shown in Figure 6 below.

The distance circumferentially along the neutral plane of the plate from point 0 is described by x , R is the radius to the neutral plane of the plate, x/R is the angle, in radians, from the diametral line through point 0 to the point at distance x , and r is the thickness of the plate.

Assuming that the shape of the hull section can be modelled by small deviations from this idealized cylinder the forces and moments necessary to assemble the two free ends together can be calculated along with the resultant deflection of the hull section. The output of this part of the elastic model is a closed cylinder with known initial deviations, out-of-roundness, from the desired shape.

Applying Castigliano's Theorem [Gallo 1988], the radial force, V , is given by:

$$V = \frac{\Delta y E I}{\pi R^3} \quad (1)$$

The tangential force, H , is given by:

$$H = \frac{E I}{(3\pi - 2) R^3} \left(\Delta x - \frac{\Delta \theta R}{\pi} \right) \quad (2)$$

and the applied moment, M , is given by:

$$M = \frac{\Delta \theta E I - 2\pi H R^2}{2\pi R} \quad (3)$$

The reactions V , H , and M_0 necessary to connect the two free ends are solved for using Equations [1], [2], and [3], and the resultant radial deflection is given by:

$$\begin{aligned} \frac{\partial U}{\partial V_0} = & \frac{1}{EI} \left\{ \left[\left(-M_0 R^2 - V R^3 \pi - H R^3 + \frac{H}{4} R^3 \right) \cos \left(\frac{x_0}{R} \right) \right. \right. \\ & + H R^3 \pi \sin \left(\frac{x_0}{R} \right) \left. \right] - \left[-M_0 R^2 - H R^3 \right. \\ & + \left(V R^2 \left(\frac{x_0}{2} - \frac{R}{4} \sin \left(\frac{2x_0}{R} \right) \right) \right. \\ & + \frac{H}{4} R^3 \cos \left(\frac{2x_0}{R} \right) \left. \right] \cos \left(\frac{x_0}{R} \right) \\ & \left. + H R^2 \left(\frac{x_0}{2} + \frac{R}{4} \sin \left(\frac{2x_0}{R} \right) \right) \sin \left(\frac{x_0}{R} \right) \right\} \quad (4) \end{aligned}$$

Fixturing for Assembly

Prior to welding two hull sections, the out-of-roundness of the hull section must be reduced. Fitting and fairing of

components for assembly may account for up to 25% of the fabrication costs of large structures [Moshaiov 1988]. Fitting and fairing aids are used to align mating, workplaces for proper welding fit-up. Fitting and fairing aids in common use in U.S. shipyards are described by Macial 1984]. The devices modeled for application to submarine hull segment circular deviations are those capable of two-point diametral loading and three-point radial loading, such as hydraulic rams, come-alongs, and push-pull jacks.

cylindrical structure under two-point diametral loading shown in Figure 7 below.

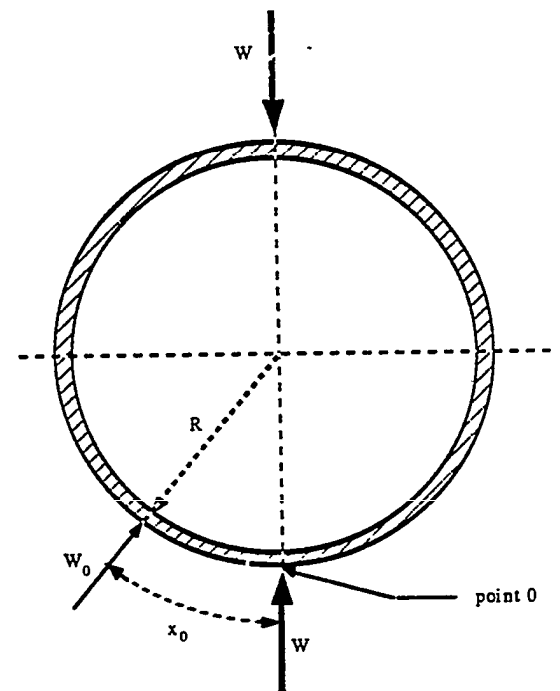


Figure 7: Two-point Diametral Loading

The radial deflection of each point x , is given by:

$$\begin{aligned} \frac{\partial U}{\partial W_0} = & \frac{R^2 W}{EI} \left[-\cos \left(\frac{x}{R} \right) \left(\frac{x}{R} - \frac{R}{4} \sin \left(\frac{2x}{R} \right) \right) - \frac{2}{\pi} \right. \\ & \left. + \left(\frac{R}{\pi} + \frac{R \pi}{8} \right) \cos \left(\frac{x}{R} \right) + \frac{R}{\pi} \sin \left(\frac{x}{R} \right) \right] \quad (5) \end{aligned}$$

Similar equations have been developed for three and four point loading [Gallo 1988].

Fourier series Description of Fixture Loading

The deviation of the actual hull segment from the desired

shape can be described by the equation:

$$f(x) = r(x) - R \quad (6)$$

where $r(x)$ is the actual radius at circumferential point x , R is the nominal radius, and $f(x)$ is the deviation. For a closed circular hull segment, $f(x)$ will be periodic, and can be decomposed into its Fourier series components. If we assume that $f(x)$ is known for a discrete number of points, m , then the coefficients of the series can be evaluated numerically [Acton, 1970]:

$f(x)$ is given by:

$$f(x) = \frac{a_0}{2} + \sum_{n=1}^N b_n \sin(n x) + \sum_{n=1}^{N-1} a_n \cos(n x) \quad (7)$$

The components a_k and b_k can be converted to their magnitude and phase components; the magnitude component is given by:

$$c_k = \sqrt{(a_k)^2 + (b_k)^2} \quad (8)$$

The phase component is given by:

$$\phi_k = \tan^{-1} \left(\frac{b_k}{a_k} \right) \quad (9)$$

The Fourier Series Decomposition for two-point fixture loading is shown in Table 2. The fundamental, the component with n equal to the number of fixture points, is significantly larger than the other components:

Table 2: Fourier Series Decomposition for a Two-point Fixture

Number (n)	C_n (in.)	ϕ_n (Deg)
0	3.4×10^{-5}	0.0
1	-3.6×10^{-17}	1.94
2	-7.2×10^{-4}	-0.656
3	-1.6×10^{-16}	-2.512
4	-5.5×10^{-5}	-1.311

To demonstrate the Fourier decomposition, a hull segment is analysed with initial deviations from a nominal radius of 192 in., as shown in Table 3. A smooth curve has been fitted through these points with the Cardinal Spline Formulation.

Table 3: Initial Deviations of Hull Segment

Angle (Deg.)	Initial Dev. (in.)
0	-1.0
45	0.0
90	1.0
135	0.0
180	-1.0
225	0.0
270	1.0
315	0.0

The result of the Fourier Series Decomposition of these initial deviations is shown in Table 4:

Table 4: Fourier Series Decomposition of Out-of-Roundness

Number (n)	C_n (in.)	ϕ_n (Deg)
0	1.9×10^2	0.0
1	1.0×10^{-2}	18.1
2	1.0×10^0	-0.6
3	1.9×10^{-2}	53.8
4	1.7×10^{-1}	71.4

In order to compensate for a given out-of-roundness Fourier series component, a fixture must be chosen that has a significant component of the same period, and oriented so that the phase angle of the fixture Fourier series component at the desired period matches the phase angle of the out-of-roundness Fourier series component. The fundamental of the Fourier series components is much larger than the other components so the effect of the fixture loading can be approximated as:

$$\begin{bmatrix} D_1 & 0 & 0 & 0 \\ 0 & D_2 & 0 & 0 \\ 0 & 0 & D_3 & 0 \\ 0 & 0 & 0 & D_4 \end{bmatrix} \begin{bmatrix} W_1 \\ W_2 \\ W_3 \\ W_4 \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \\ c_3 \\ c_4 \end{bmatrix} \quad (10)$$

where D_i is the magnitude of the fundamental of the Fourier series component for a unit fixture load, and W_i is the fixture load. The magnitudes of the fundamentals of the Fourier components for two-, three-, and four-point fixtures are given in Table 5:

Table 5: Magnitude of Fundamental Fourier Series Components

Component	Magnitude
D_2	7.2×10^{-4}
D_3	2.1×10^{-4}
D_4	1.1×10^{-4}

The fixture loading, W_i , can be calculated directly by inverting equation (12). For the example shown in Tables 3 and 4, the optimal fixture loading is:

Table 6: Calculated Fixture Loading

Fixture Type	Angle (Deg)	Load (lbs)
Two-point	-0.3	-1413.25
Three-point	17.9	-88.606
Four-point	17.8	155.031

If the fixture loading shown in Table 6 is applied to the hull segment with initial deviations as shown in Table 3, the resulting final deviations from nominal radius are shown in Table 7, which are within spec.

Table 7: Final Deviations of Hull Segment

Angle (Deg.)	Final Deviation (in.)
0.	-0.07
45.	-0.13
90.	0.15
135.	-0.10
180.	-0.03
225.	-0.10
270.	0.13

USER INTERFACE

The interactive graphics program is to be used as an analysis tool by design engineers to determine the effect of design decisions on the manufacturing process. The design parameters that maybe changed have been listed in Table I.

The program graphically outputs the resulting deflections of the workpiece as each design change is made, allowing immediate evaluation of the change's impact. The workpiece's geometry is graphically displayed by exaggerating the out-of-roundness errors so that they can be readily perceived by the designer, and the contour limits are plotted on the same scale to allow comparison with the design tolerances, as shown in Figure 8.

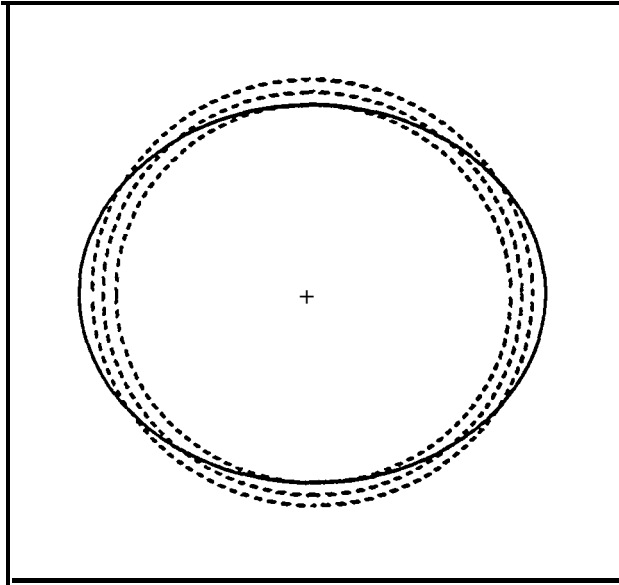


Figure 8: Graphical Display of Initial Deviations

The program is designed to be interactive with the user, and will prompt the user to make key decisions. The program is menu driven, and displays a menu listing several choices. The choices will either 1) lead to a submenu 2) perform a desired function or 3) go back to a higher level menu. The user selects the desired option by placing the mouse cursor in the box adjacent to the choice and pressing any button on the mouse.

Changing any design parameter will cause the program to recalculate the new shape of the hull section using the existing fixture loading conditions and graphically display the results. To view the numerical values of the final deflection, the user chooses the "Display Final Deflections" option from the "Main Menu". The program will then overlay the numerical values on top of the graphical display, as shown in Figure 9.

CONCLUSIONS

A computer graphics based advisory system has been developed to aid in the design and manufacture of submarine hulls. By "Designing through Manufacture" in this way the resulting design of the submarine hull section is not just a geometric representation of the desired shape of the hull, but incorporates explicit information about the materials and processes used to

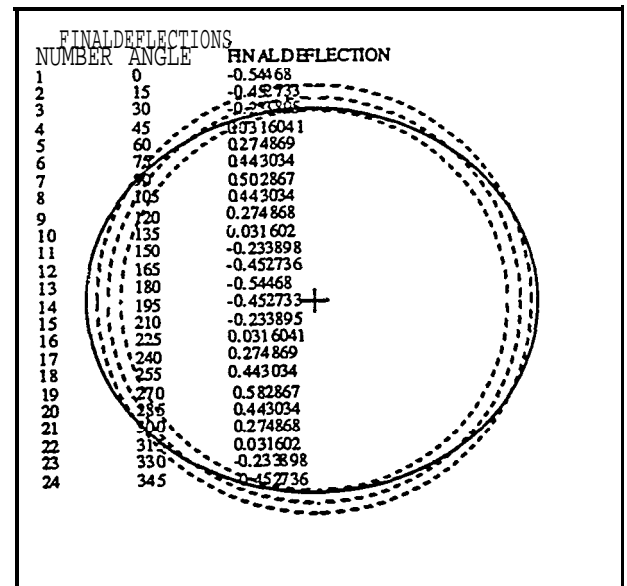


Figure 9: Display of Final Deflections

create the shape, and of the quality, as measured by the out-of-roundness of the hull, that results from the designers choice of materials and processes. The interactive graphics program provides a convenient tool for the design engineer to analyze the impact of his or her decisions on the manufacturing process. By using this tool, potential problems faced by the manufacturer can be recognized at the design stage, and may be ameliorated by selecting alternative materials or processes. TM advantages of Design through Manufacture are:

- It is not possible to design parts that cannot be manufactured
- The designer understands the effect of his design decisions on the manufacture of the part and on its quality
- The designer can be assisted by the computer to explore different design and manufacture options
- The effects of materials and processes on tolerances are explicit
- The cost of the design can be made explicit

The system that has been developed is an incomplete prototype, and does not include all materials or process that the designer might consider. In particular, it does not include models of flame-cutting or welding processes. As an incomplete system it limits the freedom of the designer and may give misleading results.

Future development is directed at incorporating more materials and processes into the system but is limited by the lack of available process models. To be useful as a design aid process models must be sufficiently faithful to the process to provide meaningful results, and yet run sufficiently quickly that they can be used interactively. The development of fast process models is an area of current research [Eager and Moshalov 1988]

An important use of Design through Manufacture systems will be in education. The problem in design education is feedback working interactively with a DTM system is a way for design engineers to accelerate their learning experience, allowing the designer to make mistakes with silicon instead of steel.

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