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FACILITIES AND ENVIRONMENTAL EFFECTS
SURFACE PREPARATION AND COATINGS
DESIGN/PRODUCTION INTEGRATION
HUMAN RESOURCE INNOVATION
MARINE INDUSTRY STANDARDS
WELDING
INDUSTRIAL ENGINEERING
EDUCATION AND TRAINING

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1987 Ship Production Symposium

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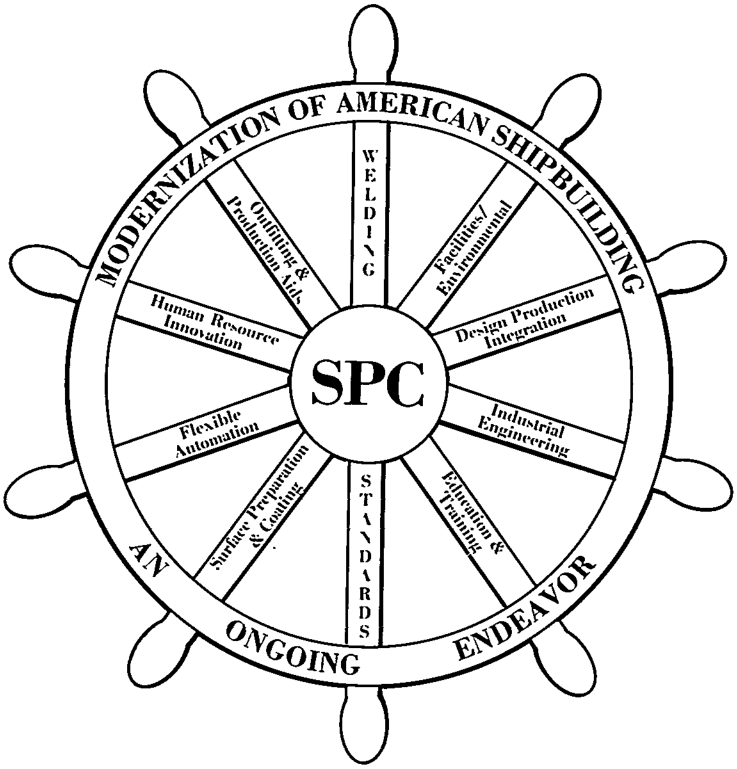

AUGUST 26-28, 1987
HYATT REGENCY HOTEL
New Orleans, Louisiana

HOSTED BY THE GULF SECTION OF THE
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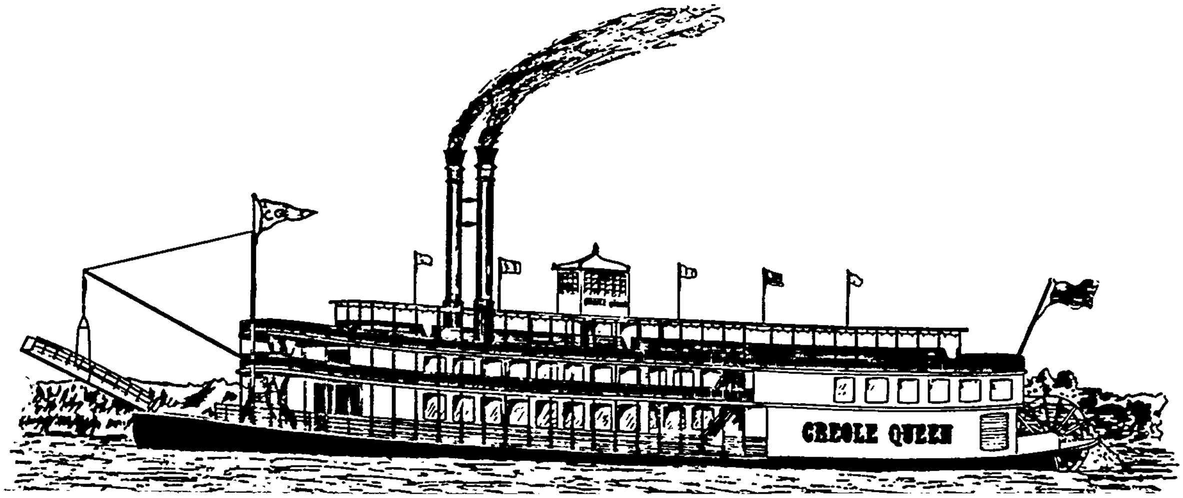

NSRP
1987 SHIP PRODUCTION SYMPOSIUM

HYATT REGENCY HOTEL
New Orleans, Louisiana
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Presented by the Gulf Section
and the Ship Production Committee
of the Society of Naval Architects
and Marine Engineers

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FOREWORD

This volume contains the texts of twenty-nine (29) technical papers presented during the 1987 Ship Production Symposium, hosted by the Gulf Section, Society of Naval Architects and Marine Engineers.

The meeting was held at the Hyatt Regency Hotel in New Orleans, Louisiana, from August 26 to August 28, 1987.

We are very pleased to report that ten of the eleven Ship Production Committee panels are represented by papers. Likewise, the participation of many shipyards has been dramatic, with the likes of Avondale, Bath, Electric Boat, IHI, Ingalls, NASSCO, Newport News, Pearl Harbor, and Puget Sound all contributing papers. Additional thanks to the following organization who also supported their people in preparing technical papers for the Symposium; ABS, A&P Appledore, Advanced Marine Enterprises, Deutsch Metal Components, International Federation of Professional and Technical Engineers, Massachusetts Institute of Technology, Naval Sea Systems Command, Ocean City Research, Penn State University, Standards International, University of New Orleans, University of Michigan, University of Washington, and Welding Engineering Services.

The Chairmen of the Steering and Technical Program Committees of the 1987 Ship Production Symposium wish to thank all committee members who worked so diligently to make this meeting a success. On behalf of the Gulf Section of the Society of Naval Architects and Marine Engineers, we extend our sincere thanks to all those who supported this meeting as authors, discussers, moderators, and attendees.

John P Hackett

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THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
601 Pavonia Avenue, Jersey City, NJ 07306
Paper presented at the NSRP 1987 Ship Production Symposium, Hyatt Regency Hotel, New Orleans, Louisiana, August 26-28, 1987

IHI's Experience of Technical Transfer and Some Considerations on Further Productivity Improvement in U.S. Shipyards

No. 2

Hiroshi Sasaki, Member, Ishikawajima-Harima Heavy Industries Co., Ltd. (IHI), Japan

ABSTRACT

Ishikawajima-Harima Heavy Industries Co., Ltd. (IHI), a leading shipbuilder in Japan, has uniquely exported shipbuilding technology throughout the world for three decades. The North American efforts, starting in the mid seventies, were stimulated by the U. S. Government/Industry National Shipbuilding Research Program (NSRP). The technology transfer, for which the U.S. Maritime Administration (MarAd) deserves much credit, has significantly modernized and improved U.S. shipbuilding systems with carryover into naval shipyard operations for overhaul of all types of warships. But, productivity levels achieved thus far in the U.S., while impressive, are not nearly as great as those in Japan.

This paper is based on analyses of the underlying differences of shipbuilding systems, technology, and practices between those in Japan and in the U.S. Hopefully, descriptions of the state-of-the-art IHI technology will serve as guidance for further productivity improvements in the U.S.

1. INTRODUCTION

The history of Japanese modern shipbuilding technology began when National Bulk Carriers, Inc. (NBC), an American corporation, leased the former naval dockyard in Kure after World War II. NBC brought to Japan the block construction method and the welding technology which made block construction possible, i.e., the most modern American rationalization of shipbuilding that then existed. Dr. H. Shinto, who had worked as the Chief Engineer under Mr. E. L. Hann the NBC team leader, systematized all the new elements so as to contribute to the development of the Japanese shipbuilding industry as it now exists (1). This is the modern Japanese shipbuilding technology which, starting in 1978, is being returned to the U.S. in a highly developed form.

But command of the transferred technology can be further improved in terms of productivity. From an IHI manager's viewpoint, the improvement effort should be focused not only on the technical elements, but also on human management. When the American shipbuilding technology was transferred to Japan, Japanese managers learned not only the technical aspects, but also something of the American pioneer spirit which contributed to later innovations in Japan.

Now, even after facility modernization consistent with a modern shipbuilding method, IHI systematically and routinely improves productivity as discussed herein.

2. PRODUCTIVITY IN JAPANESE SHIPBUILDING

2.1 CHANGES IN PRODUCTIVITY

In the latter half of the 1950s, Japanese shipbuilding tonnage became the largest in the world. Responding to the demands for larger tankers and bulk carriers, the industry promoted further modernization and expanded its facilities during the 1960s. By the beginning of the 1970s most major Japanese shipbuilding companies had yards which could construct ships of 500,000 - 800,000 DW tons.

By this time, the block construction method and zone outfitting method were highly developed by exploiting the principles of Group Technology. In other words, the decade starting in 1963 marked what may be called the golden period for shipbuilding technology development. Then, the rate of productivity increase and levels of productivity achieved were unprecedented.

Figure 1 summarizes the history of modern shipbuilding in Japan starting with the NBC Kure operation.

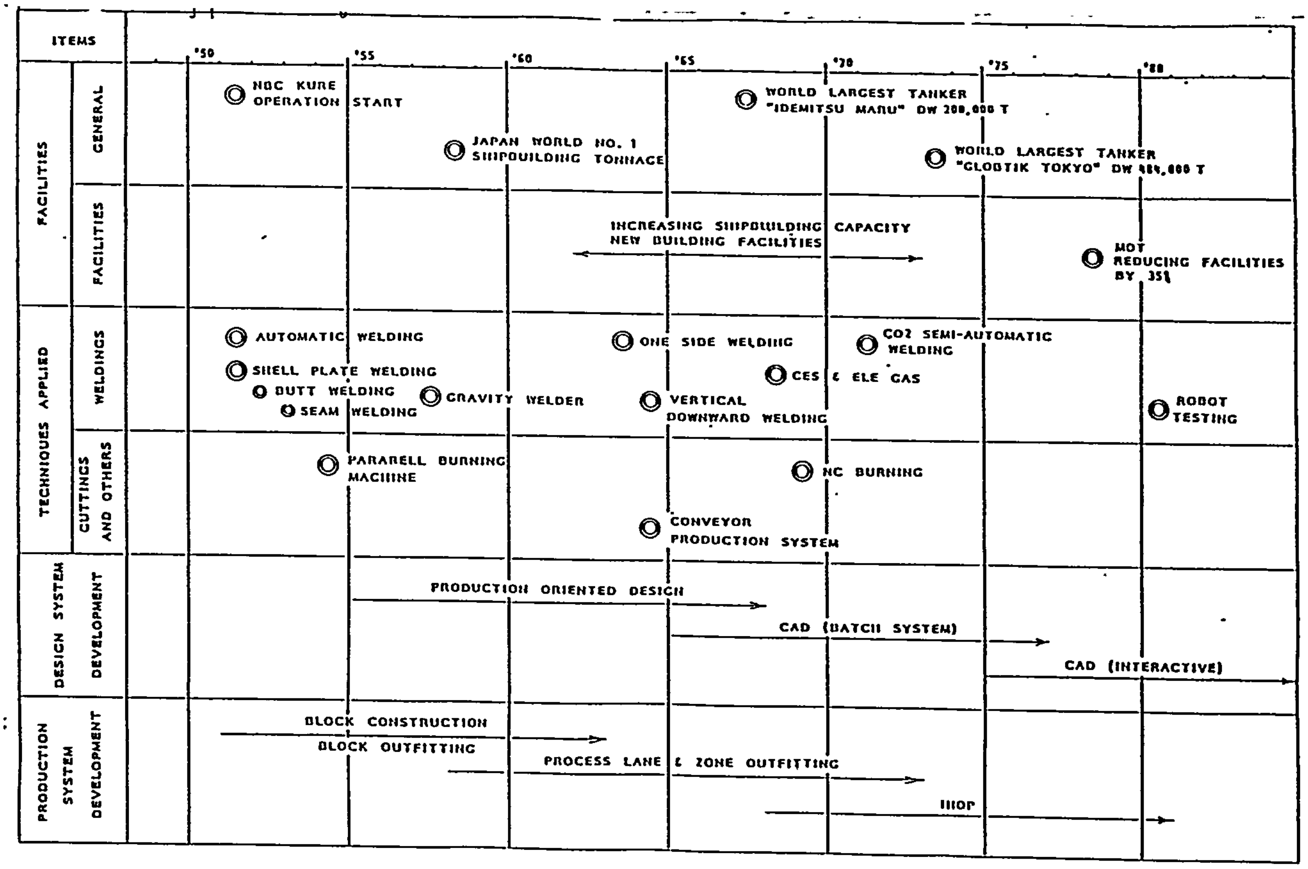


Figure 1. History of Japanese shipbuilding technology (1951-1985)

Following the 1973 oil shock the Japanese shipbuilding industry was confronted with a continuing crisis due to Japanese decline in demand. In 1978 the Japanese Ministry of Transport advised the industry to reduce shipbuilding facilities by 35 percent. Thus, some of the newly constructed large yards were converted into plants building products other than ships without full utilization of their modern facilities.

Development of the Korean and Taiwanese shipbuilding industries also contributed to the further decline of the Japanese shipbuilding industry. The competition for orders became increasingly more severe. In order to survive in this environment, cost reduction measures have become very important. IHI, no exception, is trying to survive by exerting all possible efforts for, and has made some progress in reducing costs significantly.

Figure 2 indicates the world shipbuilding tonnage completed from 1970 through 1985. As it is based on completions, the figure reflects demand trend with a time lag of about 2 years. After a peak in 1975 construction rapidly declined, reaching a nadir in 1980. As the figure shows, immediately afterwords, building tonnage for the Korean industry increased noticeably.

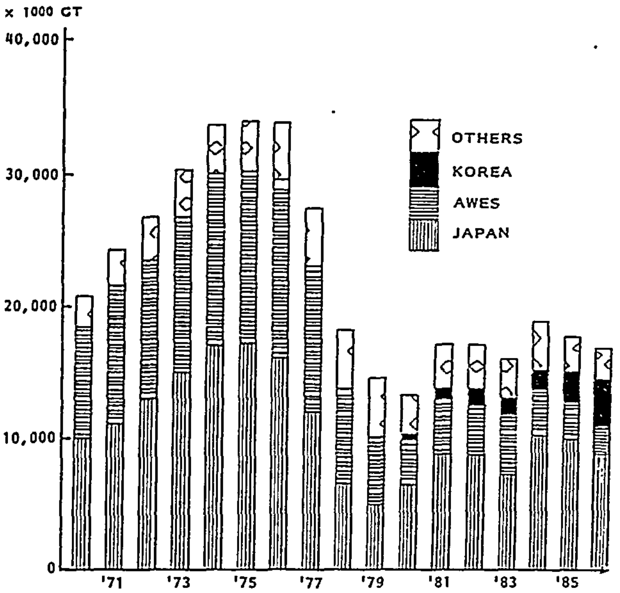


FIG. 2 NEW MERCHANT VESSELS BUILT IN THE WORLD
SOURCE; LLOYD RESISTER OF SHIPPING (2)

Figure 2. New merchant vessels built in the world
Source: Lloyd resister of shipping (2)

Figure 3 is a plot of IHI's man-hour reduction rate for building 30,000 - 60,000 DWT bulk carriers for the 10 years between 1968 and 1978. As shown, a reduction of 35 percent was achieved.

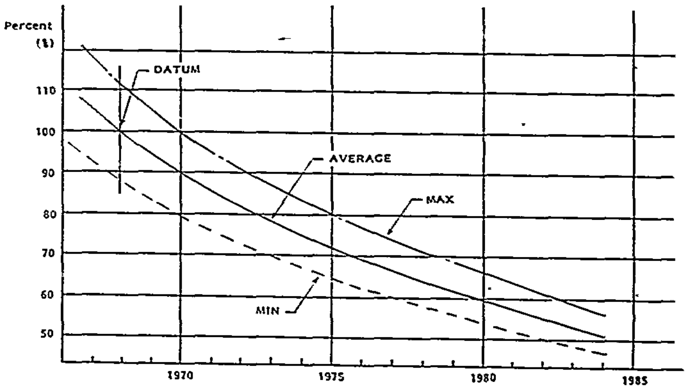
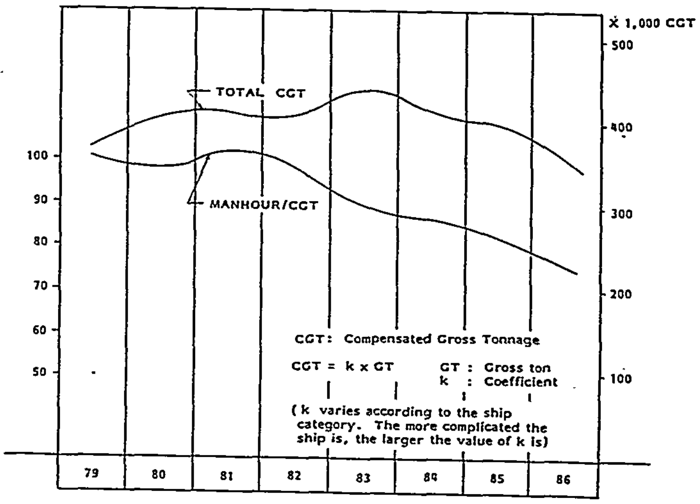


Figure 3. Man-hour reduction curve (30-60 type bulk carrier)(3)

Figure 4 shows how IHI improved efficiency for building commercial ships in recent years. The efficiency index was calculated by dividing the total man-hours consumed per year by the aggregate Compensated Gross Tonnage (CGT) of ships built in the same year, assuming the value in 1979 as 100. For the seven year period, 1979-1986, efficiency improved by 35 percent, i e, 5 percent per year.



CGT: Compensated Gross Tonnage
CGT = k x GT
GT : Gross ton
k : Coefficient
(k varies according to the ship category. The more complicated the ship is, the larger the value of k is)

Figure 4. Man-hour/CGT curve

2.2 COST COMPARISON BETWEEN JAPANESE AND AMERICAN SHIPYARDS

In 1978, in response to a unigue MarAd initiative as a part of the National Shipbuilding Research Program (NSRP), IHI disclosed its cost breakdown for building a 36,000 DWT bulker. The breakdown was used as a baseline for comparing cost estimates for the same ship if built in a U.S. shipyard. Estimates submitted for the same ship design disclosed that U.S. required man-hours were 3.5 times greater.(4)

With the "hard" data so obtained other comparisons for the 36,000 DWT bulker disclosed:

	Built in Japan	Built in U.S.A.
Cost	$20,000,000	$40,000,000
Delivery	12 months	26 months

Source: American Shipper, June 1979

Figure 5, prepared by a U.S. based tanker owner, is a comparison of estimated costs for 90,000 DWT tankers built in the United States, Northern Europe and Japan as of 1981.

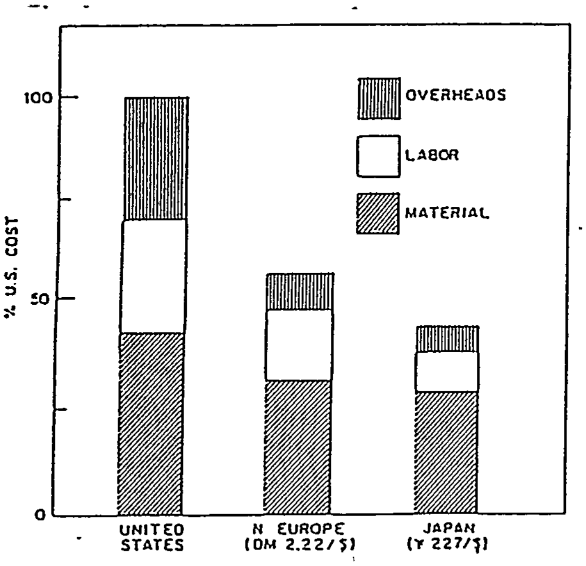


Figure 5. 90 kDWT crude carrier relative construction costs in U.S., N. European and Japanese shipyards for 1981 contract. (5)

As shown, major differences lie in the labor and overhead components of the estimates.

For the same 90,000 DWT tanker constructed in 1981 for delivery in 1983, the following comparison also apply:

	USA	N. Europe	Japan
Labor hours	100%	57%	46%
Labor cost	100%	51%	35%

But IHI managers who served as consultants concluded by 1984 that at least one U.S. shipyard had improved productivity by at least 30 percent because of the introduction of the new shipbuilding technology. This view was also reported by another interested observer (1). Other U.S. shipyards also benefited and as of 1987, from a productivity viewpoint, the ratio for Japanese yards relative to U.S. yards is 1 : 2 to 2.5.

3. TECHNICAL TRANSFER FROM IHI TO SHIPYARDS IN THE UNITED STATES

3.1 IHI'S TECHNICAL TRANSFER ACHIEVEMENTS IN THE UNITED STATES

The National Shipbuilding Research Program (NSRP) started in 1970 in order to improve the productivity of the U.S. shipbuilding industry. IHI began to participate in the NSRP in 1976 in response to two independent and simultaneous initiatives. One precipitated by MarAd's office of Advanced Ship Development led to IHI engineer-managers advising Levingston Shipbuilding Company in the application of modern methods for the construction of IHI designed 36,000 DWT bulkers. The other, initiated by Panel SP-2 of the Society of Naval Architects and Marine Engineer's Ship Production Committee, resulted in the NSRP publication "Outfit Planning" in 1979. The latter, which is highly descriptive and illustrative, gave a large number of U.S. shipbuilders their first understanding of the logic and principles employed for IHI shipyard operations. That publication and subsequent publications initiated by Panel SP-2, particularly "Product Work Breakdown Structure" first issued in 1980, were copied, translated, even into Japanese, and benefitted shipbuilders concerned with modern methods everywhere.

Thus, MarAd's early initiative alerted a number of key people that differences in management methods, not work ethic, was primarily responsible for the superior performances of Japanese shipyards. One of the people, Mr. A. L. Bossier, Jr, President of Avondale Shipyard, knowledgeable of the seriousness of the coming worldwide shipbuilding recession, was quick to engage IHI consultants in 1979 and rapidly manage a major transition to modern shipbuilding methods. The improvements were quickly manifest.

Shipyard	Project	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
LEVINGSTON SHIPBUILDING CO.	Enhancement of productivity Improvement of yard plan Supply of drawings for 32,000 DWT bulk carrier	■	■	■	■						
AVONDALE INDUSTRIES INC.	Enhancement of productivity Supply of drawings for container Ship/product carrier Design & planning assistance		■	■	■	■	■	■	■		
NATIONAL STEEL & SHIPBUILDING CO.	Technical survey for productivity of new shipbuilding Consulting & engineering service in design and production for 209,000 DWT Tankers						■	■	■	■	
BATH IRON WORKS CORP.	Advanced technology program for Design, material & planning systems					■	■	■	■	■	
LOCKHEED SHIPBUILDING CO.	Enhancement of productivity Improvement of yard plan						■	■			
TAMPA SHIPYARD INC.	Supply of drawings for 30,000 DWT tankers						■	■			
PENNSYLVANIA SHIPBUILDING CO.	Facility improvement Engineering assistance Production assistance								■	■	■
PHILADELPHIA NAVAL SHIPYARD	Application of zone logic for Ship repair										■

Figure 6. Technical collaboration schedule

Other U.S. shipyards, in order to maintain competitive positions, also retained IHI engineer-managers as consultants as shown in Figure 6. Avondale having made the greatest effort in technology transfer relatively early, has since demonstrated on impressive competitive record. In today's business atmosphere, Avondale's competitive record thus far is evidence that it is not enough to pursue modern technology. For success, a yard must be "leading the pack" in its application.

As Figure 6 shows, although the content of technnology transfer can be divided into many different categories, the main subjects pertained to assisting in design development for particular ships and for general productivity improvement.

The design efforts included preparation of drawings and technical documents with particular emphasis on work instruction drawings consisted with a product work breakdown structure.

Technology transfer for productivity improvement covered various fields such as design, production, production planning, material management, etc. The following section summarizes their main items and contents. Purposes are described here without details since they are introduced in various NSRP publications.

(1) "PRODUCT-ORIENTED DESIGN SYSTEM"

This system features a sequence of design processes, i.e. basic design, functional design transition design, and detail design (work instruction design).

The main purpose is to create and present all necessary information for preparing materials, purchasing equipment, and constructing the ship in the manner of the process lane and zone outfitting methods.

All information is issued in a format that allows it to be easily accessed and understood in the variety of uses for which it is intended.

(2) "STANDARDIZING"

The purpose of standardizing is to reduce the number of categories and quantities of materials. Productivity indicators are then not disrupted by widely varying materials. As a result, material management and processing are simplified and work efficiency improves.

(3) "MATERIAL MANAGEMENT SYSTEM"

The purpose of this system is to supply necessary materials when they are needed to the locations where they are needed (just in time: JIT). For this purpose, materials are categorized into allocated material, stock material, and allocated stock material and managed by defining and managing their delivery dates. Furthermore, the functions of the warehouse and marshalling yards as well as palletizing are clearly defined.

(4) "PROCESS LANE SYSTEM"

This system categorizes all the processes into groups consisting of those with similar work content and allocates them to specified areas in the yard. The purpose of the system is to guarantee stable product quality and to improve productivity by fixing the workers in the specified areas. The results are specialized facilities, respective production management units, and workers groups with special skills, all of which contribute to improvement.

(5) "ZONE OUTFITTING"

Block construction and on-block outfitting had been used before IHI began its technical cooperation with U.S. shipyards.

Zone outfitting consists of on-block outfitting, fitting packages, and on-board outfitting. It requires elaborate planning at the design stage with the participation of production engineers, ample discussion, and preparing and gathering necessary materials and equipment for the respective zones and stages by defined times (which are earlier than conventional timing). Therefore, the product-oriented design and material management systems mentioned before are absolutely necessary.

The purpose of this method is to execute outfitting in an environment with more ease and safety (workers work downhand without scaffolding). Also, the purpose is to minimize the movement of both workers and materials from one zone to another by completing work per zone without workers shifting back and forth from one zone to another. This method is similar to that adopted during high-rise building construction where the interior work is completed by each story.

(6) "ACCURACY CONTROL"

The purpose of accuracy control is to minimize rework, especially minimizing adjustments of hull blocks during erection.

For this purpose, the precision of interim products is improved, without using a great amount of labor, by revising production methods.

(7) "LINE HEATING"

Line heating is employed not only for bending and straightening steel plates and shapes by heating, but also for evaluating whether those materials are precisely processed with ease and precision. This contributes to minimizing unnecessary rework at following stages.

3.2 EVALUATION OF TECHNICAL TRANSFER

With the introduction of new technology, labor hours reduced considerably, although the reduction did not reach the level IHI had expected. The American shipyards must further and thoroughly execute the new systems and improve their own production systems in the future. However, there is a limit to the effects of introducing individual systems. The real task in the future, therefore, is to integrate those systems for which statistical control techniques are needed.

In integrating those systems, the role of the design process is still important. But sometimes, the design section of each yard does not recognize the importance of their own role. The improvement must be considered also from the information integration viewpoint.

Regarding productivity improvement, which is most important, the systems capable of quantitatively grasping and tracking work have been insufficient. Only a limited number of people are aware of the problem. The principle of executing the system by all workers has not yet been implemented. In such unintegrated situations, it is rather difficult to identify and solve problems.

People who perform production engineering seem rather passive and their production strategy, if any, is not considered for design development. Also, they are not given detailed information of how work processes are performing. Therefore, they can not sufficiently contribute to day-to-day productivity improvements nor provide good feedback to design. Design engineerisng and production engineering must be integrated.

4. RECENT IHI EFFORTS FOR PRODUCTIVITY IMPROVEMENT

IHI has been increasing its productivity by an average of 5 percent per year as mentioned before. This improvement tends to be offset by wages and various yard expenses which have been rising every year. Therefore, IHI has been trying to keep down all costs such as energy expenditures, any facility investment not absolutely necessary, and overhead charges. The following section describes some examples of IHI's efforts.

4.1 DESIGN AND ENGINEERING

4.1.1 Recognizing the Role of the Design Department

IHI design engineers widely accept the concept of Dr. Shinto, who advocates the role of the Design Department as follows:

"Designing is the beginning and end of production engineering" and it consists of the following four functions:

- o Determine the shape of the ship with defined functions and performance.
- o Examine with what materials, equipment, and methods a ship can be built inexpensively and quickly while satisfying the defined functions and performance specifications, express them as drawings and other documents.
- o Supply to the Material Procurement Department within a defined time schedul, information on specifications, quantities, and delivery dates for materials. Supply to the Manufacturing Department, drawings and work instructions for respective production processes within defined time schedules.
- o Analyze at both the completion and during the building processes the differences between estimates and actual figures in terms of costs, quality, and performance and plan to incorporate improvement in the next ship to be built."

(1) Responsibility Regarding Costs

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.

Also, the reduction of material costs, which consists of about 60 percent of a ship's cost, is extremely important and the design process plays a vital roll. The Design Department is responsible for reducing the total quantity of materials, while the Procurement Department is responsible for reducing cost per unit. Of course, the Design Department also makes efforts to select the most inexpensive and easily providable materials.

Reducing total material quantities and material categories leads to the reduction of production man-hours.

In IHI the Design Department itself manages both budget and actual figures regarding material quantities.

Table 4 Material Budget/Actual Comparison

ZONE	SYSTEM	ITEM	QUANTITY ESTIMATED *1	QUANTITY EXECUTION PLAN *2	QUANTITY ACTUAL *3 (R1) (R2)	QUANTITY AT TIME OF SHIPS COMPLETION *4

*1 Quantity estimated for Contract price prepared by Headquarters.

*2 Execution plan is prepared by Design Division in the Shipyard during functional design development.

*3 Actual quantities are issued when functional design is completed and again when detail design is completed.

*4 Actual quantity used for completing the ship

(2) Responsibility in Information Provision

The Designing Department is responsible for providing the Material Procurement and Manufacturing Departments with timely and necessary information.

Although the Design Department should supply to the Material Procurement Department the specifications for all the materials required and their confirmed quantities within a time frame requested by the Material Procurement Department, it is usually extremely difficult to do so. For the quantities not determined, the Design Department supplies provisional estimates and replaces them with the confirmed quantities when they are determined. While the Design Department supplies to the Material Procurement Department the information on all the material quantities, it should also provide the Manufacturing Department with material data as early as possible. The latter uses material data as the base of its master construction schedule and manning plans.

The main items of the data are:

o Hull steel weight	... each block
o Welding length	... each block
o Parametric out fitting weight	.... each zone
o Pipe weight, number of pieces	.... each zone
o Cable length	.... each zone

Delay in the drawing issues leads to delay in the material marshalling which further contributes to confusion in production work flows. Thus, design process management preparation is most important. Drawing issues must meet the master construction schedule, while keeping in mind that the manufacturing schedule must be suitable for material lead times.

Thus, the Design Department is not in a position parallel with other departments. Instead it is in a position for leading them. The Design Department's performance determines the performance of the whole shipyard.

4.1.2 Module Design and Learning Effect

The basic concept of the cost reduction strategy is how to utilize the learning effect. A new ship is designed by locating a ship similar to the new one. Records of that shipbuilding history are used as a model. IHI calls this procedure the "Module Design". That is, if parts of ships are similar, design modules from the previous history are adopted as is or with some improvement. It is important not to waste energy and resources in treating every new design as if there was no precedent.

After selecting the model ship, the Design Department examines the difference between the already known actual costs and total material quantities and the target costs for the new ship. Then, it analyzes how and where the improvements could be made to reduce costs. For identical and similar modules, design man-hours and production man-hours are reduced due to the learning effect.

The data accumulated is the company's valuable property. In order to utilize the data easily the accumulation should take the form of modules of drawings and material lists. Retrieval of and combining this type of data have proved to be effective by using the CAD system.

Of course, even with modules new concepts are involved. But, routine module design methods assist engineers to concentrate their creative energy in the new aspects.

4.1.3 Information Development and Integration in Design

In the design process, a great amount of information must be created with high precision in the relatively short period allowed for basic, functional, transition, and detail design.

Computer processing has been utilized in IHI shipyards for two decades. The processes were quite independent from one another until about 1984. Now they are fully integrated.

In the beginning of the 1970s, IHI computerized ship calculations, lines, structural analysis, etc. for functional design and computerized hull structural parts generation and pipe details for detail design. In addition material control was computerized.

Later, the system was expanded and improved in its effectiveness. But, the integration among the various systems was accomplished by batch processing using drawings as a common reference. The system was insufficient as a "data base". Operational efficiency approached an inherent limit.

Therefore, IHI decided to modernize the design process by developing and using FRESCO (Future Oriented Engineering System for Shipbuilding aided by Computer) in order to establish a total integrated system for all data as shown in Figure 7.

FRESCO consists of FRESCO-H (Hull Structure) and FRESCO-F (Outfitting) and integrates everything from basic design, functional and transition design to detail design. With this system, information is utilized in an integrated manner while simultaneously replacing manually prepared drawings with computer processing.

The FRESCO design functions include automatic design, module design, and interactive design by freely combining all of them. It is a flexible design system capable of efficient information processing.

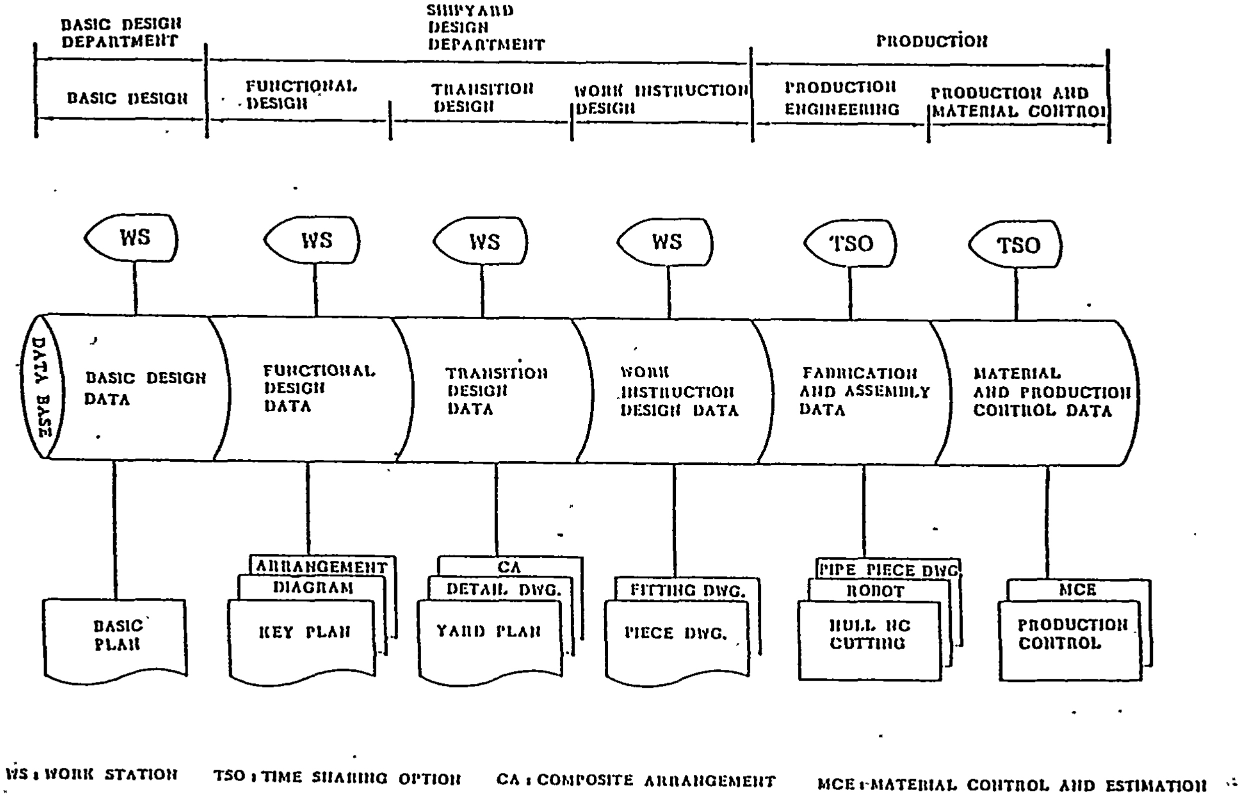


Figure 7. Coverage of Fresco system

The following section describes the characteristics of the FRESCO system.

- o Since the information is coherent, once created and entered, information can be used downstream in an integrated manner. Only the information not included in the system is retrieved from or added to the data base by dialog.
- o By standardizing the function configuration and drawings, the existing drawings can be reutilized flexibly and widely.
- o By standardizing the materials and practices, a total composite drawing can be produced quickly by computer using the data such as various functional diagrams, namely system diagrams and machinery arrangement drawings. While producing the drawings, the material procurement list can be made simultaneously.
- o By standardizing the work unit, while producing the drawings, a pallet list (material package required for the work) can be made for the most appropriate production and production control.

Figure 8 describes the coverage of the CAD system and CAD overall hardware system.

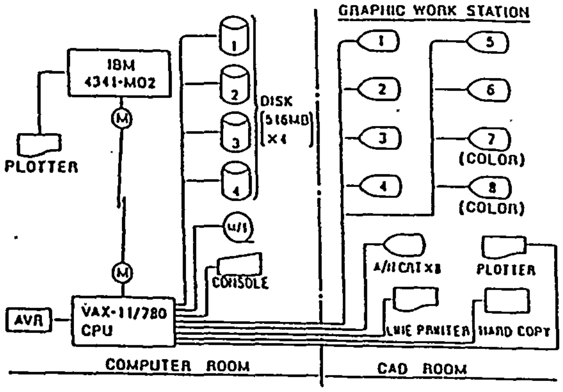


Figure 8. Fresco hardware system

4.2 PRODUCTION FACILITY AND PRODUCTION ENGINEERING

IHI completed its facility expansion and modernization by the 1970s. Since then, IHI has been executing only small scale facility improvements, mainly modifying facilities for raising productivity and for responding to increased diversification.

The productivity improvement is concentrated on:

(1) Increasing automatic machine installations

(2) Improving the work environment

(3) Improving various hand tools and jigs

The following are representative improvement items in IHI Kure shipyard:

(1) Increasing automatic machine installations

- o Welding related items

  Submerged arc welding and the gravity welder were the two main welding methods supporting productivity. IHI gradually introduced a great number of the advanced CO_2 semiautomatic welding machines which now dominate.

  The automation rate* in welding has improved by 20 percent in the past 5 years, reaching 70 percent by now. Since more than 20 percent in the remaining 30 percent is by the gravity welder, traditional stick welding is no longer in normal use.

  * Welding automation rate:

  Automatic and semi-automatic welding wire weight / Total welding wire weight x 100%

- o Burning machines

  In addition to the E.P.M. (Electro-Photo-Marking) N/C Gas Burning Machines, IHI has introduced Plazma Burning Machines. The machines are used for different situations with flexibility according to their characteristics.

o Automatic Machines, Robots

IHI has produced a welding robot on a trial basis. However, it has not yet reached the evaluation stage.

(2) Improvement of work environment

o Working Area Enclosing Mobile Structure

IHI has made all the zone outfitting areas weather proof (all weather type) by establishing mobile structures over them.

o Simplified Scaffolding Units

IHI abolished conventional scaffoldings and adopted simplified scaffolding units which are combinations of steel landings, rails, and ladders. Each is a sort of staging package moved by crane. By adopting this system, stage building man-hours were greatly reduced.

o Installation of remote control devices on shop cranes.

This installation has reduced the number of crane operators and improved work safety.

(3) Improving hand tools and jigs

IHI switched from the heavy air driving portable grinder and chipping hammer to lighter electric type machines with better performance. This shift not only improved efficiency but also contributed to electricity conservation. Replacing the chipping hammer with electric grinders, reduced noise and contributed to work environment improvement. Innumerable improvements, most of which were suggested by the workers themselves, were made regarding other hand tools, jigs etc.

4.3 REFINED EFFORTS FOR PRODUCTIVITY

The production system, production engineering, and production facilities are not purposes but means.

Their purpose is to improve productivity and quality. Simultaneously, IHI uses objective criteria with concrete measuring units in order to monitor progress. Otherwise, it is not possible to understand and find solutions to problems.

IHI's Productivity indicators are;

o Hull structural steel:

man-hours/ton of hull weight
welding length/man-hour

o Hull outfitting:

man-hours/ton of parametric outfitting weight

o Pipe fitting:

man-hours/ton of pipe weight
man-hours/pipe piece

o Electric fitting:

man-hours/cable length

o Painting:

man-hours/area

o Ship total:

Total man-hours/CGT*

* Compensated gross tonnage

The following data are included in the statistics as items indicating quality which impacts on productivity.

o Welding quality:

X-ray defect rate;
Defects/Inspected number

o Shell precision:

Gas cutting rate;
Gas cutting length/Erection gap length

Back-strip welding rate;
Back-strip welding length/Erection gap length

o Pipe precision:

Pipe remanufacturing rate;
Remanufactured number/Total number

o Steel yield:

Net weight/Invoice weight

o Palletizing completion degree:

Loss rate;
Lost line items/Total line items

By using the indices, it is possible to examine productivity quantitatively, and to establish targets for productivity increases.

4.4 ORGANIZATIONAL ACTIVATION

4.4.1 Importance of Target Management

Motivating workers is one of the important elements for improving productivity in shipyards. The final factor in production is the workers themselves. High quality production systems and facilities cannot guarantee a good production pace without their cooperation. Without strong motivation of the workers, productivity cannot improve. Usually in production sites, a situation interfering with smooth production occurs almost everyday. For example, equipment failure, material shortage, absence of workers, and product defects, can occur anytime. The workers find those problems first. Unless they take necessary action with a positive attitude or report to their supervisors for solving the problems, the impact on production cannot be minimized. The production system alone cannot cover such problems. The key here is the motivation of workers toward production. It is important to continue motivating the workers so that their positive attitude becomes a custom.

What kind of work purpose do the workers have?

In IHI the workers have their own targets such as "welding an average of 6 m per hour", "mounting 8 pipes per day", "completing a block by the end of the week etc." They all cooperate so that their targets can be attained without a great amount of difficulty.

4.4.2 Target Management and Small Groups

IHI has more than 15 years of history in small group activities. Each small group usually consists of about 10 members employed at the same work site. An assistant foreman usually assumes the role of the selected leader. Thus, each small group is the smallest size unit for yard management. The small group has a quantitative management target and its members cooperate with one another in order to achieve the goal.

The head of the target management hierarchy is the Shipyard Manager. Once a year a yard level target is set defining responsibility of the groups. The targets are set at the respective levels such as the level of the Shipyard Manager, Department Manager, Section Manager, Foreman, and Small Group.

Target achievement by each small group supports the target set by the section the group belongs to. In the same manner, the target achievement of the section supports the department and so on. Therefore, the shipyard as a whole is a cooperating body to improve productivity and product quality. A client who places an order with a shipyard with this kind of spirit and production system has great assurance for timely and quality performance. Recently, some owners have abandoned dispatching owner representatives for supervising the work. Such clients fully trust IHI.

5. ADVICE TO U.S. SHIPYARDS

IHI shipbuilding technology has been adopted in many shipyards in the United States in various areas and has proved its effectiveness. The following points are suggested, based on experiences of IHI managers who served as consultants in U.S. yards:

5.1 DESIGN

(1) The Design Department, as mentioned in 4.1.1, should have a strong role. It should not consider its own role as a department parallel to Material Procurement and Production Departments. It should clearly recognize its leading role for generating accurate and timely information.

(2) The Design Department should execute scheduling management of it's own work as in the Production Department. The former's scheduling management system should precisely correspond to those of the Material Procurement and Production Departments.

(3) Adopting a totalized CAD system

The information should be rectified according to priority and systematized. Excessive information should be avoided.
Module design, utilizing CAD, should be employed.

(4) Preferably contract design and subsequent design phases should be performed in-house. This permits a shipyard to impose a building strategy.

5.2 PRODUCTION FACILITY

(1) It is too early to adopt large size high-tech robots. Replacing and modernizing manual welding and cutting machines with automatic machines should be given priority.

Compared to Japanese shipyards, the adoption of gravity welders in the U.S. is far behind.

(2) Sub-assembly line, panel line, belt conveyer

The United States is behind in adopting conveyers for fabrication, sub-assembly and assembly lines. The major production line must maintain a defined speed. If this line is manual, the production speed may become unstable. The best solution is to adopt a conveyer line which sets the pace of production.

(3) Abolishing outdoor work

In U.S. shipyards, more work is executed outside. The work environment can be improved by adopting covered work sites.

(4) Facility improvement to reduce man-hours

Improve the crane system by adopting remote controls and improve jigs and tools for use by one worker.

5.3 PRODUCTION ENGINEERING

(1) Index expressing productivity, precision, and quality

Utilize the indices described in 4.3 as the criteria for level loading. Use them for future improvements.

(2) Process lane system

Some U.S. shipyards significantly improved productivity by adopting process lanes.

Smoothly shifting from the conventional craft system to one with different crafts working together in the same process lane is a key to success.

(3) An independent "Production Planning Department" is ineffective for accurately budgeting man-hours and scheduling. Such activities should be implemented primarily by the Production Department and should be decentralize. The same people should have both budgeting and scheduling functions. Dividing the two is not wise since it leads to unclear definition of responsibilities.

5.4 ORGANIZATIONAL ACTIVATION

(1) Practice of Target Management

Target setting should be executed in a hierarchical manner from top management to the first-line supervisor. Then concrete targets should be set, implemented, and their results should be evaluated.

(2) Introduction of Small Group Activities

Without a firm base, the introduction of this system is rather difficult. However, if target management is implemented, a small group can achieve a reasonable target set by it's first-line supervisor.

(3) Communication Promotion

The Design Department should promote communications with itself and with the Production and Material Procurement Departments.

5.5 COOPERATION WITH NAVY

Although the comments and advice in the foregoing sections are based on IHI experiences for commercial ships, most of the advice also applies to Naval ships. In fact, most of the methods have been applied for building Naval ships in an IHI shipyard.

Commercial ships and Naval ships share the same basic functions. It is true that in the case of Naval ships the emphasis is on functions with more complex systems and the cost factor is not as important as for commercial ships. There is not much latitude for improvement by a shipyard when a Navy imposes traditional ways regarding drawing types and contents, composition of progress reports, and progress payments. Some consider this situation as the factor that prevents improving productivity. Considering the fact that at present ships built in the United States are mainly Naval ships, U.S. shipbuilders should actively solicit the Navy's cooperation for productivity improvements.

6. CONCLUSION

(1) Some shipyards in the United States have been modernized and their production systems appear to have reached an upper limit of improvement. But, there is still a vast gap in productivity between Japanese and U.S. shipyards. Productivity can be further improved in U.S. shipyards by improving management of the human element.

Management's task is to create in the present systems an environment where workers can implement their roles thoroughly unencumbered by problems that workers can do nothing about.

It is easy to understand why the productivity ratio between Japan and the United States in shipbuilding is 2:1. In the United States, "there are too many workers", or, "human input is more than necessary".

This difference originates from differences in management attitudes. In the United States, when work is delayed, management increases man power. Japanese management examines why work is delayed. After analysis of the total work load and number of workers, usually decisions are made to increase the use of machines and jigs to assist workers without increasing their number.

(2) In old days, the low cost of Japanese ships was caused by cheap labor. But, today Japan is one of the countries with a high wage level. Can the shipbuilding industry survive in a country like Japan with a high wage level?

We have to make it survive.

Japanese shipbuilding facilities were reduced by 35 percent in 1978 and another large scale reduction is underway.

IHI, however, will not withdraw from the world market. The present move is a facility adjustment corresponding to world demands and expected market share by IHI. In other words, the facility reduction is for survival.

The following is a bright topic for IHI and for the Japanese shipbuilding industry as a whole:

IHI won in an international bid for a 230,000 DWT VLCC over Korea, Taiwan, and European countries. The owner's decision was made based on not only the price but also on IHI superior technology, especially regarding fuel consumption rate.

(3) Cultural and social custom difference is often cited in explaining the gap in the productivity between shipbuilding industries in Japan and the United States. This is an incorrect assumption. It is difficult to find a base for believing that productivity improvement in the United States is so limited.

(4) Today, the United States remains an admirable and strong economic power. Its manufacturing industries should obtain more international competitiveness by establishing a more balanced industrial structure. Shipbuilding is no exception.

I should be honored if this paper can contribute to productivity improvement in the U.S. shipbuilding industry.

Finally I should like to express my deepest gratitude for Mr. H. Nishi, Mr. Y. Okayama (IHI) and the people who cooperated in writing this paper:

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Increased Duty Cycle for Plasma Arc Cutting Machines Through a Separated Automatic Plate Marking Station

No. 3

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ABSTRACT

Plate marking as currently practiced limits plasma arc cutting machine duty cycle. This in turn constrains plate fabrication process lane throughput. A separate automatic plate marking station which will significantly increase plasma arc cutting capacities is defined. A 60 to 100 percent increase in plate fabrication process lane throughput is anticipated while simultaneously reducing unit direct labor. The design is supported by technical feasibility demonstrations.

INTRODUCTION

This is the report of progress of a study nearing completion at Litton Systems, Inc. Ingalls Shipbuilding Division. Increased duty cycle for plasma arc cutting machines through a separated automatic plate marking station is the primary study objective. The underlying motivation for this objective is the expectation of reduced unit costs for finished plate parts cut by direct or computer numerically controlled plasma arc machines. A secondary study objective is improved geometric fidelity between the perimeter of cut plate parts and construction and reference lines interior to the parts. This improvement will help avoid the costs associated with correcting construction and reference line layout, and with compensating for construction errors caused by improperly located lines. Both of these objectives will result in reduced acquisition costs for new construction ships and ship overhauls. Both of these objectives move manufacture of ship structure in the direction of just in time support of building schedules based on erection of shop completed outfitting packages.

The study scope begins with analysis of plate fabrication process lane features common to United States shipbuilding industries. The study scope includes developing a design concept for an automatic plate marking system, showing technical feasibility, preparing preliminary designs and specifications, and identifying the system economic justification. Capitalization, development, and implementation of particular automatic plate marking systems based on the results of this study remains the option of individual shipyards.

For simplicity the automatic plate marking system described in this paper is herein after referred to as the AUTOMARK system.

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Design Concept Development Strategy

The study objectives arise from three rather straight forward observations apparently common to most shipyards. First, although the primary function of the plasma arc machines is to cut the outline separating parts from workpiece plate scrap, a significant portion of cutting table time and labor are associated with making marks. In a significant number of cases current marking practice fails to hold sufficient geometric fidelity with the part edge. This results in rework to correct the layout or to compensate for construction errors resulting from improperly located lines. Thirdly, alignment of plate with the plasma arc machines to assure that all of the required cuts lie entirely interior to the workpiece boundary is a tedious operation, often requiring multiple check passes with the machine and manual adjustment of plate position on the platen.

Variation in line position from the intended locations on the plate parts is attributed by the shipyard operating departments to several sources. These sources include movement of thin plate on the platen caused by the repeated impacts of the marking tool and flexing of the out of plane waves characteristic of thin plate. A portion of each marking tool impact is reacted through the plasma arc cutting machine carriage. The impact reaction changes the relative alignment between the marking tool and the plasma torch. Welds joining plate parts into larger assemblages cause local shrinking. Local weld shrinking alters the position of construction and reference lines relative to the assemblage geometry.

The first two error sources will respond to modifications in the marking process and its position within the plate fabrication process lane. Line movement due to weld shrinking must be controlled by controlling weld sizes and sequences, establishing statistical norms for the shrinking that will occur, and compensating accordingly in the engineering data base.

The current practice of marking plate parts with a tool attached to the cutting tool carriage is evocative. This practice presumes a mechanically constant relationship between the marking tool and cutting tool coordinate systems. The distance and orientation from the marking tool center to the part edge generating region of the plasma torch are intended to remain fixed. In reality the situation is not quite so simple. The kerf edge varies from the torch centerline according to the direction of swirl and the direction of torch travel about the part perimeter.

Marking construction and reference lines on plate assemblages following weld joining of several parts into flat panels or curved shells is likewise evocative. Butt weld induced shrinking is accomplished prior to marking. This method requires two separate marking facilities; one for flat panels, and a second machine for curved shells. Each of these machines will be much larger, more complex, more costly, and therefore, exceedingly more difficult to economically justify than a single marking station prior to plate part joining. Additionally, unmarked plate parts must be fit for joining solely on the basis of geometric clues contained in adjacent edges of mating parts. Where part edges are curves or contain corners significantly differing from right angles, part edge based fitting is at best difficult. The likely result is an assemblage with margin geometry different from that intended.

The design concept development strategy includes the notion that automation need not mimic any prior manual or mechanized practice. Rather, it is necessary to accomplish the required properties of the production task being automated. Adjacent grouping of processes for local optimization purposes often creates productivity limits and masks opportunities available through other process combinations.

These factors taken together lead to a design concept development strategy comprised of the following elements. Develop an understanding of the properties of each task accomplished in the plate fabrication process lane, and of the bounds and constraints imposed by product requirements, production schedules and existing facility. Synthesize an exhaustive set of alternative plate fabrication process lane architectures after discarding those classes of process combination violating the bounds or constraints or otherwise obviously infeasible. Evaluate the remaining alternatives first as generalized task nodes and subsequently as embodying specific process technologies appropriate to each feasible architecture. Accomplish each of these evaluations structured against fixed criteria supporting the study objectives.

Each of the alternative system configurations is formed as a combination of three component considerations. These considerations are the choice of marking process, the choice of marking tool manipulation mechanism, and the choice of plate fabrication process lane architecture. The component considerations are very closely coupled. Each combination exhibits a unique property set. The properties of individual plate fabrication process lane architectures are evaluated separately to fathom infeasible and obviously impractical choices. The AUTOMARK system design concept is selected by evaluating the utility separately exhibited by discrete combinations of each candidate marking process with practical plate fabrication process lane architectures. Each combination anticipates embodiment with a class of marking tool manipulation mechanism particularly suited to the required process motion. The evaluations are accomplished against fixed criteria established to measure the capacity of alternative configurations to meet the system requirements and to achieve the system objectives.

The AUTOMARK system throughput capacity requirements are driven by anticipated plate fabrication shop loads through the next decade. The system should be capable of marking up to 12 maximum sized plates per hour.The maximum plate size is 720 inches by 156 inches. The minimum plate size is 72 inches by 56 inches. The anticipated mean plate size is 400 inches by 108 inches. The mark density spectrum is typical for middle sized combatant ships.

SYSTEM OBJECTIVES

System Throughput

The prime objective of the AUTOMARK system is increased plate fabrication process lane productivity realized as increased count of plate workpieces put through the installed direct numerical controlled plate cutting resources per unit time. This is accomplished by using automated marking technologies and mark sensing technologies in a way that eliminates plate marking cycle time from cutting resource operation and drives plate alignment time toward irreducible minimum. The system should reduce direct labor content of the work accomplished.

Geometric Fidelity

An additional prime objective of the AUTOMARK system is consistent high levels of geometric fidelity of construction and reference lines to each other and to the part perimeter. The total mark position error budget is 0.04 inches from true position, anywhere on the workpiece plate surface, relative to the sensed coordinate axes for plasma arc cutting. This should result in a mark true position tolerance of less than 0.06 inches relative to the cut edges of parts. Alphanumeric character placement together with the equivalent bar code representation will be error free with respect to the information in the computer aided design data base.

Mark Characteristics

The secondary objective of the AUTOMARK system is generation of marks of high legibility, of enhanced mark utility, and permanence appropriate to use. The marks must be constituted compatible with the structural use of the plate. The marks must not degrade the metallurgical properties of the base material.

Marks physically changing the plate surface topology must not exceed 0.03 inches depth and must have sufficient width to assure primer flow into and bonding to all portions of the mark cavity. The mark cavity must approximate the rounded bottom cavity shape created by low stress impression die stamping.

All marks must survive 3 hours immersion in plasma coolant and 20 weeks outdoor stowage in a harsh marine industrial environment. Fiducial marks and construction and reference line marks must survive brush off abrasive blast cleaning and be legible through a touch up coat of 0.0015 inches thickness of primer. These marks must also survive mechanical primer removal for weld preparation.

Work Status Reporting

An additional secondary objective of the AUTOMARK system is automation of work accomplishment status reporting throughout the plate fabrication process lane. Reporting should begin during preparatory stacking of stock, and continue through to completion of part fabrication and marking.

System Requirements Sensitivity

The AUTOMARK system requirements are an essential parameter of this evaluation. The system requirements are also the measure of capability to perform the designated physical task.

It is important to note that changes to the system throughput requirements or to the mark performance requirements would likely introduce additional viable alternative plate fabrication process lane architectures. Additional viable marking technologies might also emerge. In particular, a stationary plate marking station might be viable. Productivity improvement as a result of separating automated plate marking from automated plate cutting does not seem sensitive to these kinds of requirement or embodiment changes.

PLATE FABRICATION PROCESS LANE COMPONENT OPERATIONS

Plate fabrication process lanes implemented in modern shipbuilding are similar in that the same operations are accomplished in the same sequence throughout the industry. Choice of plate fabrication process lane layout and the selection of equipment by a shipyard are strongly influenced by the history of the yard, its current business premise, and geographic and political constraints particular to the site. The model used in this analysis avoids reference to any given process lane. The separate operations in the process lane are considered in generic form in the feasible system architectures. The system properties of the generic operations functioning in these architectures and the consequent interrelationships thus established form the basis of this analysis.

Stock Stowage and Retrieval

Preparatory Stacking. Stock plate material is usually procured to meet the requirements of an entire ship or some very large assembly thereof. Even where specific plate sizes are ordered to match identified cutting nests, these plates are shipped in random order and often intermingled with mill run plate of the same alloy and thickness. When the plate is received, it is stowed in racks or stacks according to some prearranged plan relating location to material type, size, and applicable contract. The utilization requirements for stock plate material are directly related to ship assembly schedules. These schedules seldom have any relation to the stowage locations. This results in a requirement to retrieve plate from widely scattered stowage locations. The widely separated location makes it difficult to support steady loading of plate onto the process lane input conveyor.

It is common practice to use a highly mobile crane to retrieve plates from stowage. The plates are landed on preparatory stacks within close reach of a crane dedicated to conveyor loading. Then plates are landed in reverse order of the intended daily utilization so that the first plate needed will be available first. Separate provision is made for landing plates required for emergent work adjacent to the conveyor loading crane.

Conveyor Loading. Conveyor loading characteristics are determined by the need to introduce varying sizes of plate into the blast cleaning station with uniform velocity and approximately uniform workpiece flow. To support uniform workpiece flow, the conveyor loading cycle time should not exceed the time for the shortest plate to advance its length through the blast cleaning station. Lifting of plate onto the conveyor from the preparatory or emergent work stacks is usually performed by a dedicated crane selected for plate handling characteristics, making numerous lifts of limited scope, and landing the plate in approximate alignment with the conveyor. The plate is mechanically aligned with the conveyor on an acorn table. The plate is then moved to the blast cleaning station on a rapid conveyor. The conveyor is comprised as a series of independently operable sections, permitting dynamic buffering internal to the conveyor of material flow into the blast cleaning station.

Blast Cleaning. The blast cleaning station is comprised as a series of machines dedicated to individual portions of this operation. Plate is handled through the machines on a conveyor. A rotary brush scours the plate surface of dirt and loosely adherent mill scale which otherwise dissipates the kinetic energy of the blast media. The brush also sweeps away any water which may have pooled on the plate surface. A blast cabinet impinges high velocity streams of blast media onto the plate to spall off tightly adherent oxides and other hard contaminants. Indentations left in the plate by impacting blast media generate an extended surface for bonding primer paints. Loose blast media is swept from the plate in a second brush machine. Finally the plate is cleaned of dusty residue in a vacuum cabinet.

Each of these machines accomplishes the action of a particular process with a constant intensity and in a static location corresponding to a small region on the plate. Process motion is derived from movement of the plate through the machines. To apply these processes uniformly, plate should progress through the blast cleaning station with a constant velocity. Wear rates are very high for blast cabinets operating unloaded. It is therefore necessary to achieve approximately uniform, near continuous workpiece flow through the blast cleaning station during operation.

Paint Application and Drying

Application of preconstruction primer to plate is accomplished by a series of two machines dedicated to the individual portions of this operation. Plate is handled through these machines on a conveyor. Spray paint application tools, usually on a linear reciprocator means with the reciprocation direction arranged transverse to plate motion, are mounted to spray the top and bottom of the plate. The process motion is a function of plate motion on the conveyor and manipulation of the application tools. The quantity of paint applied in a particular region of a plate is determined by a combination of plate motion, application tool manipulation, physical properties of the paint, and the specific atomization orifice installed in the application tools. Since these parameters are coupled, they cannot be independently varied without significantly affecting performance. Means are provided to limit the spread of paint over spray.

The paint drying tunnel is an enclosed volume with forced ventilation and elevated atmospheric temperature provided to flash the solvent from the applied coat. Means are provided as necessary for controlling release of this solvent to the environment. The time required to flash the paint solvent depends on the physical properties of the paint, mass flow of air, and the condition of air in the drying tunnel. The duration of travel through the drying tunnel is directly proportional to conveyor speed. Since these parameters are coupled, they cannot be independently varied without significantly affecting performance.

Direct Numerical Control Cutting

Each direct numerical control cutting station is comprised as a platen to hold workpieces and a servo gantry bridge and carriage arranged to manipulate the cutting tool over static workpieces. Each direct numerical control station is equipped with a controller which operates the machinery, drives the servo gantry bridge and carriage, and communicates with the computer aided design data base to receive tool trajectories. Direct numerical control cutting stations are usually equipped with pneumatic prick punch marking tools.These marking tools are capable of drawing dotted representations of lines and alphanumeric characters when supplied data in vector format. A cutting station may be equipped with a second carriage to permit simultaneous cutting of identical or mirror image parts. A cutting station may also be equipped with two platens situated endwise adjacent so that parts and scrap may be unloaded and workpieces loaded on one platen during marking and cutting operations on the other platen. Work may be accomplished using any thermal cutting process. Water shielded plasma cutting is the process usually implemented. This process is selected because it can achieve high tool rates at moderate cost.Where water shielded plasma cutting is implemented, provision must be made to flood the platen, muffling the plasma, recovering the shield water and quenching the kerf immediately following the region of working plasma.

Nest Breaking Platen

Parts remain nested with plate scrap after the part perimeters are cut. The great size and shape variety in shipbuilding plate parts require craftsmen working with mechanized lifting equipment to perform separation. Certain of the possible plate fabrication process lane architectures require handling a plate as a unit after parts cutting. For these architectures, tabs are left holding the parts and scrap as a stable structure. This structure is transferred to a dedicated platen for the final nest breaking. Craftsmen cut the tabs with manual torches and, working with mechanized lifting equipment, separate parts from scrap.

Marking Station

The marking station marks plate remotely from the direct numerical control cutting machines. This marking is accomplished in such a way that geometric registration is maintained between marks and corresponding cut plate parts. Marking remotely from the direct numerical control cutting machines reduces cycle time for these machines and increases workpiece throughput.

The marking station embodies marking devices, and appropriate marking device manipulation means, a controller to drive the equipment, and provision for handling plates through the station. Conveyor plate handling is provided through marking stations working on moving plate. Marking stations working static plate may incorporate a stationary platen. Marking stations may be partitioned according to the marking technology used to realize marks of a particular kind or intended use.

PLATE FABRICATION PROCESS LANE CONSTRAINTS

Work Capacity

Plate fabrication process lane work capacity or loading is considered in terms of workpiece plate completion rate, and the distributions of plate sizes, cutline lengths, and quantity of marks to be made. A constant work capacity is applied to all plate fabrication process lane architectures evaluated. This work capacity was developed in support of economic evaluation of automated plate marking systems, and is described elsewhere in this report.

Marking Station Process Motion

In those architectures which permit plate to remain stationary during marking operations, process motion derives entirely from manipulation of the marking device over the plate surface. Control of this manipulation requires compensation for lack of plate flatness and dynamic response of the plate under marking tool loads.

In those architectures which require plate motion during marking operations, process motion derives from both progress of the plate through the marking station and manipulation of the marking device over the plate surface. Control of this manipulation requires compensation for lack of plate flatness and dynamic response of the plate under marking tool loads. Conveying speed changes with plates of differing size and weight.

Material Flow Buffering or Queuing

<u>Dynamic Buffering Between Conveyor Plate Loading and Blast Cleaning Station.</u> Material is loaded onto the plate preparation line conveyor by piece. This loading method is essentially decoupled from any effect of plate size or weight. The result is highly varied lengths of plate are loaded at a relatively uniform rate.

Contrasting, blast cleaning operations are best performed at a uniform velocity on near continuous lengths of plate. Because the variable rate of plate length loading mismatches the loading requirements of the blast cleaning station, dynamic material flow buffering or queuing is necessary on the infeed conveyor.

Between Plate Preparation Line and Direct Numerical Control Cutting Machines. Material flow through the plate preparation line proceeds at a constant velocity based on process requirements of the constituent machines. The plate workpiece flow is directly related to the spectrum of plate lengths passing through the line at any given time. Contrasting, groups of plates are loaded onto the platens of a direct numerical control cutting machine nearly simultaneously. It is common to have plural cutting machines working in parallel. Work content and therefore the cutting machine cycle time are closely related to the character of the specific parts being cut. At best the cutting machine work content is loosely related to plate area. This results in a disparity of material flow on a plate workpiece basis between the plate preparation line and the cutting machines. This disparity in material flow requires buffering or queuing between the plate preparation line and direct numerical cutting machines.

Adjacent to Marking of Stationary Plate. In those architectures which permit plate to remain stationary during marking operations, rapid plate handling entering and exiting the marking station is necessary to provide time for accomplishing the required marks. A material flow buffer or queue is required immediately adjacent upstream to prevent plate exiting the prior operation from overtaking plate being marked. This buffer must have a capacity at least equivalent to the largest plate anticipated. An equivalent buffer is required immediately adjacent down stream to prevent rapid handling of plate exiting the marking station while preventing overtaking of plate entering the next operation. In certain architectures it is possible to to realize one of these material flow buffer or queue requirements with the static buffer between the plate preparation line and the cutting machines.

Material Handling Kinds

Automated Handling. Because of the weight involved, handling of plate and most plate parts is mechanized. Automated handling in the plate fabrication process lane with conveyors and vehicular conveyor extensions. Automated tray handling is possible but not used. Vertical and canted orientations of plate on conveyors are possible. These orientations exhibit some desirable properties but are not common because of procurement cost. Horizontally oriented plate conveyors are common. Progress along the conveyor is controlled by sensing plate position or the state of process completion on a particular plate workpiece.

Handling Requiring Manual Intervention. Crane handling on the plate fabrication process lane is accomplished with manually controlled cranes. Magnetic attachment is preferred over plate clamps except for handling small plate parts. This practice reduces handling distortion of the plate and eliminates a requirement for rigging personnel for most plate part lifts.

SYNTHESIS OF ALTERNATIVE PLATE FABRICATION PROCESS LANE ARCHITECTURES

An exhaustive set of alternate plate fabrication process lane architectures are synthesized for evaluation in development of the AUTOMARK system design concept. These architectures are shown on the accompanying diagrams, Figure 1.1 through Figure 1.5.

Bounds and Constraints

Synthesis of alternative plate fabrication process lane architectures is bounded by the fixed serial relationship between plate material stowage and retrieval, blast cleaning, preconstruction primer application, and part cutting. It is implicit that direct numerical control cutting machines receiving premarked plate must be provided with sensors to automate alignment with workpieces. It is also implicit that automated marking stations receiving precut plate must be provided with sensors to automate alignment with workpieces. Consequences of adding a marking station are considered for all possible positions on the process lane. Plate fabrication process lane throughput is currently constrained by the practice of marking with the cutting machines in series with cutting operations. Plate workpiece loading in excess of the present constraint is uniformly applied to all feasible alternatives.

Symbolic Notation

Symbolic notation of plate fabrication process lane component operations is used in diagrams to facilitate synthesis of alternative architectures.

Stock Stowage and Retrieval. Stock stowage and retrieval are considered as a single operation and noted as upper case letter S.

Blast Cleaning. All of the plate cleaning process machines are considered as constituent parts of the blast cleaning station and noted as upper case letter B.

Preconstruction Primer Application and Drying. Equipment applying and causing drying of the preconstruction primer coat on plate are considered as a single station and noted as upper case letter P.

Direct Numerical Control Cutting Machines. Each direct numerical control cutting machine is considered as a separate station and noted as upper case letter C.

Marking Station. The marking station is noted as upper case letter M. Where partitioning of the marking station is appropriate, the class of mark generated in each partition is identified by subscript. Line marking capability is identified by subscript lower case letter l as in M_l. Fiducial marking capability is identified by subscript lower case letter f as in M_f. Alphanumeric character marking capability is identified by subscript lower case letter a as in M_a. Bar code representation capability for part or cutting nest identifiers is identified by subscript lower case letter b as in M_b.

Nest Breaking Platen. Nest breaking platens, in the architectures requiring such, are separately noted as upper case letter N.

Material Handling. Material handling between positions on the plate fabrication process lane is noted as a line segment ——. Characteristics of particular moves are identified by subscript. Automated handling by conveyor, vehicular conveyor extension, or similar means is noted by subscript lower case letter c as in ——_c. Material handling by crane or other means requiring manual intervention as noted by subscript lower case letter m as in ——_m.

Material Flow Buffering. Material flow buffering or queuing is noted as upper case letter Q. Characteristics of particular buffers or queues are identified by subscript. Dynamic buffering accomplished on a conveyor or other automated handling means is identified by subscript lower case letter d as in Q_d. Buffering or queuing of material flow with plates unloaded from any handling means is termed static and is identified by subscript lower case letter s as in Q_s.

Compound Operations Within a Single Station. Conceivably marking may be compounded with the native operation of any station on the plate fabrication process lane. This compounding may be series, occurring sequentially in the same position, or parallel, occurring simultaneously. Series compounding is identified by a virgule / separating the operation symbols. Parallel compounding is identified by adjacent reverse virgules \\ separating the operation symbols.

EVALUATION OF CANDIDATE MARKING PROCESSES

The candidate marking processes are evaluated against fixed criteria established to exhibit properties relevant to operation in a plate fabrication process lane.

Marking Process Evaluation Criteria

Geometric Fidelity. Consistent high levels of geometric fidelity are essential in the generation of line and fiducial marks. Out of tolerance mark registration destroy the spatial relationship between a particular part and adjoining work. The rework created by this event is costly. Minimally, layout of the defective part must be manually accomplished. Maximally, the part or assembly of adjoining parts must be replaced. Geometric tolerances for line and fiducial marks are defined in section 3 of the system requirements.

Application Speed. Mark application speed of a particular process establishes the number of individual tools required to balance workpiece material flow in a given plate fabrication process lane. Marking process with higher inherent application speeds are more productive and tend to reduce the extent of manipulation equipment necessary. The minimum mark application speed performance is defined in section 5 of the system requirements.

System Envelope. Space is always a premium commodity within a shipyard fabrication shop. Shop floor space is presently valued approximately $50.00 per square foot. Plate conveyor systems cost in excess of $1000.00 per linear foot. In most shipyards, limited space is available for expansion of current fabrication shops. Excessive or undisciplined use of shop floor space could have far reaching detrimental effects on current productive facility and future automation projects. Allowable system envelope is defined in section 4 of the system requirements.

Legibility and Permanence of Applied Marks. Legibility and permanence of applied marks are measures of product suitability for the remaining plate fabrication process lane tasks and for the adjoining operations of assembly, erection and outfitting.

Necessary mark legibility and permanence are defined in section 3 of the system requirements.

Personnel Safety. Appropriate measures must be taken to control all health hazards posed by selected marking processes to personnel operating, maintaining, or observing the AUTOMARK system. Employers have a moral and a legal obligation to protect the safety of employees while at work. Highly complex and costly personnel safety measures increase the required system investment and potentially create task conflict. The personnel safety considerations appropriate to implementing the selected AUTOMARK system design concept are separately discussed below.

Surface Condition Impact. The surface condition of workpieces entering the marking station is established by prior processes. Marking process operating parameters and work quality may vary widely with changes in workpiece surface condition. Operating parameters and work quality of processes subsequent to marking may depend on receiving workpieces with surface conditions substantially unchanged from that delivered to the marking station. Performing marking modifies workpiece surface condition and may impact the legibility, permanence, or otherwise degrade the suitability of applied marks.

Equipment Cost. Capital equipment and system development costs for the AUTOMARK system are limited by the value of the anticipated productivity improvement. This permits recovery of the required investment in a reasonable period. Marking process related equipment and development costs are a major component of the required investment.

Operating and Maintenance Costs. The cost of operating and maintaining the present method of marking, as well as those for alternate methods is considered in the economic justification of an automated marking system.

Subordinate Criteria. Ease of marker manipulation, tool wear independence, and plate waviness impact were used as subordinate criteria in evaluating candidate marking processes.

Marking Process Evaluation Comments

Impression Stamping. Most large numerically controlled plate cutting machines in use today are equipped with automatic, pneumatic prick punch markers mounted on the torch carriage. Marking is accomplished prior to starting the cutting operation. Marking with a pneumatic prick punch offers a high degree of permanence and legibility. Equipment costs are relatively low. Marking and cutting coordinate frames are coincident. This practice also exhibits the following disadvantages.

Marking on the torch carriage accounts for a substantial amount of the total process time on the cutting platen. Shop observations revealed that approximately one third of the total alignment, marking, and cutting process time is spent marking. This reduces plasma arc duty cycle and results in constraining shop throughput as well. Thus the full cost savings attributed to installation of plasma arc machines cannot be realized.

Maintenance costs are high because of contact wear and tip breakage. An average of 5 percent of the observed total potential weekly hours per shift were lost as a direct result of maintenance required on the punch marker.

Punch marking on small thin plates (6 feet by 10 feet by 0.25 inches thick) produce observable plate motions which result in marking inaccuracies. In order to eliminate this, plates must be mechanically held in place.

The present form of punch marking is limited to a single tool. Because each must be separately drawn, the cycle time is far too great, punch marking cannot effectively generate alphanumeric characters.

Finally punch marking is extremely noisy.

The primary motivation for selecting a process lane architecture which moves the marking cycle away from the cutting machine is the potential for a significant increase in plasma arc duty cycle and shop throughput. Communication with suppliers of impression stamping devices has indicated that it is possible to manifold a great number of impression stamping tools together in fixed geometric relation to each other. With sufficient numbers of tools, adequate geometric resolution could be obtained. Approximately 2500 individually actuated punches would be necessary to accomplish the required marking. Process motion could be obtained from plate workpieces conveyed through the manifold tool. Alternatively, a smaller manifold tool could be manipulated over the workpiece surface. Several of the smaller resources would be necessary to accomplish the task since the impact marking mechanism is difficult to manipulate at high speeds because of its size and mass. Tool contact with moving plates will cause tool jerking and plate vibrations resulting in degraded geometric resolution and excessive tool failure.

Rotary Tool Engraving. Rotary tool engraving, like impression stamping, offers a high degree of permanence and legibility for relatively low equipment costs. It also has a minimal impact on plate surfaces blast cleaned for preconstruction primer application. However, rotary engraving does have four inherent characteristics which limit its applicability for high speed plate marking.

Rotary tool engraving must be implemented with very high resolution surface tracking, tool force sensing, high speed manipulation means, in order to keep the engraving tool from impacting waves and other plate surface defects. Excessive contact force would result in tool breakage. Since rotary engraving tools operate at several thousand revolutions per minute, tool breakage could be very hazardous to workers in the area of the marking station.

Rotary tool engraving can engage the workpiece with a single tool from each manipulator. This requires separate drawing of each alphanumeric character and effectively limits rotary tool engraving to the generation of line marks.

Maintenance costs are high, both for the cost of replacement burrs and the labor for installation. Because of the anticipated high rate of tool breakage, a high level of disrupted production is also anticipated.

Finally rotary tool engraving is very noisy.

Laser Engraving. Laser marking is accomplished by focusing an intense, highly amplified beam of light on a target material. Minute amounts of the target material are vaporized by the beam, creating a round bottom cavity closely approximating low stress impression dye stamping. Width and depth of mark can be controlled by modifying the power output, rate of travel, and focal length of the beam delivery optic, and selection and control of the process cover gas. The marks are highly legible and have a high degree of permanence. Laser engraving does not degrade blast cleaned workpiece surfaces. High mark application speeds can be achieved. A single high power laser can provide power to multiple resources. Excess back shift laser power is available for other productive purposes such as laser thermal forming of plate parts. Lasers consume large amounts of power. Laser equipment costs are high. Safety considerations require conduct of laser marking inside a light tight enclosure equipped with interlock controls to assure personnel exclusion during operation.

Ink Jet Printers. Several types of programmable ink jet printers are available for noncontact marking of either single or multiple lines of information per pass. This is accomplished by projecting droplets of ink at high speed toward a workpiece surface while controlling the speed and direction of the droplets electrostatically.

The compactness and low mass of the ink jet printer make it very easy to manipulate. Additionally, the compactness of ink jet printing devices permit designing a plate marking station with a very small envelope. Printing with an ink jet on a blast cleaned or primed plate workpiece minimally degrades the suitability of the product for adjacent processes or operations. Ink jet maintenance consists generally of replacing orifices and replenishing ink supplies. Ink jet operation creates little noise.

Geometric resolution and legibility of ink jet marks will be degraded by the presence of waves in the plate workpieces. Ink jet marks made prior to preconstruction primer application will be occluded by the paint. Ink jet construction line marks made after preconstruction primer drying will be destroyed in preparation for welding adjoining structural components. Ink jet reference line marks made after preconstruction primer drying will be occluded by top coat painting of the assemblage.

Zinc Oxide Powder Markers. Zinc oxide powder markers use an oxy-fuel flame to preheat the workpiece surface so that a stream of metal powder melted by passing through the flame adheres to the workpiece as cast onto the surface. As the molten zinc cools, the unprotected mark surface oxidizes forming a characteristic gray white line approximately 0.03 inches wide. The nominal nozzle standoff from the workpiece is approximately 2 inches. The process is not highly sensitive to changes in standoff. This property relaxes the manipulation requirements for dynamic following workpiece contour with the marking tool. Zinc oxide powder marking tools have high moving mass. Mark application speeds of up to 800 inches per minute have been reported for zinc oxide powder markers. Since it is a material deposition process, the line width and geometric fidelity of zinc oxide powder marking vary considerably with application speed. Vendors recommend limiting application speed to between 175 and 225 inches per minute for consistent mark quality. The limited application speed requires an increased number of marking tools to achieve the objective production level.

Water Jet Engraving. Water jet engraving marks by impinging a high speed stream with entrained abrasive onto the workpiece surface. The mark is created by abrasive cutting and by a compressive shearing at the point of impingement. The process is brittle and difficult to control in that minor changes in operating parameters result in moving from a surface material removing regime to deep cutting. The water used as a process fluid base promotes rapid oxidation of blast cleaned workpiece surfaces. Workpieces marked by water jet will require a second blast cleaning prior to preconstruction primer application. Passivation agents can be added to the process fluid to suppress oxidation. These add to operating cost of the marking system. Workpieces must still be dried and abrasive swarf removed prior to preconstruction primer application.

EVALUATION OF MARKING TOOL MANIPULATION MECHANISMS

Manipulation mechanisms are not evaluated separately since the required process motion varies with each combination of marking process and plate fabrication process lane architecture. For those architectures which permit stationary workpieces during marking, articulated arms, dynamic bridge and carriage, static manifold tool and dynamic bridge , and combinations of these mechanisms are considered. For those architectures which require workpiece motion during marking, articulated arms, dynamic bridge and carriage, dynamic carriage on static bridge, and static manifold tool on static bridge mechanisms are considered. Combinations of these mechanisms are also considered.

The evaluation first considered the suitability, and kinetic and mechanical feasibility of a particular mechanism class for manipulation of marking tools in a combination of marking process and plate fabrication process lane architecture . Second, mechanical and control complexities are considered. This includes the scale of manipulation required, the size and mass of the necessary links, difficulty of mechanical design, extent of moving mass and coupled inertia effects, and the difficultly of achieving the required positional resolution. A determination of utility differentiated between candidate mechanisms on the basis of simplicity, robustness, achievement of required process motion, and probable cost.

EVALUATION OF PLATE FABRICATION PROCESS LANE ARCHITECTURES

Infeasible Architectures

The marking processes considered in this evaluation mark a workpiece by local deposition of material in the surface or locally ordered changes in the contour on the surface. Blast cleaning spalls off tightly adherent oxides generating a new surface of randomly positioned and oriented facets. Marks made prior to blast cleaning reside on or in the oxides being removed and are destroyed as a result of the operation. Marks made simultaneously or in parallel with blast cleaning are likewise destroyed. Architectures 1 ,2 ,3 ,4 and 5 mark before blast cleaning. Architecture 6 marks in parallel with blast cleaning. All of these architectures are infeasible.

Blast cleaning and preconstruction primer application and drying acquire a component of process motion from progress of the plate workpieces through the operation station. A series or sequential combination of such processes into a single station with a moving plate marking process into a single station is a physical impossibility since plate remains in the station only long enough to complete the first of the combined processes. This is a degenerate form of architectures comprised as a series of moving plate stations. Architecture 7 is a series combination of blast cleaning and moving plate marking. Architecture 11 is a series combination of preconstruction primer application and drying moving plate marking. Both of these architectures are infeasible.

Architecture 10 is a parallel or simultaneous combination of moving plate marking and preconstruction primer application and drying. Marks generated by material deposition processes are occluded by applied paint. Metal removal marking processes create locally high temperatures which may serve as an ignition source for paint solvents. Impression marking equipment includes many moving parts with small clearances and high bearing loads. Impression marking equipment operating in a single station with preconstruction primer application would be quickly destroyed by abrasive action of paint pigment or seized by binding with paint vehicle residues. Architecture 10 is infeasible.

Parallel or simultaneous operation of marking and thermal cutting of plate as in architecture 19 might be realized in several conceivable ways. First, marking equipment might be manipulated over the workpiece surface by an articulated mechanism mounted in the cutting machine bridge but working independently of the torch carriage. The articulated mechanism would be occluded from operation on the side of the cutting machine bridge opposite the articulated mechanism mounting. The course of marking trajectories is independent from the course of cutting line trajectories. The lengths if both trajectory classes are generally of the same order of magnitude. Simultaneous operation of both processes and completion in the same time frame requires a marking tool manipulator reach of at least half the diagonal of the largest plate anticipated. The manipulator must have a tool point operating speed in excess of torch speed and tool point positional accuracy better than 0.0315 inches. These requirements exceed the state of art in both mechanical design and positional control.

The second alternative is an independent marking bridge with retractable marking tools such that the cutting bridge may pass through. Tool velocity along the marking trajectories must be greater than along cut line trajectories to compensate for not marking during cutting bridge pass through periods. Height to allow clear passage of the cutting bridge requires mounting the marking tools on a telescoping mechanism. The marking tools are then cantilevered approximately 10 feet to the bearing support mounted on the cutting machine bridge. The required positional accuracy of marking is 0.0315 inches. These requirements are near the leading edge of art in mechanical design.

A third alternative is an independent marking bridge not able to pass the cutting bridge. After a short period one of the bridges would often preclude the other from most work opportunities. In this case, operation reverts to the series equivalent architecture.

The final alternative is an endwise dual position cutting platen. Each position of the platen is provided with an independent bridge not capable of passing. Both bridges are equipped to accomplish marking and cutting. Both bridges could accomplish work on either end. Since cutting trajectories should be continuous, one bridge would often preclude the other from most work opportunities. Handling plate on the platen and picking out cut parts and scrap occupies a major portion of cutting time. Thus marking speeds must be much higher than cutting speeds. These speeds are not supported by the state of art in marking. Working the bridges separately is the equivalent of doubling the number of serial marking and cutting machines. Architecture 19 is infeasible.

In architectures 20, 27, 28, and 29 marking is combined sequentially or in series with breaking of the nest and separation of parts and scrap. Tabs connecting the parts to the nest skeleton remain after cutting to facilitate handling. Nest breaking and parts separation are inherently manual operations and require a stationary workpiece. In these architectures marking is realized as a stationary workpiece operation. Plate workpiece cycle time for series combined marking and nest breaking is at least on the order of plate workpiece cycle time for part cutting . This excessive plate workpiece cycle time in a single station constrains throughput for the plate fabrication process lane. Architectures 20, 27, 28, and 29 fail the system prime objective and are infeasible.

Marking is combined simultaneously or in parallel with breaking of the nest and separation of parts and scrap in architectures 21, 24, 25, and 26. Economically feasible automated marking requires apriori fixed part location and orientation internal to a particular plate workpiece. Nest breaking and parts separation destroys this relation. Automated part marking is incompatible in parallel combination with nest breaking and parts separation. Workpiece cycle time for manual parts marking far exceeds the workpiece cycle time for part cutting. This excessive plate workpiece cycle time in a single station constrains the plate fabrication process lane throughput. Architectures 21, 24, 25, and 26 fail the system prime objective and are infeasible.

Architectures 34, 35, 36, 37, 38, 39, and 40 implement nest breaking and separation of parts and scrap prior to part marking. Automated part marking requires apriori knowledge of part identity, location, and orientation. Automation to preserve this knowledge for loose parts is economically infeasible. Manual parts identification, positioning and orientation for automated marking add sufficient plate workpiece cycle time to this station to constrain plate fabrication process lane throughput. Manual layout and marking of loose parts requires additional plate workpiece cycle time. Architectures 34, 35, 36, 37, 38, 39 and 40 fail the system prime objective and are infeasible.

Feasible Architectures

Practicality. Independent of the marking technology implemented, it is evident that the feasible plate fabrication process lane architectures exhibit varying degrees of practicality. The system objectives anticipate economic gain realized through productivity enhancement. Criteria used

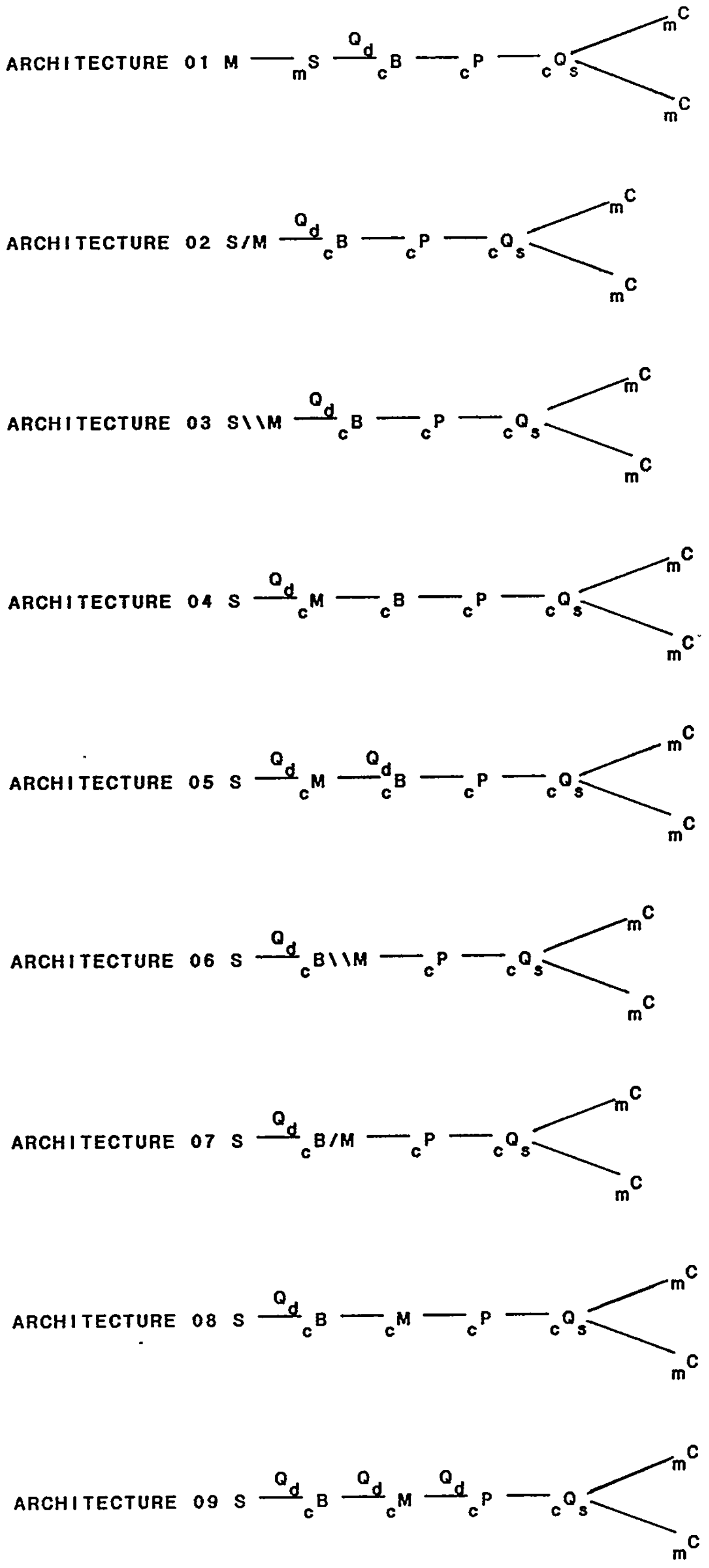


Figure 1.1. ALTERNATIVE PLATE FABRICATION PROCESS LANE ARCHITECTURES

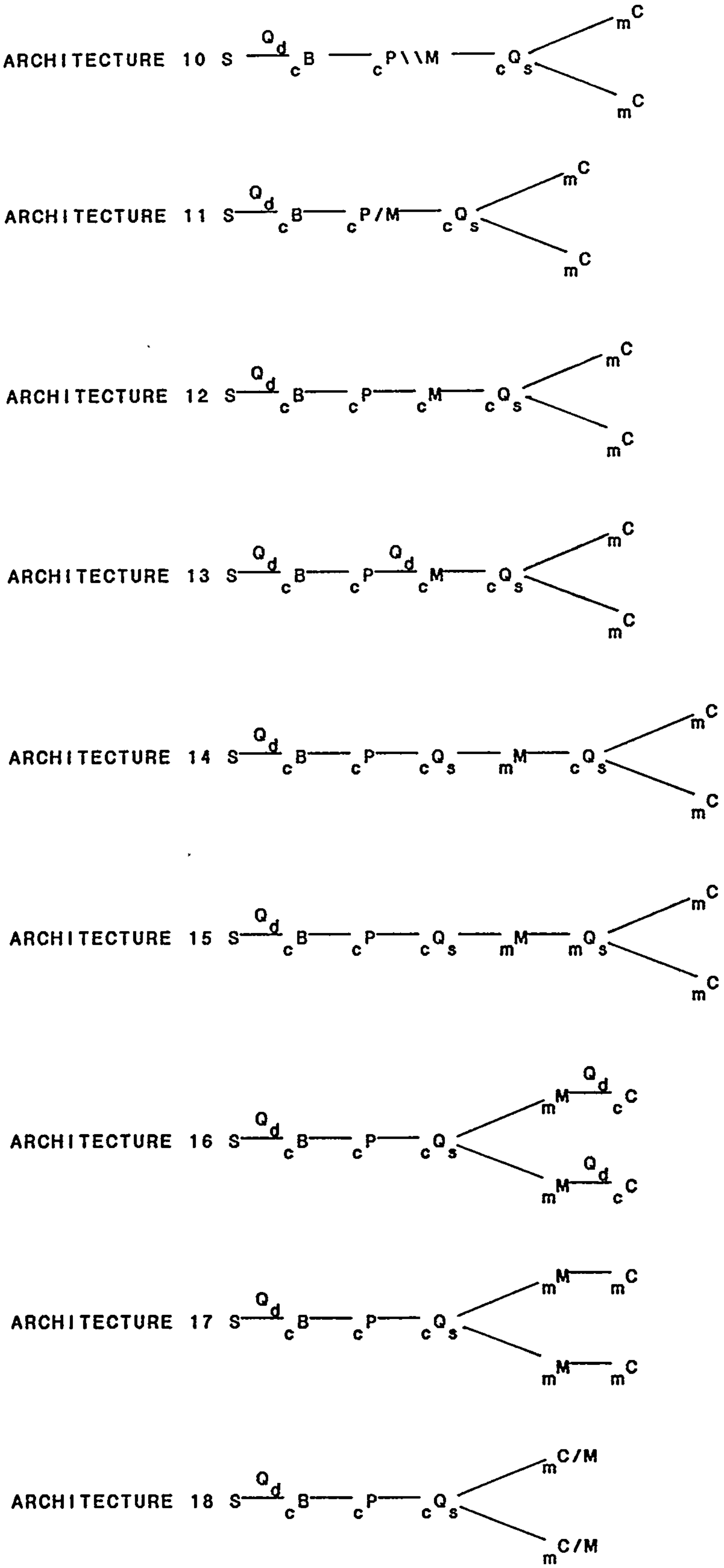


Figure 1.2. ALTERNATIVE PLATE FABRICATION PROCESS LANE ARCHITECTURES

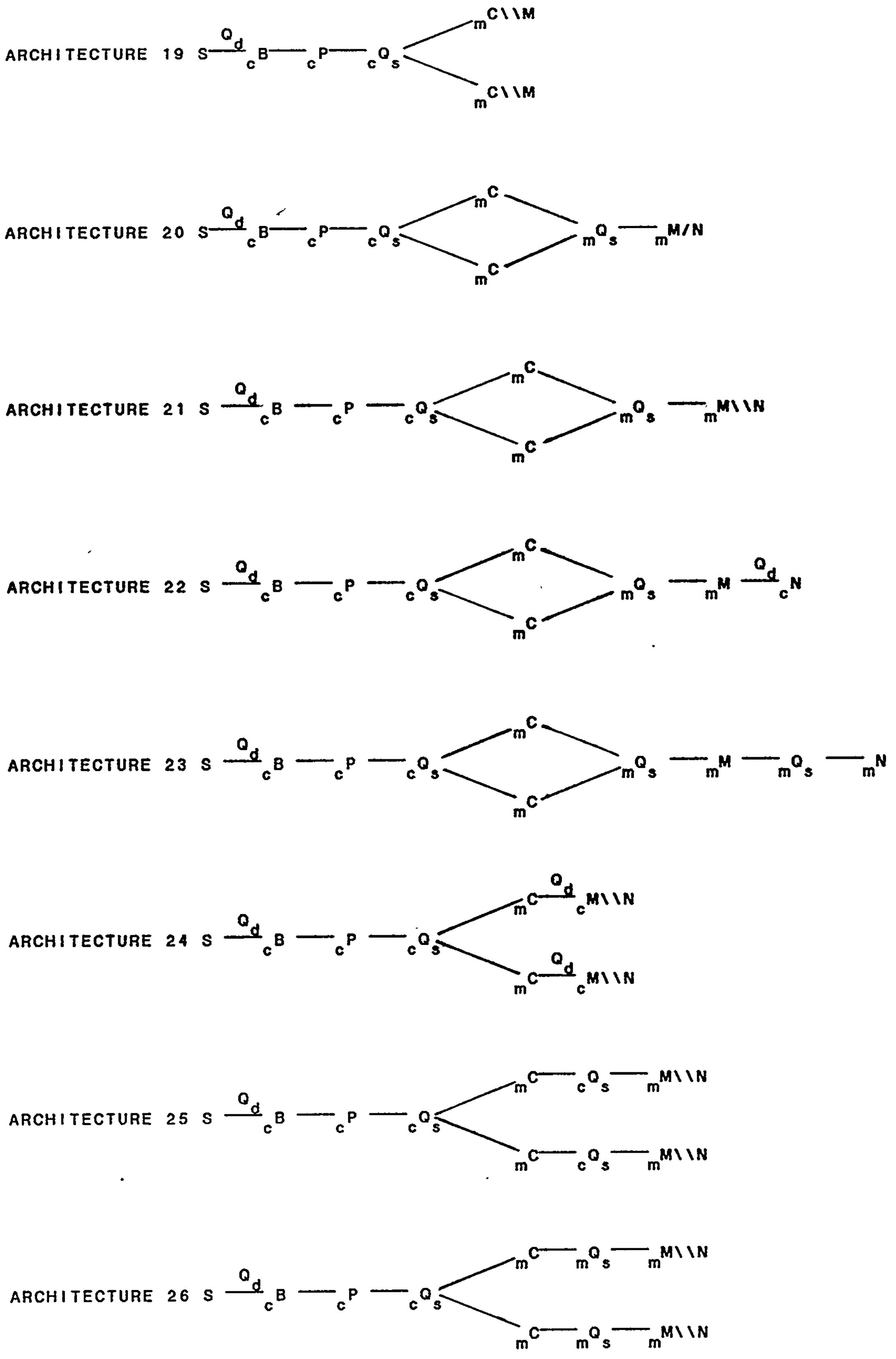


Figure 1.3. ALTERNATIVE PLATE FABRICATION PROCESS LANE ARCHITECTURES

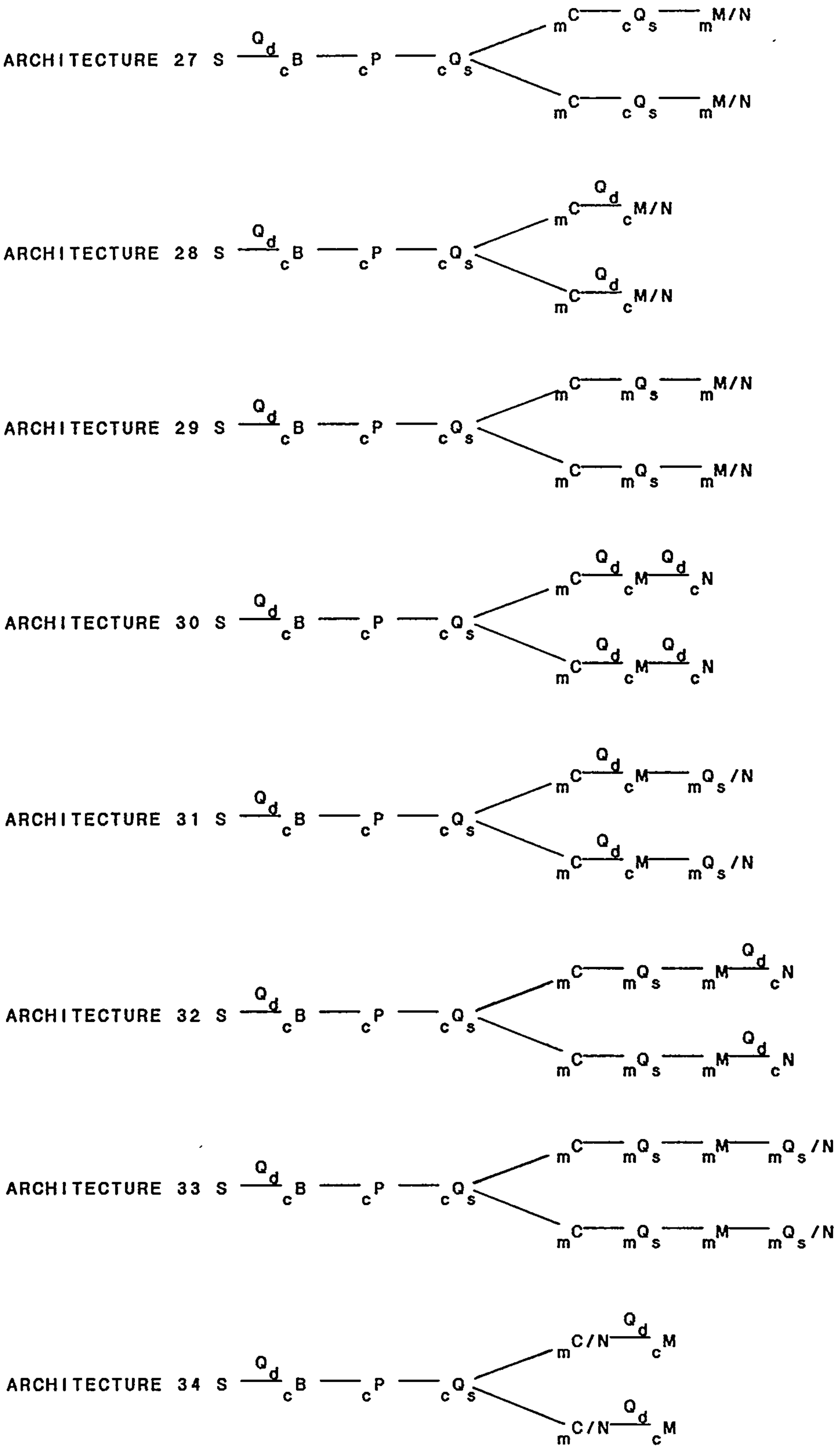
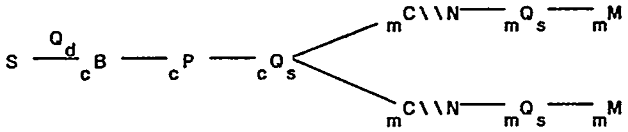
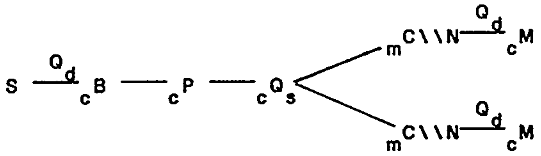


Figure 1.4. ALTERNATIVE PLATE FABRICATION PROCESS LANE ARCHITECTURES

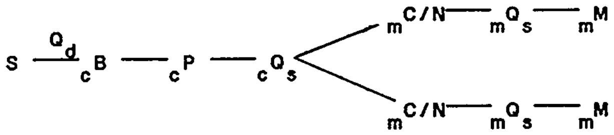
ARCHITECTURE 35



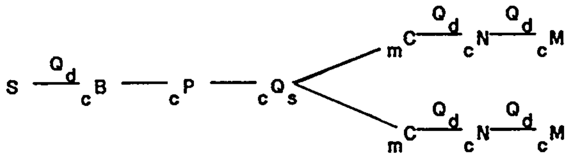
ARCHITECTURE 36



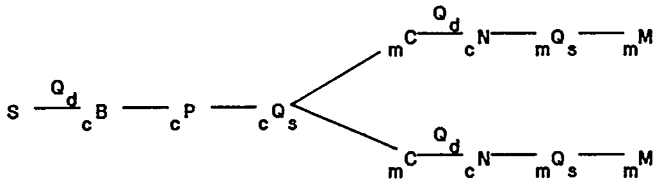
ARCHITECTURE 37



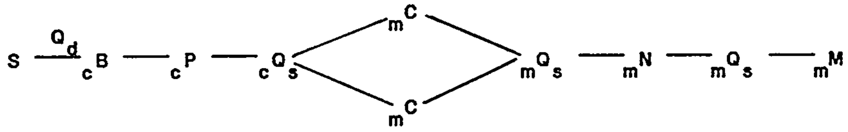
ARCHITECTURE 38



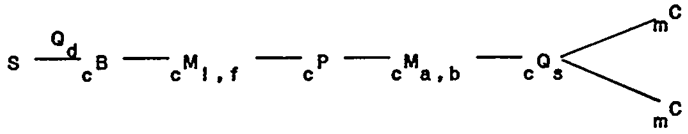
ARCHITECTURE 39



ARCHITECTURE 40



ARCHITECTURE 41



ARCHITECTURE 42

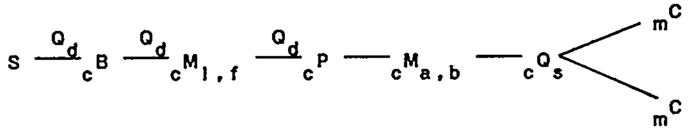


Figure 1.5. ALTERNATIVE PLATE FABRICATION PROCESS LANE ARCHITECTURES

to evaluate practicality derive from economic considerations.

Practicality Evaluation Criteria. There is a strong correspondence between the floor area occupied by a process lane and the topology of the process lane architecture. Architectures with numerous stations or complex material handling paths occupy larger areas. The manufacturing floor of most shipyards is largely populated with existing facility. If implementation of a manufacturing system within the process lane requires expansion of the floor under roof or relocation of existing productive facility, the related costs are often comparable with the acquisition costs of the new equipment occupying the area. Architectures occupying less manufacturing floor area are more practical.

In an economically driven environment the cost of equipment is a significant measure of manufacturing system practicality.Each architecture is directed toward achieving the same level of productivity enhancement. The less costly is the more practical. Cost is roughly related to the product of the amount of equipment required and the necessary mechanical complexity. Development and the necessary controller complexity also affect equipment cost but are strongly influenced by the selection of specific processes for implementation.

Dynamic material flow buffers, parallel process stations and additional bridge cranes or other material handling devices increase the amount of equipment required to accomplish a particular functionality. Adding degrees of freedom to the marking tool manipulator, or conveyor platens to the direct numerical controlled plate cutting machines increases mechanical complexity. Apart from a contribution to acquisition cost, increased mechanical complexity introduces added risk of development difficulties and tends to further reduce practicality.

The extent of touch labor required in plate fabrication is an inherent property of these architectures. The controllable touch labor content is mostly related to material handling requiring manual intervention and to nest breaking. Touch labor related to marking is controllable only in those architectures accomplishing this operation after part cutting. Reduction of the touch labor content of plate fabrication is a system objective. Increased touch labor content as a consequence of plate fabrication process lane architecture reduces practicality.

The probability of task conflict, competition between workpieces for the same resource or between resources for the same workpiece is particular to the topology of each architecture. The conflict arises from an imbalance of work rates in the component stations of the process lane. Extremely wide variation in work content exists between individual plate workpieces; particularly for plate marking and for plate cutting. The affect of this imbalance may be reduced by careful routing of workpieces through parallel resources. Craftsmen are essential to some links of these architectures, but add to task conflict by performance variability not accounted for in the route planning model. Task conflict tends to multiply the touch labor requirement of work accomplishment. Increased task conflict decreases practicality.

It is reasonably assumed that the reliability of a component resource can be made relatively constant and independent of position within the process lane architecture. The affect of failure of a component resource can vary widely with position in process lane architecture. In the case of the otherwise practical architectures considered in this study, however, the affect of marking resource reliability is not discriminating.

Each of the criteria are considered to weigh equally in the evaluation. A high level of impracticality under a single criterion is sufficient to determine a plate fabrication process lane impractical. In support of the determination the table also shows the contributions under subordinate criteria to the overall properties of the feasible plate fabrication process lane architectures. The following comments identify particular reasons for finding certain of the architectures impractical.

Practicality Evaluation Comments. Architectures 9 and 13 are similar. Both mark stationary workpieces in the plate preparation line portion of the process lane. Workpieces are handled into and out the marking station on the plate preparation line conveyor. Dynamic buffering isolates the marking station from other plate preparation stations. Architecture 42 is related to architectures 9 and 13. The marking resource is partitioned to accomplish line and fiducial marking prior to preconstruction primer application. Alphanumeric marking and generation of bar code representations of nest and part identifiers are accomplished following preconstruction primer drying. The time spacing of workpieces on the plate preparation line taxes the available speed of current marking technologies for completing the required marks on a nominal plate cutting nest.

The time required to handle plate into and out of the marking station reduces the time available for completing plate marking before impacting preparation line operation. Many workpieces are significantly different from the nominal plate cutting nest. Existence of these different from nominal plates creates task conflict that results in unacceptable delays in preparation line operation. Resolution requires impractical numbers of marking tools.

The time spacing for cutting plate is different and often greater than the intervals between stations on the plate preparation line. Positioning a marking resource between the preparation line and the cutting machines reduces the burden of mark generation speed and the production sensitivity to the amount of marking per plate associated with marking of stationary plate. This requires isolation of the marking station from the plate preparation line with a static buffer or queue. In architecture 14 plate workpieces are crane lifted from the queue to the marking platen and handled out the marking station on a conveyor and into a second queue to await cutting. In architecture 15 plate workpieces are crane lifted from the queue to the marking platen and crane lifted from the marking platen to a second queue to await cutting. The additional crane handling implemented in these architectures requires acquisition of an additional crane to accomplish marking station workpiece handling and a portion of the cutting machine loading tasks. Operation of two cranes in the same queue implies at least a medium level of task conflict. Architecture 16 implements parallel marking stations crane loaded from the queue at the end of the plate preparation line. Each of the marking stations is coupled to a single cutting machine with a conveyor equipped for dynamic buffering. This topology provides additional workpiece time available for marking. Mismatch between marking time and cutting time for separate plates still exists and implies at least a medium level of task conflict. These architectures require high to very high envelope. These architectures require high to very high equipment cost. Knowledge of plate size, thickness, and alloy is created as individual stock pieces are retrieved from storage and loaded onto the plate fabrication process lane infeed conveyor. Preservation of this data is essential to automatic correlation of material with marking and cutting information. While plate remains on the fabrication process lane infeed conveyor the identity of each workpiece is intact. When plate is removed from the conveyor to the queue, workpiece identity is destroyed. Craftsmen determine the need to load plate from the queue to the marking station. It is not possible to guarantee a specific order of plate removal from the queue. Functioning of these architectures requires manually maintained identity by some means equivalent to application of bar coded labels to each workpiece entering the queue. Otherwise the information must be recreated during loading of the marking station. Architectures 14, 15 and 16 are impractical.

Most shipyards currently mark plate in series combination with cutting. Plate is crane lifted onto the platen and manually aligned with the cutting machine axes. After the cutting machine operator sets the datum to the plate edges, a pneumatic prick punch mounted in the torch carriage automatically marks construction and reference lines. Direct numerical control plate cutting machines are usually equipped to generate the alphanumeric characters necessary for part identification. This capability is seldom used because the large cycle time required constrains plate workpiece throughput. It is common practice for the cutting machine operator or a layout man to manually identify parts in parallel with the line marking operation. This practice is potentially dangerous and is subject to error. Architecture 18 achieves the objective throughput increase by at least doubling the number of direct numerical controlled cutting machines currently installed in the plate fabrication process lane. Several factors combine to establish the impracticality of this architecture. The number of additional plate cutting machines required have a very large envelope and a very high acquisition cost. Because of the length of traverse involved a second crane is required . This architecture does nothing to reduce the manual labor content of plate fabrication. Knowledge of workpiece size, thickness, and alloy must be recreated during cutting machine loading. The cutting nest assignment of the plate must then be identified. Finally, two cranes servicing several plate cutting machines from a single queue implies a high level of task conflict. Architecture 18 is impractical.

The architectures that accomplish marking after plate part cutting form two related topological groups. Architectures 22 and 23 complete plate part fabrication in a single line of operation stations. Workpiece handling arrangements differentiate between these architectures. Architectures 30, 31, 32 and 33 complete plate part fabrication in parallel lines of operation stations. Workpiece handling arrangements differentiate between these architectures. All members of both groups require very high envelopes and involve very high acquisition costs. All have a high touch labor content and involve a very high level if task conflict as inherent properties of the architecture. Architectures 22, 23, 30, 31, 32 and 33 are impractical.

Combined Utility. The AUTOMARK design concept is selected by evaluating the utility separately exhibited discrete combinations of each candidate marking process with practical plate fabrication process lane architectures. Each combination anticipates embodiment with a class of manipulation mechanism particularly suited to the required process motion. The number of marking tools implemented in each is variable and specific to each combination. Adequacy of each combination to meet the plate fabrication process lane throughput improvement is assumed. The evaluation considers the coupled properties of each combination. Utility is evaluated according to the properties of each combination measured against fixed criteria. These criteria express the suitability of the product for assembly and other subsequent shipyard operations, marking tool manipulation factors influencing the magnitude of required investment, the magnitude of operating costs, and the means necessary to assure personnel safety. In support of the determination the properties of each combination are also examined against subordinate criteria.

Combined Utility Evaluation Criteria. It is essential that the product of the plate fabrication process lane exhibit a consistent high level of geometric fidelity and mark legibility. Line marks must withstand assembly and erection operations. Identification marks must maintain legibility at least through first level assembly. The parts will be stored outdoors in a harsh marine environment. Degradation of the required mark legibility or permanence by or as the result of factors associated with adjacent processes reduces suitability.

Separate classes of mechanism are more suitable than others for the manipulation of each candidate marking processes in a given position within the plate fabrication process lane architecture. The mechanism class and the moving mass anticipated with each embodiment reflect the mechanical complexity associated with the combinations. These factors together with closing of the manipulation kinematic chain by workpiece contact marking processes are reflected in the combination control complexity. The number of marking tools required multiply the complexity. All of these factors contribute to increased capitol investment requirement. In an economically driven environment, other factors being equal, reduced investment requirements increase utility.

Operating costs include power and expendables, and the costs associated with reliability and maintainability considerations. These factors directly influence utility in terms of return on investment. Power, expendables, and maintenance labor and supplies appear as pure costs. System down time appears as production opportunities lost and disruption to adjacent processes and operations.

Personnel safety must be assured without compromise. The complexity of assuring personnel safety is specific to each combination of marking process, manipulation mechanism, and position in the plate fabrication process lane. Greater safety assurance complexity is reflected in greater required investment and reduced utility.

Combined Utility Evaluation Comments. The most influential factors in determining utility for practical plate fabrication process lane architectures coupled to particular marking process and suitable manipulation mechanisms are the effects of adjacent processes on the suitability for purpose of the resulting cut and marked plate parts. These factors establish the unacceptability of water jet engraving and zinc oxide powder marking. Ink jet marking is unacceptable in architecture 8 because preconstruction primer application occludes the marks. Ink jet marking is unacceptable for lines but good for alphanumeric characters and bar code representations of cutting nest and part identifiers in architectures 12 and 17. Impression stamping before and after preconstruction primer application if the number of impressions is reduced and the the impression impulse and marking tool dimensions are carefully controlled so that damage to the preconstruction primer is limited. The very great mechanical complexity of impression stamping equipment necessary for this application will create an unacceptable reliability and maintainability problem. Rotary tool engraving will exhibit a similar reliability problem. Very high levels of tool breakage and out of specification marking cuts are anticipated because of the difficulties of high speed force and position controlled manipulation over waves and other imperfections in the plate workpiece surface which cannot be well known apriori. The best balance of product suitability is obtained by partitioning the marking resource as in architecture 41, and selecting laser engraving for lines and fiducial marks, and ink jet marking for alphanumeric characters and bar code representations of cutting nest and part identifiers. This choice is substantiated by the marking tool manipulation factors, and by the the operating factors. The complexity of assuring personnel safety is acceptable and not significantly different than in the other architectures.

DESIGN CONCEPT DETERMINATION

The design concept selected for the AUTOMARK system partitions the workpiece marking task into 2 separated marking stations. The partition is made because of differing marking tool requirements for lines and for alphanumeric character marks. The partition is also made because of differing permanence requirements for lines and for alphanumeric character marks. Lines and fiducial marks are laser engraved on moving plate workpieces prior to preconstruction primer application. Alphanumeric characters and bar code representations of cutting nest and part identifiers are ink jet marked on moving plate workpieces following preconstruction primer drying. The direct numerical control cutting machines are provided with machine vision sensors to automate alignment of the plasma arc torch trajectories with workpieces on the platen.

Figure 2, is a schematic representation of the design concept selected for the AUTOMARK system. It illustrates process accomplishment and shows information flow through the system.

Beginning with the daily or the weekly cutting plan, a requirement for specific stock plates is generated. This requirement is transmitted an item at a time to the plate stock stowage yard. There the identity and location of the required plate are displayed for the conveyor loading personnel. As each workpiece plate is loaded onto the conveyor and confirmed, its association with a particular cutting nest is created. The shipyard material data system is advised. The next stock plate requirement is then displayed and the conveyor loading operation repeated.

The mechanical sequencing preserves the nest association of the workpieces. The corresponding line and alphanumeric character data is accessed. Fiducial mark locations are generated and added to the nest. After data parsing, marking tool trajectories are planned for the line marking station and the alphanumeric character marking station. Operation of the line marking station and operation of the alphanumeric character marking station creates the marks planned for each particular workpiece plate. Workpiece plates are automatically unloaded from the preparation line conveyor into a static queue following marking completion.

Plates are lifted from the static queue and landed onto the direct numerical control cutting machine platens. Automated alignment begins with the direct numerical control cutting machine bridge and carriage positioned such that the machine vision camera images the corner of the workpiece opposite the lead in cut. Plate size data is accessed through the cutting nest identifier marked on the plate. Using this data as apriori guidance information, and edge location data from the machine vision camera as feedback, the AUTOMARK system traces the workpiece plate boundaries counterclockwise to the lead in cut. The fiducial marks along these boundaries are made in positions related to plate size. The fiducial marks serve as the coordinate reference for the line marks on the workpiece. When the machine vision identifies a fiducial mark, the location of the fiducial mark in camera coordinates is associated with the current camera location in cutting machine coordinates. The relation between the workpiece coordinate reference and the direct numerical control cutting machine coordinate reference is computed using the sensed locations of the fiducial marks. The cutting trajectories are then translated and rotated according to the result and the plasma arc torch operation initiated.

TECHNICAL FEASIBILITY DEMONSTRATIONS

Technical feasibility demonstrations were accomplished to establish reasonable assurance that the AUTOMARK system can be successfully developed and that the system performance will meet the study objectives. These demonstrations concentrate on the making of line and fiducial marks and the sensing of fiducial marks for automatic alignment with the cut trajectories. Because the required speeds and geometric fidelity requirements thoroughly tax the state of available technology, these tasks are considered more difficult than ink jet application of alphanumeric characters and the bar code representations of these characters.

The demonstrations show that it is possible to laser engrave marks meeting the system requirements. They show that it is possible to construct a control device to place these marks anywhere on the largest plate and in any direction required. The demonstrations further show that sufficient data exists in the nest images as currently formatted to programmatically place fiducial marks in the nest image, to parse the data, and assign marking duty among the several line marking subresources, and to

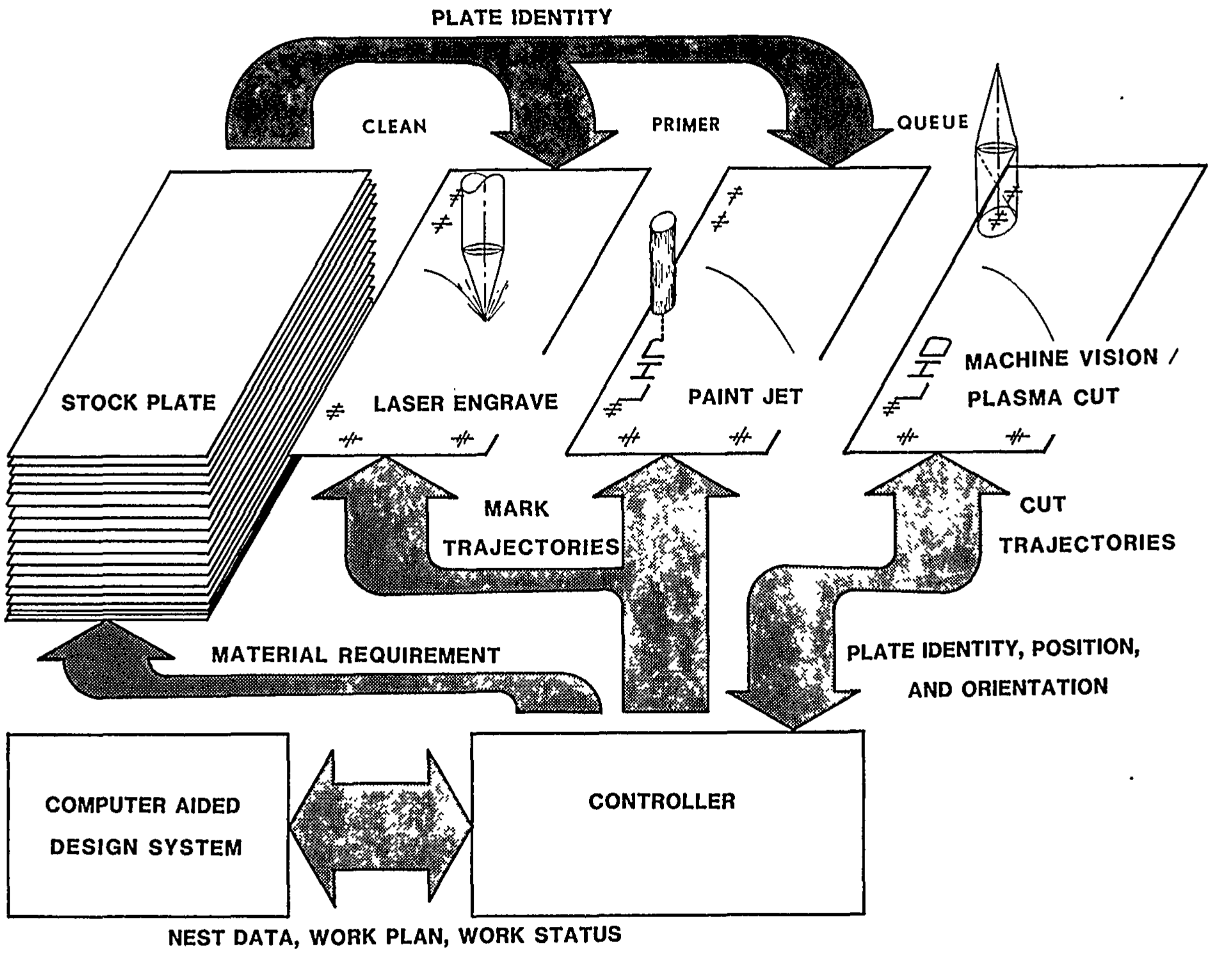


Figure 2. AUTOMARK SYSTEM DESIGN CONCEPT

generate the necessary marking subresource trajectories. These trajectories are shown to accomplish the required marks. Finally, the demonstrations show that the plate edge and the fiducial marks can be sensed by commercially available machine vision subsystems. These data provide adequate information for near real time software alignment between the the plate workpiece and the cut trajectories.

Line Marking Vector Geometry

The capability to create marks in any particular orientation by manipulating a marking resource along a line crossing the direction of workpiece motion is determined by 6 physical parameters. These are the marking speed of the process, S_p, the velocity of workpiece motion, V_p, the marking resource manipulation velocity, V_m, the length of mark required, W_p, the orientation of marking resource manipulation relative to workpiece motion, and the direction of marking resource motion along the manipulation line.

Laser engraving created acceptable marks at maximum marking speeds of at least 300 inches per minute. In order to support the worst case shop load requirement for *total length of plate* per shift, the workpiece velocity is fixed as 180 inches per minute. Commercially available linear stepper motors exhibit maximum rated load velocities of 3000 inches per minute. The most difficult mark to create is a line across the full width of a workpiece. The maximum plate width is 156 inches.

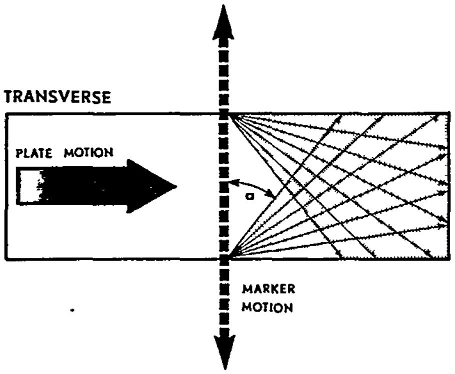


Figure 3. SUPERPOSITION OF POSSIBLE MARK ORIENTATION FAMILIES WITH MARKING RESOURCE MANIPULATION NORMAL TO WORKPIECE MOTION

It is required to create marks at any arbitrary orientation and location on the workpiece surface. It follows that it is requires to create marks at right angles to the direction of workpiece *motion. This cannot be accomplished* by manipulating the marking resource normal to the direction of workpiece motion, since infinite marking speed is not available. To create marks at right angles to the direction of workpiece motion requires marking resource manipulation along a diagonal line. Figure 3, illustrates this fact. The figure shows superposition of mark orientation families possible with marking resource manipulation normal to the direction of workpiece motion. These families occupy mirror image regions. The approach of either region to the workpiece motion direction normal is bounded by equal angles, a. A vector representation of the limiting conditions is shown in Figure 4. Note that the effect of workpiece *velocity*, V_p, is the same as manipulating resource in the opposite direction.

$$a = \text{Sine}^{-1}(|S_m|/|V_p|)$$

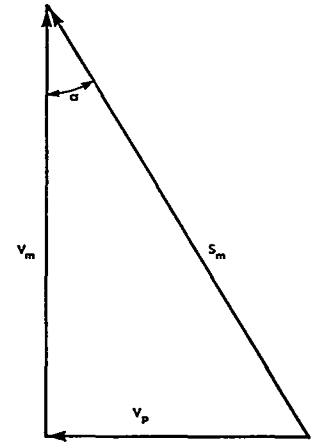


Figure 4. LIMITING MARK ORIENTATION FOR MARKING RESOURCE MANIPULATION NORMAL TO THE DIRECTION OF WORKPIECE MOTION

The angle, d, between the direction of workpiece motion and the direction of the marking resource manipulation line cannot be uniquely determined because only a single fixed value and a pair of maxima are known. The bounds on d can be established. Consider the angle which just satisfies the requirement to mark across the full plate width, W, normal to the direction of workpiece motion. Consider also the angle which *necessitates maximum marking speed* to just achieve the normal to workpiece motion. Figure 5, is a vector representation of these bounding states.

For the state bounded by maximum workpiece plate width,

$$d_1 = \text{Tangent}^{-1}(|W|/|V_p|)$$
$$= 40.91 \text{ degrees.}$$

For the state bounded by maximum marking speed,

$$d_2 = \text{Tangent}^{-1}(|S_m|/|V_p|)$$
$$= 590.04 \text{ degrees.}$$

Reversing the direction of marking resource manipulation results in an entirely different condition. This is represented in Figure 6. The angle, e, between the workpiece motion direction and the marking resource manipulation line is the supplement to angle d. The bounds on d apply likewise to e.

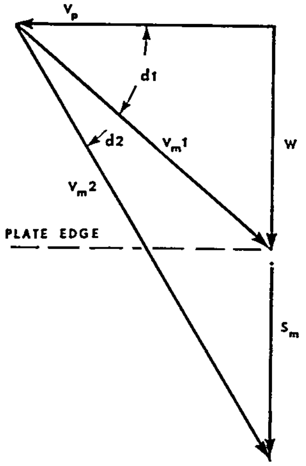


Figure 5. BOUNDING STATES FOR MARKING NORMAL TO THE WORKPIECE MOTION DIRECTION WITH DIAGONAL MARKING RESOURCE MANIPULATION

e_1 = 139.09 degrees.

e_2 = 120.96 degrees.

f is the angle between reverse motion marking resource manipulation and the resulting mark on the workpiece. Using the law of Sines;

$$f = \text{Sine}^{-1}\{(|V_p|/|S_m|)\text{Sine } e\},$$

f_1 = 23.14 degrees,

f_2 = 30.97 degrees.

The angle, g, between the limiting mark orientations and the workpiece motion direction is the difference of d and f.

g_1 = 17.77 degrees

g_2 = 28.07 degrees

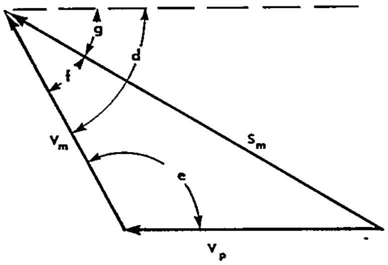


Figure 6. REVERSE DIRECTION DIAGONAL MANIPULATION OF MARKING RESOURCE

Since neither bound permits complete workpiece coverage, a second marking resource is required with manipulation along the opposite diagonal.The arrangement overlaps a second, mirror image, family of possible mark orientations onto the above. This results in complete workpiece coverage. Superposition of the families of possible mark orientations is illustrated on Figure 7.

The sum of workpiece velocity and maximum marking speed are less than maximum marking resource manipulation velocity. In no state is marking resource manipulation velocity a controlling parameter.The length of marking resource maximum traverse associated the workpiece bounded state is 21.37 feet. The length of marking resource maximum traverse associated with the marking speed bounded state is 16.33 feet. AUTOMARK system velocity tolerances and the possible need for retrograde marking orientations must be traded off in the final design with the accuracy and economic implications of the shorter traverse.

Laser Engraving Process Parameter Determination

Tests were accomplished for initial determination of process parameters of laser engraving for a system to automate marking of structural plate. It is anticipated that the work specified will identify potential marking speed and the necessary functional relationships between marking speed, power, pulse rate, and beam delivery to conduct trade-off studies.

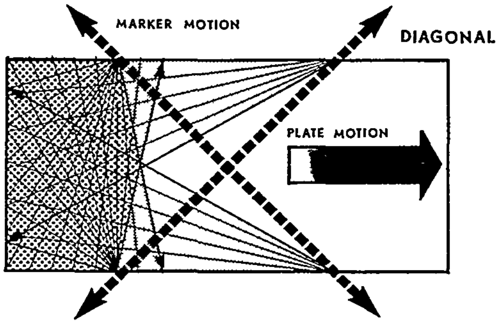


Figure 7. SUPERPOSITION OF FAMILIES OF POSSIBLE MARK ORIENTATIONS WITH DIAGONAL MARKING RESOURCE MANIPULATION

The test coupons were steel plate in a abrasive blast cleaned condition with a surface profile of approximately 0.002 to 0.006 inches. This surface condition is identical with that expected on plate workpieces during system operation. After an initial process parameter estimation, the remaining coupons were marked as follows. The objective mark design required near continuous font with mark width at least equal to depth. A maximum mark width of 0.03 inches was allowed. Mark depth at least 0.008 inches below the effective plate surface and not greater than 0.02 inches was required. The mark design required a rounded bottom contour with a minimum radius approximately equal to mark depth. The minimum allowed speed of advance along a principle direction of line marks is 300 inches per minute.

The effect of process parameter variation on engraving steel plate with a carbon dioxide laser operating in pulsed mode was tested. The effect of process parameter variation was also tested engraving steel plate using carbon dioxide laser operating in continuous wave mode. In continuous wave operation the beam was delivered to the work piece through a final optic such as a boring optic rotating in a small radius about an axis through the line direction of the mark. Alternately some other available means could have been used to generate time variation of continuous wave power delivered to the leading portion of the cut.

Using experience and optional testing as appropriate, a baseline process parameter set with pulsed laser operation and a baseline process parameter set with continuous wave laser operation were determined. Beginning with the baseline process parameter set power was increased over a sequence of intervals. Line mark speed was also increased over a sequence of intervals. Each sequence of intervals formed an approximate exponential series. Each sequence was scaled to permit at least 5 intervals within the capabilities of the equipment.

All parameter combinations from the defined sequences were tested by electing to hold either line marking speed or power constant and varying the other parameter according to the defined sequence along the length of a continuous line trajectory.

Using results of the power and speed functionality tests the power values which exhibited acceptable marking over the widest range of line mark speed were selected. Also, the line mark speed values which exhibited acceptable marking over the widest range of laser power were selected. These parameter combinations were then tested to determine laser engraving process variation with change in beam delivery frequency. Acceptable results were achieved with line marking speeds up to 500 inches per minute.

Using results from all of the previous testing, process parameter sets that exhibited the largest regions of parameter variation that generate acceptable marks were selected. A coupon was positioned such that the surface sloped horizontally with the gradient in a plane parallel to the direction of marking trajectories. Depth of focus tolerance was tested by making a continuous mark along the coupon from a point where the surface was well below the focus to a point where the surface was well above the focus. Machine vision test coupons were marked with a principal line 3.0 inches long. The principal line was crossed with a perpendicular bisector 1.0 inch long such that 0.5 inches of the bisector length lies to either side of the principle line. The principal was also crossed with 2 perpendicular interceptors, 1 to either side of the bisector, spaced 1.0 inch from the bisector. The perpendicular interceptors were be 0.5 inches long such that 0.25 inches of the length of an interceptor lies to either side of the principal line.

Control Feasibility

Copies of typical plate nest images as currently generated for use with a direct computer numerical controlled plasma cutting machine equipped with a pneumatic prick punch marker were used to demonstrate AUTOMARK system control feasibility. The nest images contained marker trajectories, and associated control data, plasma torch trajectories and associated control data, and high speed traverses separately associated with marking or cutting. The nest images were realized in ESSI notation.

Nest image data was parsed into marking fields and cutting fields. The parsed marking field consisted of a list of marking trajectories. High speed traverses associated with marking trajectories were delimited by the marker control characters. The parsed cutting field contained all nest image data associated with operation of the plasma torch.

Locations and orientations for fiducial marks were programmatically identified according to the rules included in the system requirements. Trajectories for accomplishing the several fiducial marks were programmatically generated and linked to the parsed marking field.

A time domain plan was programmatically evolved for accomplishing line marking spatially distributed over the surface of a plate passing through the marking resource at uniform velocity. The marking resource is partitioned into functionally independent subresources as shown in Figure 8. Marking duty of an individual marking subresource was multiplexed between any number of lines within the physical constraints of the system. Marking duty along any particular line was multiplexed between any number of marking subresources within the physical constraints of subresourse operation defined in the system requirements. The plan allocated marking duty among the marking subresources and defined time domain trajectories along the translational axis of each marking subresource as necessary for accomplishment of the required marks. Plate velocity and motion properties of the marking subresorces was in accordance with the system requirements. The marking duty plan evolved in the following sequence.

Fiducial marks and critical line features such as intersections, stops, and arc segments were identified.

Marking duty assignment and marking subresource trajectories for fiducial marks and critical line feature marks were defined. This assignment accounted for all fiducial mark and critical line feature marking trajectories and traverses of separate marking resources between marking trajectories.

Marking duty assignment and marking subresource trajectories for running line marks were defined. This assignment accounted for running line marking trajectories as well as the maintenance or replacement of fiducial mark and critical line feature mark trajectories. This assignment also accounted for traverses of separate marking subresources between marking trajectories.

Computer graphic display of simulated mark accomplishment was made showing the marking subresource trajectories relative to the plate. The simulation displayed the time domain accumulated result of the several marking subresorces operating simultaneous along the trajectories defined above.

Fiducial Mark Sensing

Laser engraved coupons were coated with approximately 0.001 inches thickness of inorganic zinc primer. These coupons were then used to demonstrate the capability of commercially available machine vision subsystems to image, to programmatically identify the workpiece edge, and to accurately establish the location of these features in the camera field of view. The machine vision subsystems used in these demonstrations were first taught the fiducial mark and the coupon edge features. These programs were then exercised with the coupons placed in differing locations and orientations throughout the camera field of view. The fiducial mark and coupon edge were successfully tracked at frequencies up to 10 Hertz. This frequency is sufficient to support servo controlling camera position from the sensed edge of the workpiece. The frequency is also sufficient to support the equivalent of real time fiducial identification and location in cutting machine coordinates.

PRELIMINARY DESIGN

Evolving a preliminary design simultaneously with preparing system development specifications from the requirements list performs at least three useful functions. The preliminary design serves as an illustrative example of the intent of the specifications and promotes more effective communication between the system designer and potential developers. Evolution of the preliminary design forces careful consideration of conflicts, missing elements, and unrealistic expectations within the specification and encourages resolution. Through the preliminary design, reasonable assurance of system performance levels are gained, and sufficient knowledge of system technical complexity and material requirements are obtained. This knowledge enables computation of reliable system economic justification estimates.

Material Handling Design

The selected AUTOMARK design concept marks plate workpieces while the plates are in motion on a linear conveyor means. For the task of distributing marks over the plate surface, plate motion thus becomes a component of the marking process motion. Very precise real time estimates of the plate location and velocity are necessary to maintain the required line mark geometric fidelity. A test was conducted to measure the components of plate velocity and deflection as the plate was conveyed using the present facility. The roller spacing is 36 inches and nominal conveying speed is 125 feet per minute. Surprisingly little yawing or crabbing motion was observed. Vertical excursions in excess of 2 inches were measured as the leading edge of the plate passed over each succeeding roller. It is necessary to suppress most of this vertical motion in order to establish achievable bounds on the control bandwidth for the laser dynamic focusing mechanism and to preclude collision of the marking tools with the plate. Analysis shows that the vertical motion amplitude is coupled to the conveying speed and very strongly coupled to the conveyor roller spacing. Accordingly, the spacing between full conveyor width rollers is reduced by a third in the preliminary design to 24 inches in the line marking station. In order to further attenuate the amplitude of the plate vertical motion in the marking station, additional short span rollers are positioned between adjacent full conveyor width rollers. Conveying speed is reduced by seven eighths to 15 feet per minute. This conveying speed will just support the worst case plate length shop loading anticipated for the system. This material handling design should result in reducing the vertical motion of the plate to less than 1 per cent of the previous value.

Vertical axis rollers are provided along one edge of the conveyor to establish a physical boundary. Plate workpieces entering the marking station are forced across the conveyor to the boundary rollers. The pusher mechanisms contact workpiece plates with vertical axis rollers. These rollers are isolated from the rest of the pusher mechanism with volute type gas springs to provide a measure of compliance to the actual plate orientation, to suppress impact loading, and to prevent overload of the plate as it achieves alignment with the conveyor edge boundary rollers. Full conveyor with rollers in the marking station are skewed 5 degrees from normal to the conveyor axis to preserve the plate alignment to the boundary rollers achieved by the pusher mechanisms.

Linear arrays of retroflective optical beam breaks are mounted in the gaps between sections of full conveyor width rollers. These sensors provide the AUTOMARK system controller with plate position data and estimates of plate velocity.

Laser Beam Delivery Optics Manipulation

The parameters driving design for delivery of the laser beam to an individual subresource of the line marking station derive from the properties of light transmission and the very large amount of marks to be made. The final delivery optic must be manipulated along linear trajectories up to 30 feet long at velocities as great as 60 inches per second and with acceleration on the order of 50 inches per second squared. The delivery optic is required to dynamically focus on a workpiece with out of plane waves having amplitudes up to 1 inch in thin plate and wave lengths on the order of tens of inches. The required pointing accuracy is on the order of 0.01 inches from true position measured on the plate surface.

Taken together, this means that the laser beam will experience long air passes and be caught by a turning mirror moving along a linear traverse as part of the car carrying the final delivery optic. The dynamics require a compact, very stiff and minimal mass design for the final delivery optic, the car carrying the optic, its attachments and accessory equipment, and any necessary utilities and signal connections. This requirement precludes on car mechanizations of dynamic alignment error compensation and motorized final delivery optic focusing. Focusing will be accomplished with a servo gas cylinder integrated into the design of the barrel of the final delivery optic and powered with excess cover gas or gas from the way bearing supply. Motion of the final delivery optic car is powered by a linear stepper motor for maximum drive response and minimum drive inertia and complexity. The car runs on gas lubricated way bearings for high stiffness and minimal friction. To maintain highly accurate alignment the way bearings are mounted on the sides and the top surfaces of a trapezoid section monocoque beam and grouted into place after final adjustment. Two independent cars operate one on each side of the beam. There are a total of 4 beams supporting 8 final delivery optic cars. The arrangement is shown on Figure 8.

Ink Jet Tool Manipulation

Manipulation of ink jet tools over the surface of workpiece plates to apply alphanumeric character marks is similar to manipulation of the final delivery optic. The trajectories are linear. High speed manipulation dynamics are required by the large amount of marks to be made. Because ink jet tools can achieve a very high character generation rate, and because the position and orientation tolerances for alphanumeric character location are much broader than for line marks, only 2 ink jet tools are required. These are mounted on separate cars running independently on opposite sides of a single beam across the width of the conveyor. The cars are each driven by linear stepper motors and supported on gas lubricated way bearings. Ink jet tools offer sufficient depth of field for satisfactory process operation so that dynamic compensation for out of plane waves is not required. Adjustment is provided for the various nominal thicknesses of workpiece plate to be marked. The ink jet tools are incapable of rotating characters into alignment with the marking trajectory over the workpiece plate surface. This function is accomplished by a hollow shaft stepper motor which serves as a rotary mounting stage for the ink jet marking tool.

SAFETY CONSIDERATIONS [1]

When high energy density processes are proposed it is essential to question in detail the ability of industry to safely implement the proposal. The AUTOMARK system design concept incorporates a very large laser operating in an environment which cannot feasibly be totally enclosed. Numerous lasers of the proposed type are operational in similar environments throughout the metals working industries. Disabling, and sometimes fatal accidents have happened to personnel working with, or maintaining such lasers. The record shows that these accidents occurred because of disregard of the requirements of law, standard industrial laser practice, or failure to follow other standard industrial practices. Conscientious compliance with the requirements of law Conscientious compliance with the requirements of law and standard industrial practice will result in safe laser use. The Laser Research and Technology Division, Los Alamos National Laboratory, achieved a decade without known permanent biological damage to any of more than 400 personnel working with numerous lasers of various types and wavelengths.

The applicable law is Title 21, Section 1040, Code of Federal Regulations (21CFR1040). The Federal Code references American National Standards Institute (ANSI) Z 136.1 American National Standard For Safe Use Of Lasers as the norm for safe use of lasers in industry. The requirements include a thorough hazard analysis, implementation of engineering controls commensurate with the level of hazard,and institution of management controls to assure compliance.

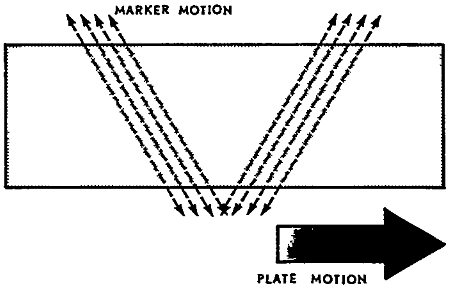


Figure 8. LINE AND FIDUCIAL MARKING STATION RESOURCE ARRANGEMENT

Hazard Analysis

The primary step in analysis of the hazards posed by industrial lasers is to establish the type and class of laser to be implemented, the process to be accomplished, the associated hazard sources, and the probable biological consequences of personnel exposure to these hazards. The AUTOMARK system is proposed using a class 4 pulsed carbon dioxide laser operating with an emissions output power of up to a kilowatt. The laser will emit light with a wave length of 10.4 micrometers. The emissions are within the infrared portion of the electromagnetic spectrum and are not visible. Light from this portion of the spectrum is very heavily attenuated by most glasses and optical grades of plastics. This will permit

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[1] This section and associated subsections draw heavily on the requirements and discussion contained in American National Standards Institute (ANSI) Z 136.1-1986 American National Standard For Safe Use Of Lasers. This section and associated subsections are intended as an abstract and analysis of the requirements applicable to AUTOMARK system design and implementation. This section and associated subsections are NOT a substitute for the requirements of law or the American National Standards Institute.

the use of optically clear materials for the necessary process viewing ports and for mandatory use safety glasses.

The optical power of class 4 lasers is sufficient that exposure of personnel to even a portion of the direct beam, and under certain circumstances to diffuse reflections will exceed the maximum permissible exposure.

The maximum permissible exposure has been established for each portion of the electromagnetic spectrum at levels generally a tenth of the damage threshold level for 50 per cent of the general population. These levels show a negligible probability for damage as the result of accidental exposure.

Excessive infrared exposure causes a loss of transparency or produces a surface irregularity in the cornea. The maximum permissible exposure is well below the energy or power required to produce a minimal lesion. A minimal corneal lesion is a small white area involving only the epithelium and whose surface is not elevated or swollen. It appears within about 10 minutes after the exposure. Very little or no staining results from flourescein application. A minimal lesion will heal within 48 hours without visible scarring.

Damage results from the heating of the cornea by absorption of the incident energy by tears and by tissue water in the cornea. The absorption is diffuse, and simple heat flow models appear to be valid. The identity of the sensitive material or protein in the cornea is not known. Although the critical temperature threshold is not known, it does not appear to be much above normal body temperature, and there are indications that it is a function of exposure time.

The large skin surface makes this body tissue readily available to accidental or repeated exposures to laser radiation. The biological significance of irradiation of the skin by lasers operating in the visible and infrared regions is considerably less than exposure of the eye, as the skin damage is usually reparable or reversible. Effects may vary from a mild reddening (erythema) to blisters and charring. Depigmentation, ulceration, and scarring of the skin, and damage to the underlying organs, may occur from extremely high powered laser radiation.

Latent and cumulative effects of laser radiation are not known at this time. The possibility of such effects occurring, however, should not be ignored in planning for personnel safety in laser installations.

The AUTOMARK system design concept permits light tight enclosure of the laser air pass and target workpiece interaction zones. The design concept, however, requires continuous conveying of workpiece plates into and out of the line marking station. Careful engineering controls are required to ensure negligible probability of direct beam or diffuse reflection radiation exceeding the maximum permissible exposure exiting these openings.

Laser cutting and welding operations have been shown to create similar potentially hazardous vapors and fumes as electric arc and flame cutting and welding procedures. The AUTOMARK system line marking station will operate in approximately the same process region as laser cutting. Adequate exhaust ventilation is required to reduce the concentrations of the resultant fumes and vapors to levels below the appropriate threshold. Generally, ventilation adequate for processes using conventional energy sources are also adequate for laser systems accomplishing work at a comparable rate.

Studies have shown that plasma emissions created during a laser welding operation may contain sufficient ultraviolet or blue light content to raise concern for operators viewing a laser welding process long term without additional protection for the plasma emission. The plasma created by the accomplishment of laser engraving of steel plate may contain sufficient ultraviolet or blue light to warrant attenuation of these wave lengths through the process viewing ports.

Operating laser power supplies and discharge tubes are energized to very high potentials and often exhibit considerable capacitance. These circuits pose an electrical shock hazard to maintenance personnel. These circuits should be contained in access interlocked enclosures and provided with bleed down resistors to remove static charges following shut down. Work rule grounding of high voltage parts must be accomplished prior to maintenance. Metallic parts, not intended as current carrying members, should be permanently grounded.

Class 4 laser systems develop sufficient energy densities to serve as ignition sources. It is essential to construct the AUTOMARK system laser enclosure of flame resistant materials.

Safe operation of the AUTOMARK system line marking station requires implementation of a series of engineering hazard controls, and institution of appropriate management controls to assure compliance.

Engineering Hazard Controls

Operation and maintenance of the AUTOMARK system laser will be limited to trained authorized personnel under key control.

The laser will be procured as commercially available equipment embodying standard class 4 laser source safety features. These will include access interlocks and bleed down resistors on high voltage circuits, and explosion containment for the laser tube.

Beam delivery from the laser exit to the subresource distributor will be totally enclosed. It will be provided with a fail safe beam stop capable of absorbing the entire output power of the laser. The beam delivery system will also be provided with a class 1 laser to simulate emissions of the class 4 laser for accomplishing optical alignment.

A long air pass of the direct laser beam is necessary from the distributor to each of the subresource final delivery optics. There also exists significant probability of spectral reflections off facets in the workpiece plate surface. The facets are created as a consequence of abrasive blast cleaning operations. The AUTOMARK system line marking station will be completely enclosed in a room constructed of durable light tight materials such as concrete block. The enclosure room will have a double door for maintenance access. The maintenance access doors will be equipped with panic hardware for emergency exit. Inside the maintenance access doors, a vestibule area will be protected by split overlapped curtains of infrared attenuating plastic. The enclosure room walls will be provided with safety glass process viewing ports. Secondary protection at the process viewing ports will be provided by infrared attenuating plastic curtains hung inside the enclosure room. Metal pass through sleeves will be fitted over the conveyor, at either end of the enclosure room. These sleeves will shield the workpiece plate entrance and exit from the most probable reflections and direct beam paths. Multiply split and overlapped infrared attenuating plastic drags will seal light paths close to the plate surface. Exhaust ventilation will be provided to remove laser engraving process fumes and vapors. The enclosure room doors will be provided with an interlock such that the laser will not operate with the doors ajar. Opening either of the doors during laser operation will result in immediate stopping of the beam and shut down of the laser. Manual restart will be required. Floor mat switch pads located in the enclosure room vestibule and adjacent to the beam distributor and the subresource manipulators will be included in the interlock circuit. Separately hard wired emergency master disconnect switches will be located near the subresource manipulators, in the enclosure room vestibule, on the wall outside the enclosure room doors, and on the operators console. Warning lights and bells will be the first functioning equipment during a laser start evolution. An automatic 2 minute delay will be required, after initiation, to complete a laser start evolution. This delay will allow personnel sufficient time to act to avoid exposure. The bells will be silenced with the beginning of laser beam delivery. The warning lights will continue during laser operation.

The AUTOMARK system will be posted with appropriate advisory and warning signs.

The enclosure room will be provided with permanent lighting, utility electrical power and compressed air, and permanent overhead padeyes for material handling during equipment installation and maintenance.

Management Control of Laser Hazards

A Laser Safety Officer will be designated with the authority and responsibility to monitor and enforce the control of laser hazards, and to effect knowledgeable evaluation and control of laser hazards. He is responsible for hazard evaluation of laser work areas including establishment of the Nominal Hazard Zones. The Laser Safety Officer will recommend and shall approve all laser alignment, operating, and maintenance procedures. He is responsible for assuring that the prescribed control measures are in effect, and shall periodically audit the functionability of the control measures in use. The Laser Safety Officer shall approve the wording on all laser work area signs and equipment labels. He shall approve protective eyewear, clothing, barriers and screens, and shall assure periodic auditing of the proper working order of these items. Prior to initial use of the laser, he shall verify proper installation of equipment or proper restoration of these systems following maintenance. He shall assure that adequate safety education and training are provided to all laser work area personnel. The Laser Safety Officer shall assure the accomplishment of medical surveillance of all laser work area personnel, and cause maintenance of the appropriate records.

Procedures for laser related work will be prepared in consultation with, and approved by the Laser Safety Officer. These procedures will describe in step wise detail the actions to be taken aligning, operating, and maintaining the

AUTOMARK system line marker. Verification signature control will be maintained to assure that all laser work area supervision, operating, and maintenance personnel have read and understood the applicable procedures.

Safety education and training will be provided to all laser work area personnel. The instruction shall assure that all laser work area supervision, operating, and maintenance personnel are knowledgeable of the potential hazards and the control measures for the AUTOMARK system. The instruction will describe the biological effects of laser radiation on the eyes and skin, relation of specular and diffuse reflections and other hazards of lasers including reaction by-products. The AUTOMARK system and the function of the component equipment items will be described. Overall management of laser operations and the responsibilities of individual employees will be explained. Medical surveillance practices for laser work area personnel will be discussed. Training for maintenance personnel and maintenance supervision will include electrical safety practices and cardiopulmonary resuscitation.

Physical fitness assessments are used to determine whether an employee would be at increased or unusual risk in a particular environment. For workers using laser devices, the need for this type of assessment is most likely to be determined by factors other than laser radiation.

Direct biological monitoring of laser radiation is impossible, and practical indirect monitoring through the use of personal dosimeters is not available.

Early detection of biological change or damage presupposes that chronic or subacute effects may result from exposure to a particular agent at levels below that required to produce acute injury. Active intervention must then be possible to arrest further biological damage or to allow recovery from biological effects. Although chronic injury from laser radiation in the ultraviolet, near ultraviolet, blue portion of the visible, and near infrared regions appears to be theoretically possible, risks to workers using laser devices are primarily from accidental acute injuries. Based on risks involved with current uses of laser devices, medical surveillance requirements that should be incorporated into a formal standard appear to be minimal.

Other arguments in favor of performing extensive medical surveillance have been based on the fear that repeated accidents might occur and the workers would not report minimal acute injuries. The low number of injuries that have been reported in the past 20 years and the excellent safety records with laser devices do not provide support to this argument.

Except for examinations following suspected injury, only preassignment medical examinations are required. These examinations establish a baseline against which damage (primarily ocular) can be measured in the event of an accidental injury. The examinations identify certain workers who might be at special risk from chronic exposure to selected continuous wave lasers. Workers medical histories, visual accuity measurement, and selected examination protocols are required. The wave length of laser radiation is the determinant of which protocols are required. Although chronic skin damage from laser radiation has not been reported, and indeed seems unlikely, this area has not been adequately studied. Limited skin examinations are suggested to serve as a baseline until future epidemiological studies indicate whether they are needed or not. Periodic examinations are not required. The primary purpose of termination examinations is for the legal protection of the employer against claims for damage that might occur after an employee leaves a particular job. The decision on whether to offer or require such examinations is left to individual employers.

PRELIMINARY ECONOMIC JUSTIFICATION

Plate currently exits the preparation line into a static queue to await cutting. Cut part shape, size, and the number of identical replications determine the cutting machine destination of each workpiece. The order of plates in the static queue regarding the cutting machine destination of individual workpieces is sometimes quite random and results in considerable shuffling through the queue to reach particular plates.

The majority of plate is cut on either of 2 direct numerical control plasma arc cutting machines. Each machine is provided with a single servo bridge. A pair of servo carriages are mounted on the bridge of each machine. These carriages may be operated singly, with parallel motion to produce identical parts, or with opposing motion to produce mirror image parts. Each of the carriages is provided with a plasma arc cutting torch. Each carriage is also provided with a separately operable pneumatic prick punch marking tool mounted a fixed offset away from the plasma arc torch.

Lines and arcs are drawn as a series of closely spaced punch impressions made into the workpiece surface. The pneumatic prick punch marker is also capable of creating representations of alphanumeric and any special characters that can be described by a series of line and arc segments.

The tool rate of the pneumatic prick punch is limited by the maximum slew rate of the cutting machine bridges. Since a single marking tool can be engaged with any particular workpiece, mark production is limited by the maximum bridge slew rate. Drawing alphanumeric and special character representations as a series of line and arc segments requires additional time for machinery accelerations at either end of every stroke. Additional traverses to position the marking tool are generally required between productive strokes to draw a particular character, and between adjacent characters. Because of the limited mark production rate, and the inherent inefficiencies of separately drawing characters, the pneumatic prick punch requires an unacceptable amount of time to accomplish character marking. Consequently, the character drawing capability is not used.

Alphanumeric character marking of plate is accomplished by a layout craftsman using a paint tube and referring to a hard copy drawing of the nest to be cut. The craftsman also marks any necessary special characters indicating particular features of the layout and conveying manufacturing instructions.

Manual marking usually proceeds roughly simultaneous with automatic pneumatic prick punch marking of construction and reference lines. The practice is intended to approach transparency of the character marking operation with regard to plate fabrication process lane workpiece productivity. For those cutting nests that include numerous parts, manual character marking is often only partially completed when the automatic marking of lines has finished. Cutting may be delayed until the manual marking is completed. Optionally, manual marking may continue after cutting, during parts pick out. The choice depends upon the press of production schedules and the availability of a second layout craftsman for assignment to the cutting machine. Either way, the unit cost of cut and marked plate parts is increased.

Placing a layout craftsman on a workpiece for manual character marking during automatic line marking involves a small risk of collision of the cutting machine moving parts with the craftsman. Placing the layout craftsman on a workpiece during plasma cutting operations is dangerous. Plasma coolant puddles on the workpiece surface and can cause slipping. Cut parts are held in place primarily by jamming in the kerf. Parts or scrap can spring loose unexpectedly.

Each of the 2 direct numerical control plasma arc cutting machines is provided with a water table platen. The water table platens are each partitioned into 2 separate tanks arranged endwise adjacent. The platen area of each tank is sized for cutting 2 plates 60 feet long by 13 feet wide arranged side by side. Any other arrangement of smaller plates, not exceeding the maximum dimensions of the tank platen, may be accommodated. The endwise arrangement of separated platens permits parts pick out and stock lay down operations to be conducted in one platen partition while workpiece alignment, marking, or cutting operations are accomplished in the adjoining platen partition. This enables plasma arc cutting machine material handling operations that are transparent in regard to plate fabrication process lane workpiece productivity. These material handling operations were carefully observed. They are not included in the economic justification model since under the current arrangement plasma arc cutting machine material handling operations do not determine any component of workpiece productivity.

The support bars in the plasma arc cutting machine platens are spaced sufficiently far apart to create a significant probability of tertiary plate parts falling through the grating. Tertiary plate parts are often required in quantities of multiple tens of identical pieces for a particular structural assembly. Nesting tertiary plate parts on workpieces together with primary and secondary plate parts results in very costly parts sorting and accounting tasks to assure that assembly requirements are met. Consequently, tertiary plate parts are cut using a one to one template following machine to manipulate multiple oxy-fuel cutting torches in parallel. This produces multiple identical plate parts in a single machine pass. The machine is also provided with direct numerical control capability. This eliminates the necessity for a physical template. Stock for tertiary plate parts is drawn from the larger panels dropped in cutting nests of primary and secondary plate parts. Tertiary plate parts are manually laid out with physical templates or working directly on the stock. Alphanumeric and special character marks are manually drawn with a paint tube.

A flame planer is available for simple edge or end trueing and plate squaring operations. A hydraulic shear is used to break plate into bars. Finally, the plate fabrication process lane is equipped for manual burning operations and manually set track following tractor flame cutting. These secondary methods involve a very large touch labor content for the volume of completed product. Often these methods require production and use of physical templates in support of shop floor work.

Detail shop observations were made of the fabrication of parts from 55 plates cut on the direct numerical control plasma arc cutting machines. The nests were selected as representative of the spectrum for middle sized combatant ships. Drawings of an additional 100 nests were studied to extract such parameters as plate length, length of line marks, number of character marks, length of part edge cut line, and the number of parts per workpiece. The drawing study confirmed that the detailed shop observations are representative of the shipyard work planned for the next decade. Taken altogether the shop observations and the drawing study account for in excess of 2 per cent of the total steel plate part population for LHD 1 class ships.

The maximum plate length fabricated is 60 feet with the mean at 34 feet. The maximum length of line mark required per nest is 1560 feet with the mean at 123 feet. The maximum number of character marks required per nest is 6928 with the mean at 300. The number of character marks required per nest exhibits a significant secondary spike near 2000 characters per nest. The maximum length of part edge cut line is 533 feet with the mean at 167 feet.

Detail observations of the plate fabrication process lane operations and the component tasks performed in accomplishing these operations were made. During these studies it was learned that alignment of plate with the cutting machine occupies 15 to 30 percent of the time that a workpiece is on the platen.

To make maximum use of stock, cutting nests are designed with part edges as close as 0.5 inches from the nominal plate boundaries. Workpieces must be physically aligned with the principal axes of the direct numerical control plasma arc cutting machines. This is necessary to preclude the possibility of a portion of the cut line trajectories from laying outside the plate. Cutting out of the plate boundary produces ragged edges that require rework to repair. Cutting out of the plate boundary can also produce incomplete parts. This generally results in loss of the plate and all prior work on the plate.

Alignment of the plate to the cutting machine is accomplished by the operator positioning the plasma arc torch over a corner of the workpiece and traversing the torch along the plate length to the adjacent corner. From the change in the relative position of the plasma torch and the plate edge, the operator infers any necessary correction. The operator then levers the workpiece in the direction required to achieve alignment. Alignment is retested. This process is repeated until satisfactory alignment is achieved.

Alternately landing workpieces against fixed stops has been considered and rejected. Fixed stops would have to extend approximately 2 inches above the platen in order to adequately align thin plate stock in the warped condition commonly observed. Alignment to stops this high would pose a collision hazard with the plasma torch holder and the workpiece surface sensor unless the cut line limit were redefined 3 inches inside the plate boundary. This level of planned material scrapping is unacceptable to the shipyard.

Simple designs for movable alignment stops have been considered. The movable alignment stops might consist of torque tubes below the platen grate with bearings submerged in plasma coolant. The torque tubes would be provided with stop bars mounted directly to the torque tubes and operating in a lever like manner through the grate. Designs of this class have been rejected for inflexibility to the numerous workpiece arrangements required on the platens. More flexible designs are conceived as mechanically much more complex, costly, and difficult to make reliable. Consequently, highly flexible stop designs have not been considered as viable candidates.

Line marking typically occupies 35 to 50 percent of the time a workpiece is on the direct numerical control plasma arc cutting machine platen. The variation is due to the widely varying amount of line marks required. During the observations, the plasma arc cutting machines incurred 11.2 hours of down time. Roughly half of this down time was attributed to automatic pneumatic prick punch marker related problems.

The AUTOMARK system will reduce the time required to accomplish alignment between the workpiece as landed on the cutting machine platen. Approximately 2 to 2.5 minutes, or about a third of the time of current practice will be required. Time for marking lines or characters with the workpiece on the cutting machine platen will not exist. This will result in the ability to increase workpiece productivity through the plasma arc cutting machines 60 to 100 per cent with reduced manning. This in turn results in operating fewer shifts to achieve the same work, compressed plate fabrication process lane schedules and more flexible support of erection and outfitting requirements.

Budgetary projections place the cost of the AUTOMARK system installed and ready to initiate production at the order of a million dollars. As with any capital expenditure for manufacturing equipment, the existence of a real and hypothesized work load is required to establish economic justification. Based on plate parts fabrication to support manufacture of ships at a rate equivalent to 40 000 displacement tons per year, the AUTOMARK system should return cost in about 2 years.

CONCLUSIONS

The AUTOMARK system is technically feasible. It will result in marked productivity improvement fabricating plate parts. Development and implementation of the AUTOMARK system can be economically justified.

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The Use of Computer Simulation of Merged Variation to Predict Rework Levels on Ship's Hull Blocks

No. 4

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ABSTRACT

In the modular construction of ships, significant productivity losses can occur during the erection stage, when the modules, or hull blocks, are joined together. Frequently, adjacent blocks do not fit together properly, and rework of one or both of the mating block interfaces is necessary to correct the problem. The specific cause of rework is the variation of plate edges at the block interface, which is itself a cumulative product of numerous manufacturing variations inherent in hull block construction. Variation in manufacturing is unavoidable, but not uncontrollable. The application of accuracy control techniques in shipbuilding has proven that a statistical analysis of variation makes possible an accurate prediction of its effects. This report presents an examination of block interface variation, and the subsequent development of a computer simulation method of predicting rework levels on those blocks.

The complex interaction of all the edges' random variations at the block interface gives rise to a unique rework probability distribution. This probability distribution is evaluated by means of the computer simulation program, which provides estimates of the average rework anticipated, the shape of the probability curve, and other parameters. Similar predictions are also available for cost and labor of required rework. In addition to predicting rework levels, the simulation program can be a useful tool for reducing those levels.

1. INTRODUCTION

Why Predict Rework?

A shipyard's need to predict rework is no different from its need to be in control of all other aspects of its operation. There are both short term and long term imperatives at work. The short term concern is the scheduling of the current project. It is necessary to have accurate forecasts of the time required for every work package in the project. The construction of a large vessel involves the coordination of thousands of work packages into a single, interdependent network of activities. If the duration of a job is overestimated, the result is an underutilization of resources. Scheduling inadequate time for a specific job, however, can disrupt the whole network. In the long term, a shipyard must direct attention to winning future contracts. A yard that knows its costs, including projected rework costs, is in the best position to bid realistically, and therefore successfully.

Rework is an intrusion on traditional construction schedules. Because it is an "unplanned" activity, there has been proportionally little effort invested in characterizing the rework function, compared to "regular" jobs. But rework can be a significant fraction of the total project. Quoting from Michael Wade of the University of Michigan:

"Regardless of how refined or standardized a planning system becomes, there is a high probability that during the life cycle of a ship construction project, rework....will befall the production schedule with very little warning. It is unrealistic to plan vessel without consideration for the impact these disruptive factors can have on man-hours and completion dates....The ability to measure performance at all levels of production will have a direct effect on a shipyard's ability to bid new work consistently and confidently." [1] (emphasis added.)

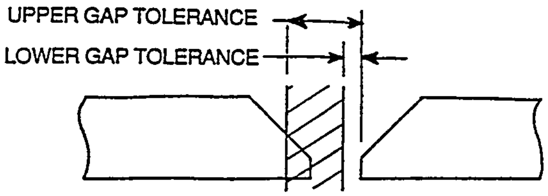
2. THE REASONS FOR ERECTION STATE REWORK

Variation at The Block Interface

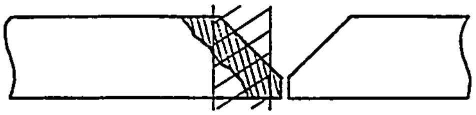
The cause of rework at the erection stage, neglecting design error, is variation at the block interface. Variation, in its formal definition, is a deviation from design dimensions. In an absolute sense, there is variation existing in every dimension of every item that has ever been manufactured; so long as an attribute can be measured closely enough, it can be found in deviation from what it is supposed to be. The question of practical concern is the magnitude of variation.

When two hull blocks are to be joined at erection, the critical dimension is the gap between the mating edges of the respective blocks. A uniform gap between all the edges at the erection joint allows the welding of the blocks - in many cases, robotic welding - to proceed as scheduled. Excessive variation of the edges of one or both of the block interfaces spoils this uniform weld gap and interrupts the erection schedule, as a certain percentage of the interface must be reworked to achieve a proper fit.

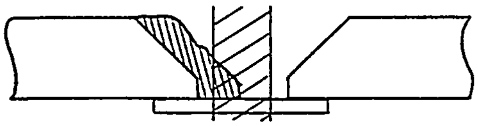
Specifications on weld joint preparation vary with the different types of welding, but there is in each case a gap tolerance, an upper limit and a lower limit on gap width, beyond which the quality of the weld suffers. As shown in Figure 1, when the weld gap is too narrow, or if there is interference between the plates, material must be removed by torch cutting from one or both sides. If the existing gap is too wide, a backing strip must be welded across the gap before the joining weld can be made.



PROPER GAP - NO REWORK REQUIRED



GAP TOO SMALL - CUTTING REQUIRED



GAP TOO WIDE - BACKSTRIP WELDING REQUIRED

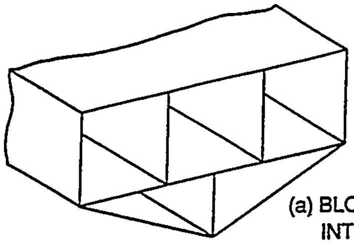
Fig.1. Rework Criteria - Cutting and Backstrip Welding

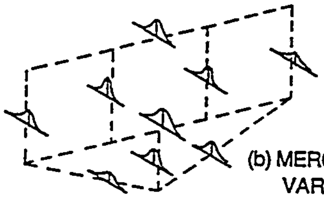
Of the two types of work, backstrip welding to close a gap is more expensive than torch cutting to widen one. Traditionally, shipbuilders, resigned to performing considerable rework at erection but anxious to minimize backstrip welding, would add a margin to part dimensions at the block interface to insure that, whatever the final block variation, a uniform gap could be achieved by cutting away from all the edges the portion of margin remaining. The practice is essentially a commitment to rework, and considering this, it is no surprise that erection stage rework levels at traditional shipyards are quite high. The use of margins may have been the minimum cost solution of the past, before the advent of statistical accuracy analysis, but times have changed. The application of accuracy control techniques is now permitting progressive builders to achieve much greater accuracy in hull block construction, making it possible to join hull blocks with less rework, and without margins.

Quantifying Variation

These same accuracy control techniques that make possible the reduction in block variation have an additional use as well. They can also be used to help determine how to deal most effectively with the variation that can not be eliminated. Through statistical characterization of the interface variation associated with a particular block design, it is possible to anticipate some of the consequences of that variation. Specifically, it is possible to make a prediction, before any steel is cut, on the amount of rework the block will require at erection.

Consider Figure 2, which shows a simple block interface and the variation of its edges. The design specifications of this hypothetical block are that the edges of all decks, bulkheads, and other members at the interface will lie on a single plane, as seen in Figure 2(a). However, due to variations of parts and processes in the construction of the block, each edge will exhibit some measurable variation from the design plane. Each edge's variation can be modeled separately as a random variable with a normal distribution. It is possible to predict the random variations of each of these edges by writing a series of variation merging equations. Figure 2(b) represents the normal probability distributions of longitudinal variation of all the edges, with respect to the design plane (transverse and vertical variation can be evaluated as well, but not within the scope of this paper). These probability distributions are each characterized by a merged mean variation ($\bar{Z}_M$) and a merged standard deviation (S_M). Note that some of the distribution curves are centered a little aft of the design plane and some are centered a bit forward. This illustrates a scattering of mean variations values above and below a value of zero.


(a) BLOCK INTERFACE


(b) MERGED VARIATION

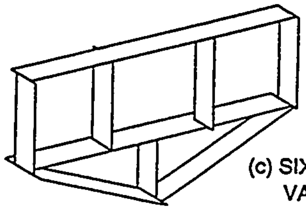

(c) SIX-SIGMA VARIATION LIMITS

Fig.2. Longitudinal Variation of Edges at Block Interface

A necessary precondition to the writing of variation merging equations is that all random part and process variations associated in the block construction be known, and known to vary under a normal distributon. A full description of the process of writing merging equations can be found in "Three Dimensional Accuracy Control Variation Merging Equations," by R.L. Storch and P. Giesy. A brief description of the principle of merging equations is provided by L.D. Chirillo:

> "If the distribution of such variations for a specific work process is Gaussian, that is, normal per a bell-shape curve, the process is said to be under control. When work is so controlled, and verified daily by nominal random sampling, the normal distribution of a work stage can in accordance with the Theorem of Variance, be added to that for a second work stage in order to <u>predict</u> the distribution for a third work stage." [2]

It is impossible to predict exactly where a given edge will end up within its probability distribution. That is a random variable. Under a normal distribution, however, it can be said with fair certainty that the resultant positions will be within three standard deviations of the mean, within the so-called "six-sigma envelope." Figure 2(c) shows these six-sigma limits at the block interface. If 100 blocks were built from this design, they would all be different, but the configuration of each block interface will fall with certainty somewhere within that six-sigma matrix. Knowing that variation at the interface is thus constrained, is the first step in the development of a method for predicting erection stage rework levels.

3. DEVELOPING A REWORK STRATEGY

Variation vs. Weld Gap Tolerance

It can be stated then, that erection stage rework is primarily a function of two opposing factors: the random variations of edges throughout the block interface, and the weld gap tolerance (there is a third factor, of course, called "economics," which will be incorporated presently). The greater the variation at the interface, and (or) the smaller the weld gap tolerance - the greater the probability that rework will be required; and expected levels of rework will be greater as well. Figure 3, which is a continuation of the hull block example started in Figure 2, illustrates this relationship. The two upper drawings show again the block interface and the six-sigma envelopes for all the edges. The diagram of variation limits at the bottom is simply a different representation of the six-sigma envelopes; it emphasizes the relative widths and longitudinal positions of the edges' variation limits. Since the relative lengths of the edges has been lost in the transition, that information is given in a column beside the diagram.

Note the cross-hatched area overlaying the variation limits in Figure 3. This represents the weld gap tolerance. As stated earlier, the weld gap throughout the erection joint must be between certain boundary values to avoid the necessity of reworking one or both edges of the gap. It does not matter what the upper and lower tolerance limits are, only the width of the tolerance zone is important. This visual comparison gives a feel for the probabilities of rework being required at the block interface.

To simplify the rework model being developed, this example will be presented as a case of one-sided variation. Under this constraint, manufacturing variations are present only on the block shown. The adjoining block is assumed to be "perfect," and therefore not a factor in determining rework requirements. Extension to the more realistic model of two-sided variation will be dealt with later. Simply stated, the rework criteria (with one-sided variation) is this: when the measured longitudinal span of plate edges at a block interface exceeds the weld gap tolerance, then rework is required. In the case of Figure 3, it is apparent that the variation limits are much wider than the weld gap tolerance. Intuitively, it is clear that the odds are very low of having these nine edges (effectively nine random variables) ending up in a zone smaller than the width of the weld gap tolerance. This is the same as stating a high probability that rework will be required at that interface.

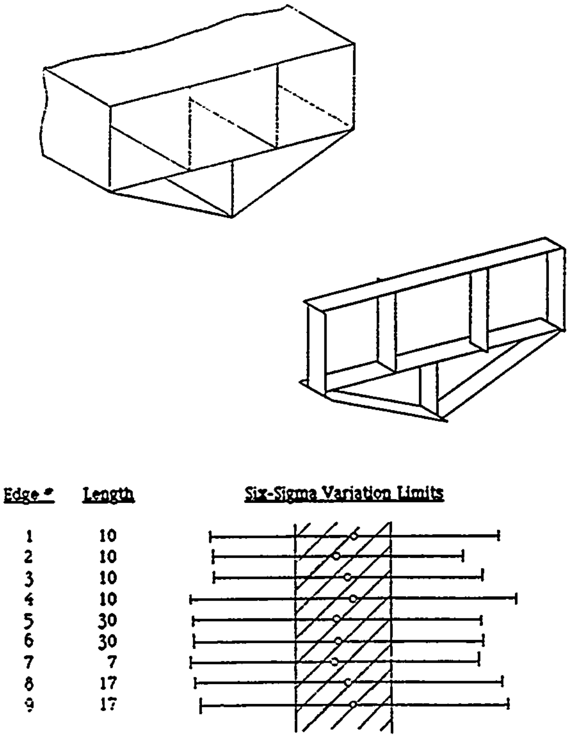


Fig.3. Diagram of Variation Limits

The Optimum Rework Solution

But how much rework will be needed? Which edges will likely require cutting or backstrip welding? To answer these questions, it is necessary to examine the decision criteria of erection stage rework. The rework solution (which edges to cut, which to backstrip weld) for a specific block is dependent not only on the resultant longitudinal position of each edge after random variation has taken its toll, but on the length of each edge as well. In each case, the problem becomes one of finding the optimum solution out of a set of feasible solutions.

To demonstrate this process of rework optimization, consider that our hull block from the previous examples has finally been built. Figure 4 shows the relative longitudinal positions of the nine edges at the interface. Maintaining the assumption of one-sided variation, the adjoining block can be represented as a flat wall, shown on the right. The shaded region near the wall represents the weld gap tolerance zone.

Finding the optimum rework solution can be viewed as an iterative thought experiment that is performed by moving the wall through the group of edges, stopping at each edge to calculate the implied rework for that case, and then selecting as the optimum solution the case requiring the minimum amount of rework. Since there are nine edges in our example, there are nine possible rework solutions: A, B, and C, shown in Figure 4, represent three of these. Solution A would be the first one evaluated. The wall is moved to the left until the first edge coincides with the minimum weld gap. At this position, the second edge is also within the tolerance zone, and so escapes rework. The remaining edges must be backstrip welded, for a total 114 feet of rework. Solution B is better than solution A. With the wall (actually the minimum weld tolerance) at the third edge, the first two need cutting and the last four need backstrip welding, for a total of 107 feet. Solution C, at 101 feet, is better than A or B. An evaluation of all nine solutions would confirm that C is in fact the optimum solution.

This example has represented a case where the unit costs of torch cutting and backstrip welding are equal. In actuality, backstrip welding is a more costly operation than cutting, and this affects the derivation of the optimum rework solution. The selection criteria changes from minimum rework to minimum cost. One would expect this to result in a shift, on the average, to somewhat higher levels of rework, but with a much smaller percentage of backstrip welding.

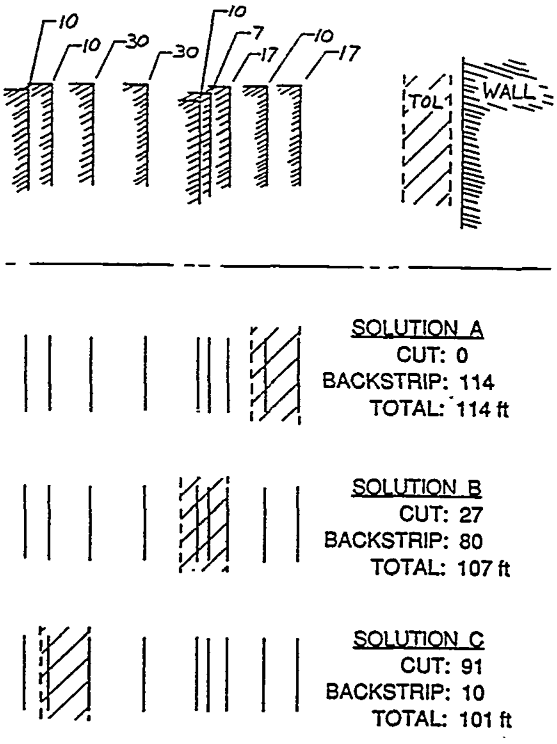


Fig.4. Rework Optimization

4. DETERMINING REWORK PROBABILITIES THROUGH SIMULATION

Estimating the Rework Profile

It has been established that the optimum rework solution is a function of edge variation, edge length, the weld gap tolerance, and rework costs. The only problem remaining is the one that we began with, that of how to predict the amount of rework that a given block design is likely to require. It is a problem that does not lend itself to an analytical solution. Though edge lengths, weld tolerance, and costs are all constants, and the variation distribution of each edge is characterized by a mean and a standard deviation, the complex interaction of those random variations, influenced by all of the constants, defies expression.

But analysis is not the only method available. Much can be said about rework. Since rework is a function of random events, it is itself a random variable, and can be represented as a probability distribution of optimum solutions. It is not a continuous distribution, since it cannot take on a continuous range of values. The values that rework can take are constrained to the finite set of all possible combinations of sums of edge lengths.

This type of problem is best solved through statistical modelling. In other words, using empirical methods, rather than analytical. The most straightforward method would be to sample a large number of hull blocks built from the same design, and generate statistics, such as average rework and standard deviation, to describe the rework distribution. Sampling is a valuable statistical tool, which has already played an important role earlier in this chain of analysis: it was sampling that was used to determine the parameters of the specific shipyard process variations. And the process variations, of course, are what the distributions of merged variation of edges at the interface are derived from. Sampling of hull blocks, however, would appear to defeat the purpose of predicting rework prior to construction - unless a computer was used to generate the sample. The following section describes a computer program written for such a purpose.

The Rework Simulation Program

With a rework simulation program, it is possible to "build," and evaluate for rework, many hull blocks at no cost and in very little time. And many hull blocks will be needed. If optimum rework was known to have a normal distribution, then a mean and standard deviation could be inferred from as few as ten or twenty observations. But since the shape of the rework distribution is not (yet) well defined, the profile must be "constructed" as a histogram of a large number of observations. This program estimates the rework profile with a histogram derived from two hundred simulated hull blocks.

The program described here is written in Pascal, and runs on an Apple Macintosh™ personal computer. The Macintosh has excellent graphics capabilities, and the mouse-interface enhances the "friendliness" of the program. A complete listing of the program is given in the appendix.

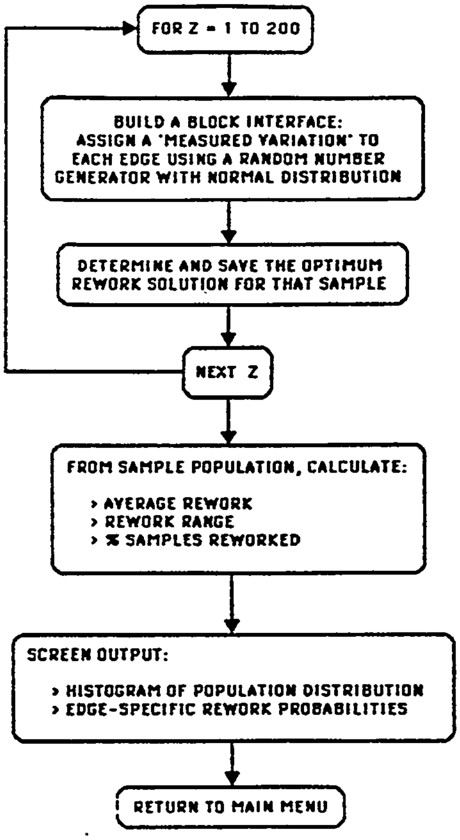


Fig.5. Simulation Subroutine Flowchart

The mechanics of running a simulation are outlined in Figure 5. For each sample hull block, a "resultant variation" is assigned to each edge at the interface using a random number generator that complies with the normal distribution of merged variation of that edge. The algorithm for this is as follows:

First, a random number (N) with a [0,1] normal probability distribution (i.e., mean = 0, standard deviation = 1) is generated with the equation:

$$N = (-2 \log_e R_1)^{1/2} \cos(2\pi R_2)$$

where R_1 and R_2 are uniform distribution random numbers from 0 to 1.

Then, the "resultant variation" for the j^{th} edge is:

$$Z_j = \bar{Z}_j + (N * S_j)$$

where $\bar{Z}_j$ and S_j are the edge's merged mean variation and standard deviation, respectively.

A new "N" is generated for each edge.

After each block interface is created in this manner, the program then determines that block's optimum rework solution, using a preselected weld gap tolerance and costs of torch cutting and backstrip welding. The optimum solution, chosen on the basis of minimum cost, is recorded in terms of total linear feet of rework, irrespective of type. At the same time, a cumulative counter (over the 200 samples) makes note of the specific edges that required rework, and which type.

This whole procedure is repeated two hundred times to simulate the construction and rework of the entire sample of hull blocks. The two hundred optimum rework values become the raw data that are used to estimate the rework distribution. The rework mean and standard deviation are calculated from the sample data, and the shape of the distribution curve is approximated by a histogram of the data.

A full flowchart of the program is shown in Figure 6. On startup, the user must load a block variation table (either by hand, or from a file) into the program memory. This variation table lists the names, merged mean variations, and standard deviations of all the edges at the block interface, and their respective lengths. The program then proceeds to the main menu, where the user may choose to run a simulation, display or edit the variation table, or end the program. After each simulation, the user can call to the screen, or print, four different graphical reports: the Rework Distribution, Cost Distribution, Labor Distribution, or Edge Specific Rework Probabilities.

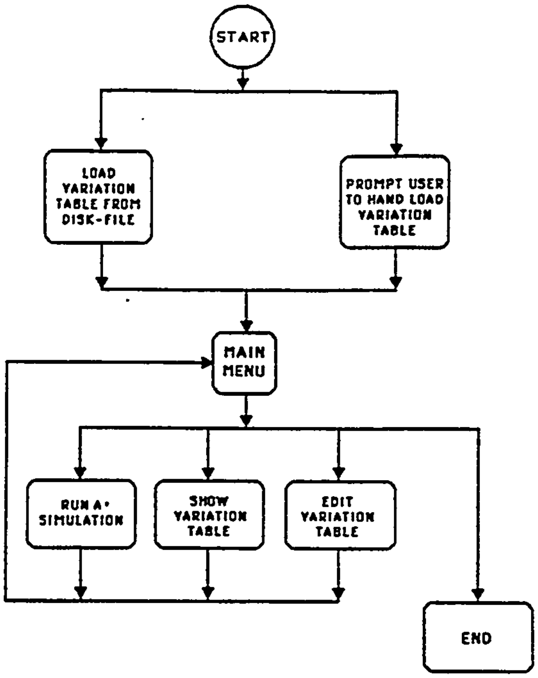


Fig.6. Rework Simulation Program Flowchart

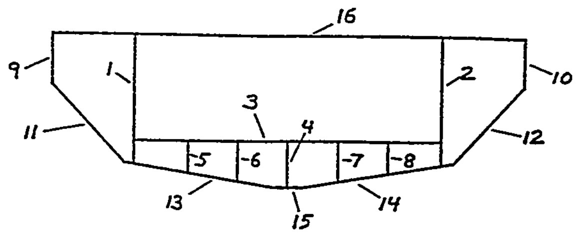
5. A CASE STUDY: THE T-AGOS REWORK PROFILE

An Introduction to The T-AGOS Case

In 1983, R.L. Storch produced a paper called "Accuracy Control: A Guide to its Application in U.S. Shipyards" [3], which was based on research that had been done at the University of Washington and at the Tacoma Boatbuilding Co. in Tacoma, Washington. The main purpose of that research was to outline the procedures for determining typical shipyard process variations and constructing variation merging equations. A major project then at Tacoma Boat was a Navy contract to build a series of twelve T-AGOS class ocean surveillance vessels.

Three years later, in "Three Dimensional Accuracy Control Variation Merging Equations" [4], Storch and Giesy wrote a series of merging equations, characterizing the merged longitudinal variation of all edges at the erection interface of a specific hull block: the T-AGOS stern section. A full list of the edges at the stern block interface is given in Figure 7.

This complete collection of block interface variation parameters provides a realistic data set to run through the simulation program. However, it is first necessary to explain an additional complication in the T-AGOS variation table that was not covered earlier.



Edge #	Name
1	Longitudinal Bulkhead (stbd)
2	Longitudinal Bulkhead (port)
3	13'6" Steering Gear Flat
4	Centerline Floor Frame
5	Diagonal Floor Frame (1)
6	Diagonal Floor Frame (2)
7	Diagonal Floor Frame (3)
8	Diagonal Floor Frame (4)
9	Side Shell (stbd)
10	Side Shell (port)
11	Bilge Strake (stbd)
12	Bilge Strake (port)
13	Bottom Shell (stbd)
14	Bottom Shell (port)
15	Keel Plate
16	Main Deck

Fig.7. Summary of T-AGOS Stern Block Interface

Independent vs. Relation Variation

The T-AGOS variation table is shown in Table 1. Note the appearance of a factor called "Mutual Variation" associated with some of the edges. This indicates the presence of the phenomenon of Related Variation, revealed through the writing of the variation merging equations. Edges 3 through 8 are a group of edges whose merged variations are related; they will be said to comprise Related Group #1. Likewise, the Main Deck, originally seen as one continuous edge, is more accurately represented as five shorter edges with related variation, making up Related Group #2. The variation of an edge in a related group is characterized by a random independent variation and also a random mutual variation that is common to every edge in that group. The rework simulation program must be able to take occurrences of related variation into account to realistically predict rework on hull blocks that contain these related groups.

Table 1. T-AGOS Variation Table

T-AGOS - VARIATION TABLE

Edge #	Name	Length (ft)	Independent MeanVar/StndDev	Mutual MeanVar/StndDev
1	Long'l Bhd (stbd)	8.00	-0.220/0.260	---
2	Long'l Bhd (port)	8.00	-0.220/0.260	---
3-1	13'6" Flat	26.00	-0.020/0.220	-0.160/0.250
4-1	Centerline Frame	2.50	-0.020/0.220	-0.160/0.250
5-1	Diag. Frame (1)	1.75	-0.020/0.200	-0.160/0.250
6-1	Diag. Frame (2)	2.14	-0.020/0.200	-0.160/0.250
7-1	Diag. Frame (3)	2.14	-0.020/0.200	-0.160/0.250
8-1	Diag. Frame (4)	1.75	-0.020/0.200	-0.160/0.250
9	Side Shell (stbd)	3.60	-0.060/0.180	---
10	Side Shell (port)	3.60	-0.060/0.180	---
11	Bilge Strake (stbd)	6.60	-0.060/0.180	---
12	Bilge Strake (port)	6.60	-0.060/0.180	---
13	Bottom Shell (stbd)	14.25	-0.080/0.260	---
14	Bottom Shell (port)	14.25	-0.080/0.260	---
15	Keel Plate	1.60	-0.080/0.260	---
16-2	Main Deck (1)	8.00	-0.010/0.170	-0.170/0.210
17-2	Main Deck (2)	8.00	-0.010/0.170	-0.170/0.210
18-2	Main Deck (3)	8.00	-0.010/0.170	-0.170/0.210
19-2	Main Deck (4)	8.00	-0.010/0.170	-0.170/0.210
20-2	Main Deck (5)	8.00	-0.010/0.170	-0.170/0.210

The explanation of Group 1's related variation is found in the internal structure of the T-AGOS stern block. Figure 8 shows a partial exploded view of the block. The location of the block interface is at station 96, where the forward edges of the 13'6" flat, the centerline frame, and the four diagonal frames are seen to lie. The merged variation of these edges (and of all the other edges at the interface) are calculated with respect to bulkhead 100. The exploded view shows the 13'6" egg box abutting the 15' egg box, and the 15' egg box in turn abutting bulkhead 100. The forward transverse of the 15' egg box (at station 96) therefore determines the position of the 13'6" egg box. The location of this transverse frame, however, will have variation with respect to bulkhead 100, variation that will affect equally the variation of the edges at station 96. This, then, is the mutual variation that is shared by all edges in related Group #1. The edges' independent variations come from process variations that occur forward of station 96.

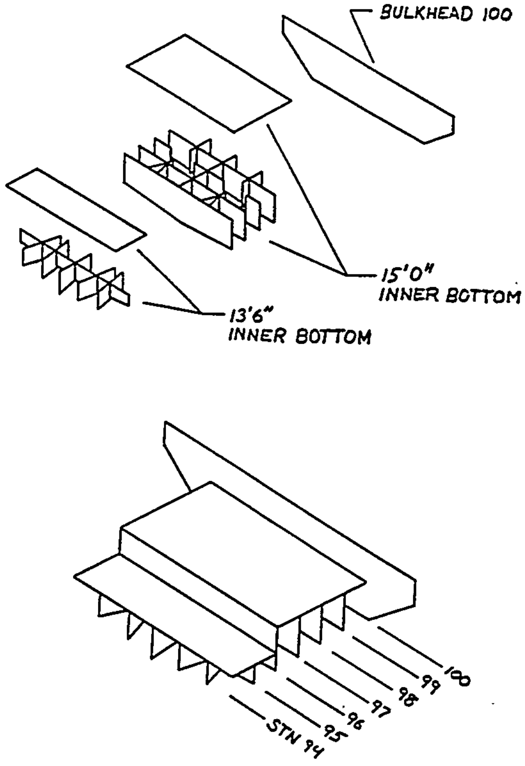


Fig.8. T-AGOS Stern Section - Exploded View

The reason that the Main Deck was subdivided into a related group is because of its assembly sequence. The Main Deck is originally assembled from five flat panels, running fore and aft. There is variation associated with the construction of these five panels that will manifest itself independently for each panel. After the panels are joined, however, they constitute the Main Deck, and its installation onto the hull block results in additional variation that is mutually experienced for each of the five previously separate edges.

When variation tables with related groups, such as the T-AGOS table, are loaded into the rework simulation program, both mutual and independent variation are randomly generated to represent the "construction" of the two hundred hull blocks. The following section presents the program's estimate of rework for the T-AGOS stern block, and a sensitivity analysis to evaluate options on improving it.

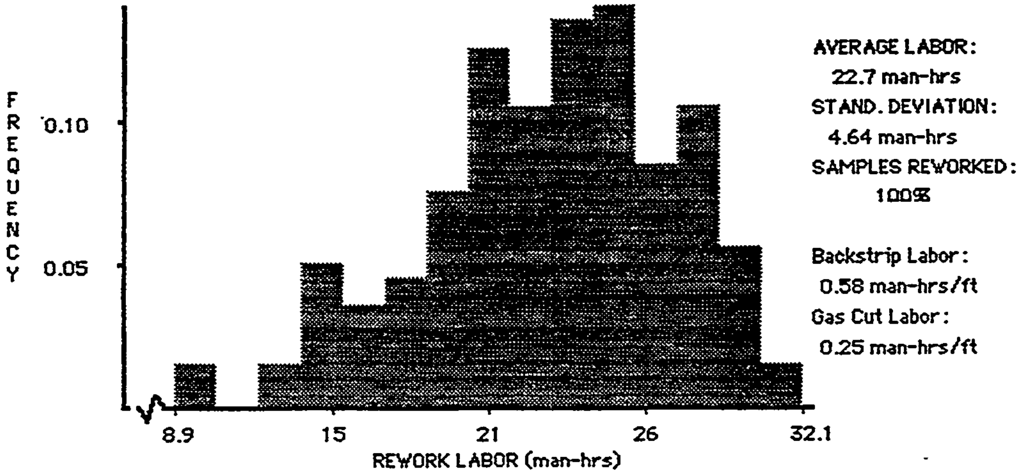
The T-AGOS Rework Profile

The probability of rework on the T-AGOS stern section will be assessed in terms of the labor required instead of by the actual linear feet of rework (cutting and backstrip welding) at the interface. A focus on rework labor can be an equally effective method of monitoring accuracy performance, and projections of labor requirements are more useful for purposes of scheduling the build sequence. The simulation program evaluates rework labor by allocating predetermined man-hour rates (per unit length), for cutting and backstrip welding, to the optimum rework solutions generated in the simulation.

For the T-AGOS simulation, a labor rate of 0.25 man-hours per foot for cutting and 0.58 man-hours per foot for backstrip welding will be used. These are hypothetical values, and do not imply standards of welding performance at Tacoma Boat or any other shipyard. This represents a ratio of labor rates of about 2.3, and since labor constitutes the major element contributing to total rework costs, a cost ratio of 2.5 will be used to determine the optimum rework solutions.

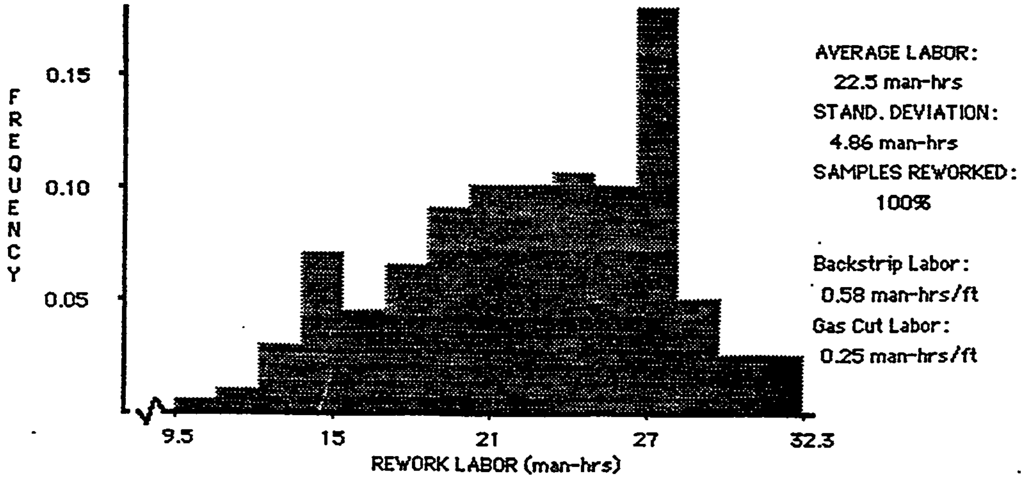
Figure 9 shows the distribution of rework labor for two separate runs of the simulation program. Both profiles are skewed to the right, though there are differences in the details. The mode of the upper profile is at approximately 28 man-hours, while that for the lower profile lies at around 24 man-hours. The labor averages, however, differ by only about 2%, at 22.7 and 22.2 man-hours, respectively. If a better approximation of the true distribution is needed, it can be had by taking a greater sample size in the simulation.

T-AGOS - Distribution of Rework Labor



(200 Samples, 0.25" Gap Tolerance, Strip/Cost Ratio: 2.50)

T-AGOS - Distribution of Rework Labor



(200 Samples, 0.25" Gap Tolerance, Strip/Cost Ratio: 2.50)

Fig.9. T-AGOS Labor Profiles from Two Separate Simulation Runs

Having obtained an estimate of the anticipated rework on the T-AGOS stern block, the next step is to run a few more simulations to observe how certain design changes will affect the profile. The first axiom of quality control is the importance of reducing variability. In the T-AGOS case, there are several ways of approaching the problem. Figure 10 is the diagram of variations limits for the edges at the block interface (these limits come directly from the variation table in Table 1). The figure shows that the edges in related group #1 - the 13'6" Flat, and the Centerline and diagonal frames - exhibit the greatest amount of variation, while the forward edges of the side shells and bilge strakes have the least variation. A reduction in these variation limits would certainly reduce variability. But since these are merged variations, this implies the need for either a different assembly sequence or a reduction in the process variations throughout the shipyard; neither of which might be immediately available to the engineering staff.

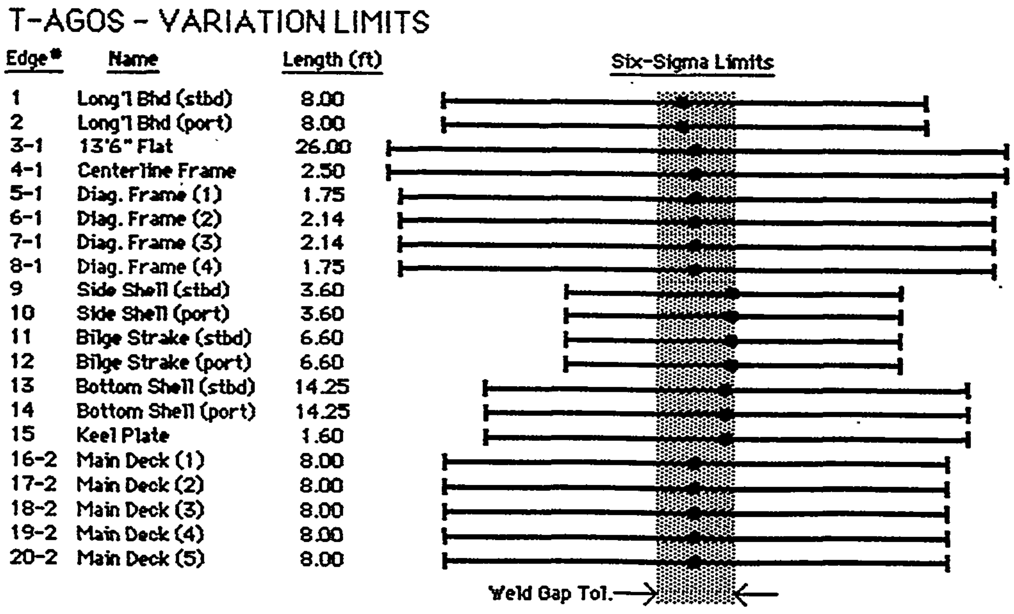


Fig.10. T-AGOS Variation Limits

The case does present, however, an element of variability that can be very easily dealt with, and this is that the merged mean variations of the edges at the interface are not all the same. This is evident in Figure 10 in the misalignment of the six-sigma variation limits. Lining up the variation limits is accomplished by normalizing all of the mean variations to a single value. A merged mean variation can be changed by simply introducing an "engineering variation" somewhere in the build sequence - by, for instance, telling the N.C. cutting machine to cut out a plate that is slightly longer than called for in the drawing. This would change the mean variation at the block interface without affecting the standard deviation.

This strategy was tried out on the simulation program. The T-AGOS variation table was edited to bring all of the edges' mean variations to zero, and the new table designated "T-AGOS(zero)." The results, given in Figure 11, show a reduction in average rework labor, but not by much. The improvement amounts to something between 2% and 4% of the original average. Clearly, there is still much improvement to be gained through a reduction of merged standard deviations.

To evaluate the effect of a general reduction in standard deviation, two more simulations were run. The two new variation tables are called T-AGOS(90%) and T-AGOS(80%), reflecting an overall

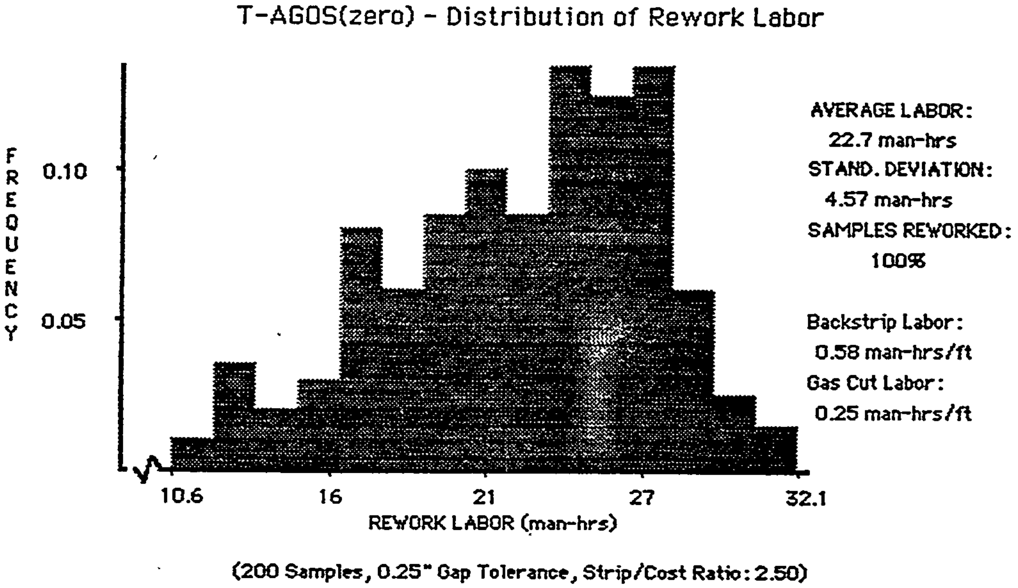


Fig.11. T-AGOS(zero) Labor Profile

reduction (from the original T-AGOS) of all the edges' merged standard deviations by 10% and 20%, respectively. The results are shown in Figure 12. The 10% and 20% reductions in standard deviation produce around 5% and 9% reductions in average rework labor.

It is difficult, and probably of little value, to try to compare these two different approaches to reducing variability. Going from a T-AGOS to a T-AGOS(zero) is very simple, once the merged variations are understood, but the benefits are limited. Getting from a T-AGOS to a T-AGOS(90%) may take many years of Accuracy Control work, but ultimately there is much more potential for economic reward along that path. Even though it all falls under the heading of Accuracy Control, it appears that accuracy is relatively easy to achieve - it's precision that takes a lot of work.

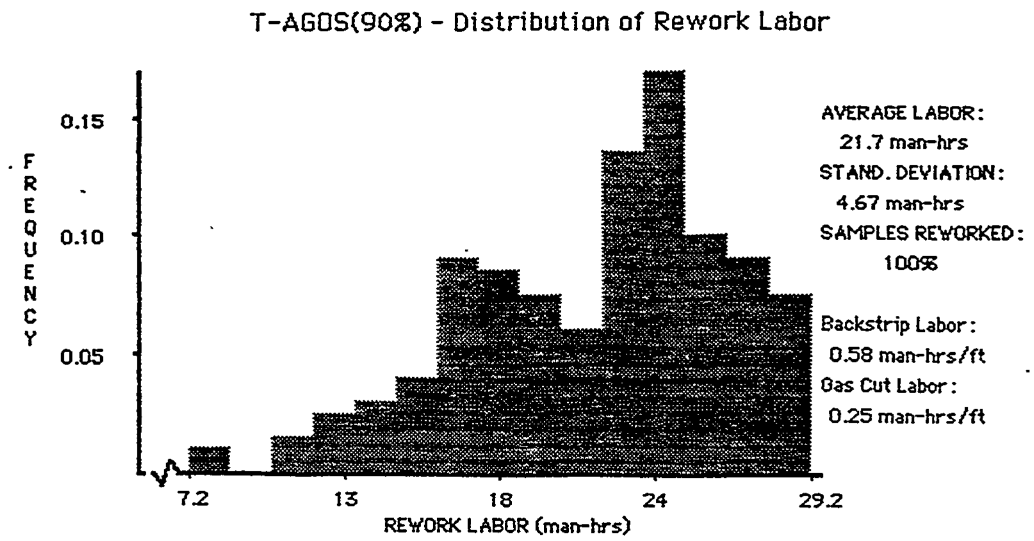
6. STEPS TOWARD PRACTICAL APPLICATION

Sections 1 through 4 have been devoted to developing a model of merged variation at the block interface, explaining the decision criteria for performing rework on the interface, and introducing and testing a simulation program written to predict the rework outcome on a given hull block, based on the assumptions in the model. The program is shown to be capable of producing useful output. Its graphical representations of the rework, cost, and labor distributions are easy to interpret, giving the user a good grasp of the probabilities associated with easy case.

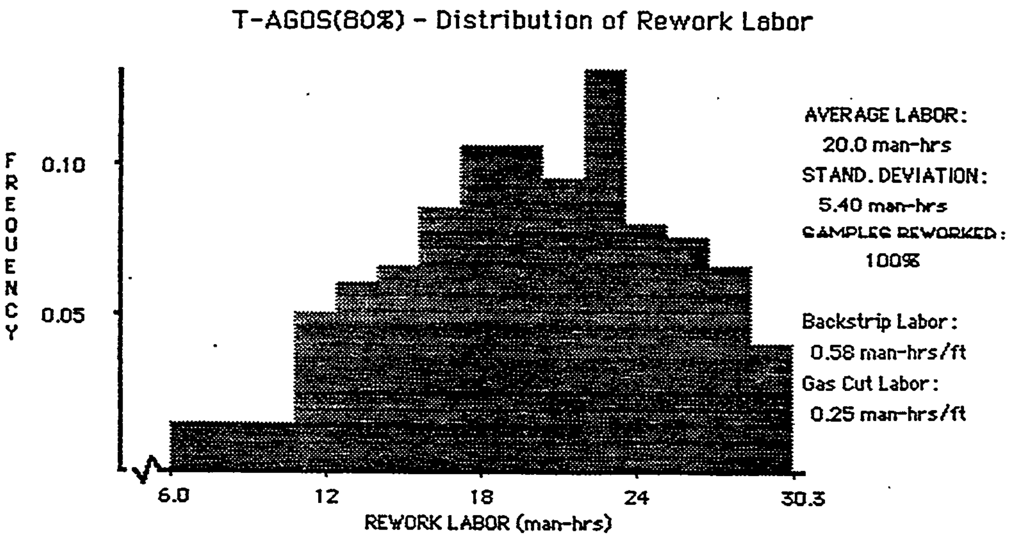
Given all this, however, the program is still not ready for service in a real application. The variation/rework model presented here contains several major simplifications, as is appropriate in early stages of research, which need to be addressed before the program is finally ready for use. This section presents a brief discussion on some of these remaining issues, and sketches out what work is left to be done for the refinement of the model and the implementation of the simulation program

Choosing an Effective Sample Size

At several points in this report, the axiom, "the bigger the sample, the better the approximation," has been used to acknowledge the topic of sample size. The sample size of two hundred hull blocks, used in these simulations, was chosen fairly arbitrarily. It is necessary, however, in an industrial application, to address more specifically the questions of "how much" versus "how good," because the decisions have an economic consequence.


T-AGOS(90%) - Distribution of Rework Labor

(200 Samples, 0.25" Gap Tolerance, Strip/Cost Ratio: 2.50)


T-AGOS(80%) - Distribution of Rework Labor

(200 Samples, 0.25" Gap Tolerance, Strip/Cost Ratio: 2.50)

Fig.12. T-AGOS(90%) and T-AGOS(80%) Labor Profiles

How good will a prediction of average rework be for a given sample size? Actually, the quality of the prediction depends not only on sample size, but also on the profile and standard deviation of the population. Statistically, the best way to answer this sort of question is in terms of a confidence interval. A confidence interval is an interval, centered about the sample mean, within which it can be stated (at a certain level of confidence) that the population mean lies. A 95% confidence interval implies a 5% chance of error, or an "alpha error" of 0.05.

Assuming that the rework profile is a normal distribution (which it isn't), then it is a simple matter to calculate confidence intevals. The formula is:

$$\bar{X}-(S/\sqrt{n})Z_{\alpha/2} < \mu < \bar{X}+(S/\sqrt{n})Z_{\alpha/2}$$

where :
μ=population mean
$\bar{X}$=sample mean
S=standard deviation
n=sample size
$Z_{\alpha/2}$=the standard normal value with an $\alpha/2$ probability.

Applying this formula to the first T-AGOS simulation, with a sample mean of 22.7 man-hours and a standard deviation of 4.45, a 95% confidence interval is calculated to be: 22.7 ± 0.62 man-hours, or $22.08 < \mu < 22.32$. The width of the confidence inteval is about 5% of the value it constrains. Table 2 lists 95% confidence intervals for the T-AGOS case for sample sizes of 50, 100, 200, and 500. Since the rework function is <u>not</u> a normal distribution, these are only rough estimates, but they provide at least a basis for comparing the size of the simulation with the accuracy it delivers.

Table 2. Confidence Intervals for Various Sample Sizes

Sample Size	95% Confidence Intervals (man-hours)
50	$\bar{X}$ ± 1.23
100	$\bar{X}$ ± 0.87
200	$\bar{X}$ ± 0.62
500	$\bar{X}$ ± 0.39

Characterizing Merged Variation in Three Axes

In this paper, fluctuations in the erection weld gap have been attributed to merged variation at the block interface only in the longitudinal direction. Obviously, a constructed hull block will experience some variation along the transverse and vertical axes as well, affecting the weld gap, and consequently rework. This would seem to imply that three orthogonal sets of variation merging equations must be written for each edge at the interface to fully characterize its impact on the rework function. A simulation program could certainly be written to accommodate this, though at some point, the added complexity of the calculations may render the program unworkable on a mere personal computer.

It's possible, however, that such complete characterization is not always necessary. An edge's contribution to the rework function might be found to consist of only two factors: its longitudinal variation, and its <u>perpendicular</u> variation. For instance, in the case of a vertical bulkhead, the longitudinal and transverse variations are the only relevant factors; any vertical variation encountered will not affect the weld gap. Likewise, for a horizontal deck, only its longitudinal and vertical variation might need be considered. The variation of obliquely angled edges would have to be characterized in all three directions, but even this case can be resolved to just longitudinal and perpendicular variation through a rotation of coordinate axes. Curved edges, unfortunately, are not amenable to any of this rationalization.

The nature of the erection weld joint might also have a bearing on how many axes of variation must be addressed. This brings the adjoining block into consideration. If a weld joint is edge-to-edge, then the play (or rather, the interplay) of both longitudinal and perpendicular variation will determine the weld gap. Depending on welding technology, rework criteria may either remain in terms of overall weld gap tolerances, or depend on the interrelated result of a longitudinal gap and a planer gap. On the other hand, if an edge on the first block is to be welded to the face of a bulkhead on the second, then the edge's perpendicular variation is not a contributing factor to the quality of the weld joint (though, granted, it may be of great concern to the American Bureau of Shipping's strength requirments).

Considering Two-Sided Variation

Since the "adjoining block" has entered the discussion again, it is an appropriate time to talk about another shortcoming of our present variation/rework model. As it stands now, the simulation program assumes a model of one-sided variation, that is, variation on only one of the blocks at the erection joint. But in reality, variation from both of the blocks will actually determine the rework function. There are two ways that this can be addressed.

The first method is to revise the rework program to simulate the variation at the interface of both of the blocks. Two variation tables would be loaded into the program instead of one, and the simulation would begin by "building" two hundred blocks of the first type and two hundred of the second. Determination of the optimum rework solution of each case would in principle be the same as before, but would necessarily account for the variation on both sides of the weld joint. Instead of moving a flat plane through the interface of the one block, and evaluating in turn each possible rework solution encountered, one block would be moved through the other, with the coincidence of each pair of mating elements representing a possible rework solution. At each out-of-tolerance joint, it would be immaterial which of the two edges actually received the rework. The optimum solution would still be the one that incurred the minimum cost. The subroutine to perform this task would be more complex than the one in current use, but still within the scope of a competent programmer.

A second method for modeling two-sided variation would, as opposed to the first, require no revision of the current program, and should yield an equivalent solution. The plan involves "merging" the merged variation of mating elements at the interface to create a "two-sided variation table " that can be processed by the current, one-sided model. This can also be described as the action of "folding," or transferring, the variation of the second block onto the first block, thereby maintaining the model of one-sided variation. If an edge on one block has a mean variation of 0.25" and a standard deviation of 0.20", and its mating edge on the other block has a mean variation of -0.25" with a standard deviation of 0.30", then the combined effect would correspond to a one-sided mean variation of zero, with a standard deviation of 0.36".

Assuming that the second proposed method is equivalent to the first, it would accomplish the same task with much less computational effort. The reasoning seems intuitively sound, but at this time, a formal proof of the equivalence cannot be presented. The most straightforward test would be to write two parallel simulation programs, one for each method, and compare the results.

Using Feedback to Improve The System

No matter how complex the model becomes, it will always remain just an approximation of real life. Unforeseen factors, or inaccurate representation of chosen factors, can bias the results of the simulation. This is not to imply that the simulation program cannot be a valuable tool, but it does suggest a strategy for further improving the quality of the program's output. Once the system is in place, recorded rework can be compared to the program's predictions, to characterize the overall accuracy of the model. The concept is similar to the analysis of residuals in a designed experiment.

The error of each prediction - that is, the difference between the projected and actual values - can be determined for every erection joint. If the predicting errors are normalized to (for instance) a percentage of the actual outcome, then they can all be plotted together to detect possible trends. The rework prediction for one interface might be 10% high; for the next interface, it might be 6% low. If there is no bias in the model, then the average error will be zero. If the model does contain bias, then future simulation results can be amended to compensate for the average percentage error, and achieve a more accurate prediction. The monitoring of error can also lead to an improvement of the model itself, if it can point out specific inaccuracies in the current assumptions. The goal of a continuously improving manufacturing ssytem is facilitated in part by a continuously improving control system.

7. CONCLUSIONS

The purpose of this report has been to show the capabilities of computer simulation in predicting rework on ship's hull blocks at erection. This simulation of the rework function is made possible because of two very powerful concepts that have effected great changes in shipbuilding technology over the last few decades. These are Group Technology Manufacturing and Statistical Process Analysis. Group technology promotes the rational organization of a large project into categories of similar work packages, shifting focus from the building of ships to the building of interim products. Statistical process analysis gives the shipyard a direct understanding of its own manufacturing capabilities, and at the same time, a practical framework for continuously improving those capabilities.

This greater element of control in shipbuilding technology permits a characterization of the factors that lead to erection-stage rework. Random block variation at the erection interface is modeled through the writing of variation merging equations. Rework for a given hull block design is the function of this random variation, as well as several fixed factors. All of these factors can be represented in a computer simulation. This report demonstrates the use and usefulness of the author's simulation program by applying it in the context of a case study. The significant findings from the variation and rework studies, as well as the simulation results, are summarized below.

1. Rework on hull blocks is performed to rectify the effects of variation of the edges at the block interface. The specific goal of rework is to create a uniform weld gap at the erection interface by bringing all of the edges into the same weld tolerance zone. When considering a given constructed block, there are many rework solutions through which the interface can be made acceptable. The optimum rework solution is the one incurring the minimum cost, based on the four-way interaction between the resultant variation of the block's various edges at the interface, the lengths of the edges, the weld gap tolerance, and the relative costs of rework.

2. As merged variation at the block interface occurs randomly, the optimum rework solution is itself a random variable, having a unique probability distribution profile. The rework simulation program, by modelling all of the factors listed above, can sample from the "population" of hull blocks and generate an estimate of the rework distribution to any accuracy desired. The program also produces estimates of the rework cost and labor profiles, and the rework probabilities of the specific edges at the interface.

3. The characterization of the rework function can be very useful when writing schedules and budgets for the erection stage of construction. The forecasts for each of the ship's blocks can be assessed during the design phase to look for blocks with high rework probabilities, where design changes might be needed. The estimate of edge specific rework probabilities can identify when certain edges are contributing an excessive amount to rework levels at the interface. Such early detection of potential problems can help the shipyard to avoid costly disruptions in the building schedule.

4. Overall projections of rework levels for the entire ship can be obtained by summing the individual block projections. The management can use overall projections to evaluate the producability of the design, and the product's acceptability with respect to the buyer's expectations. Preliminary projections may indicate a likelihood of cost or schedule overruns, in which case, negotiation can be initiated as early as possible to reach the most satisfactory outcome.

5. In addition to its value in costing and scheduling, the simulation program can also be an important tool for increasing productivity. The program can be used to assess the impact of proposed process improvements, such as greater precision of certain manufacturing operations, or an increase in weld gap tolerance. With this information, operations spending can be prioritized to yield the greatest impact for the dollar.

The program presented here is just a demonstration model. Every shipyard that elects to make use of such a program will incorporate into it the characteristics of those fabrication and rework practices that are unique to that yard. It should evolve and improve, in reflection of the shipyard itself, becoming a valuable asset to future production capabilities.

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Performance Teams: A Participative Approach to Productivity Improvement

No. 5

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ABSTRACT

The Performance Team program's purpose is to increase the productivity of the organization. The program's concepts are based on participative management, top-down involvement, objective setting, and analytical problem solving.

The Performance Team program has the potential to:

1. Increase the involvement of production personnel in the labor management process.
2. Improve the supervisor's analytical problem solving skills.
3. Identify and improve work methods and productivity.
4. Develop an improved rate structure.
5. Improve communication between functional departments.

This paper explores the development and implementation of the Performance Team program at National Steel and Shipbuilding Company. The application of the Performance Team concepts should be of interest to all production management interested in productivity improvement.

BACKGROUND

Various factors led to the development of the Performance Team idea.

Production Experience. Assignment to the Transportation/Rigging and Electrical Departments, as Staff Engineer, led to a new and broadened perspective of production: The production supervisors' were able to take the information fed to them from various departments, and make it work. With whatever problems arose, it remained their task to finish the job; and they did.

Training. Assignment to the Electrical Department began to focus on the development of schedules which led the department to improved scheduling techniques. My experience was coupled with the experience of others, to develop scheduling training classes for all production foremen, as requested by management. These training classes presented techniques for both long and short term scheduling.

As a follow-on to the scheduling training classes, management requested the focus turn toward the labor management process. In trying to develop training material, various problems arose:

1. Budgets did not receive great credibility.
2. Workrates were not considered accurate.
3. Direct involvement in the labor management process was not perceived.

With the existance of such doubts, the task of developing training material became an examination of the labor management process.

Production Involvement. The problem appeared to center on production's disbelief of their involvement. Their disbelief created minimal concern for accurate cost collecting, thus effecting future budgets and estimates. Increasing their perceived involvement in the labor management process appeared to be the answer.

Training classes began, identifying production's role in the labor management process. Estimating, Master Planning, and Production were each identified as an integral part of the cycle; employing different focuses to their manpower development.

With the role of production identified, focus turned toward training the supervision in labor management skills. Production foreman needed new skills to be involved in the process.

Industrial Engineering Techniques. The training focused on methods improvement, rather than rate development. Finding a more efficient way to do the job was expected to provide more immediate results than rate development.

Work sampling was chosen as a technique which could provide the foremen with the ability to measure, monitor, and improve their productivity.

Performance Teams. The idea of Performance Teams developed as the labor management training progressed. Placing the responsibility on the foremen was going to require support from all levels of management, a common focus, and open communication. A program which incorporated these philosophies was required. Initial ideas for the program development grew from the works of D. Scott Sink, PhD. The Performance Team program included concepts of participative management, Management by Objective, and top-down involvement.

PROGRAM STRUCTURE

Purpose. The purpose of the program is to decentralize the responsibility for cost improvements and increase the productivity of the organization, to more actively involve the supervisory levels of production in labor management practices.

Goals. The program established the following goals as the primary targets for all subsequent objectives and activities:

1. The establishment of proactive budgeting practices.
2. The identification and improvement of work methods.
3. The increased ability to measure performance.

4. The development, improvement and validation of a productivity rate structure.

5. The increased involvement of salaried supervision in the Labor Management process.

Management Involvement. Management involvement is critical to the program structure. Without management support, the strength of the program would be limited. The levels of management with full responsibility for the success of the Performance Teams were identified to include Senior Vice President Operations, Directors, Superintendants and the salaried supervisors on the Teams themselves.

The management components considered critical to the success of the program are defined as:

Hard Work—Each level of management needs to devote time and effort to document their own understanding of current rates and methods in order to responsibly provide leadership to the other management levels.

Involvement/Participation—Emphasis needs to be given to understanding and integrating the insights and recommendations of each management level.

Innovation—As abilities and motivations increase, suggestions for change and improvements are likely to evolve. New ideas and creative suggestions must be viewed with openess and realism. Where opportunities for improvement make sense, all management levels must be willing to take the risk necessary to innovate success.

Directionality—The structure, emphasis, and actual follow through of this program depends greatly on the direction and climate set by each management level participant. Directionality was particularly influenced by the program's objective setting process.

Objective Setting—To maintain a common focus, the Performance Team program is based on an objective setting process. This process is to allow each level of management to set objectives for their level of responsibility. A "planning form" was developed to formalize the objective setting process.

During the program start-up, the Performance Teams were to propose initial objectives to their Superintendant and Director. The Superintendant and Director were then responsible for identifying their own expectations for the Performance Team, and discussing these objectives with the Team. The Superintendant, Director, and Sr. Vice President Operations would then meet to review and accept the objectives. The review process was intended to maintain communication between management levels.

Planning Form. The purpose of the Performance Team Planning Form (see figure 1) is:

1. To prepare for discussing the primary target, objectives, and action steps that are relevant to the Performance Team Program.

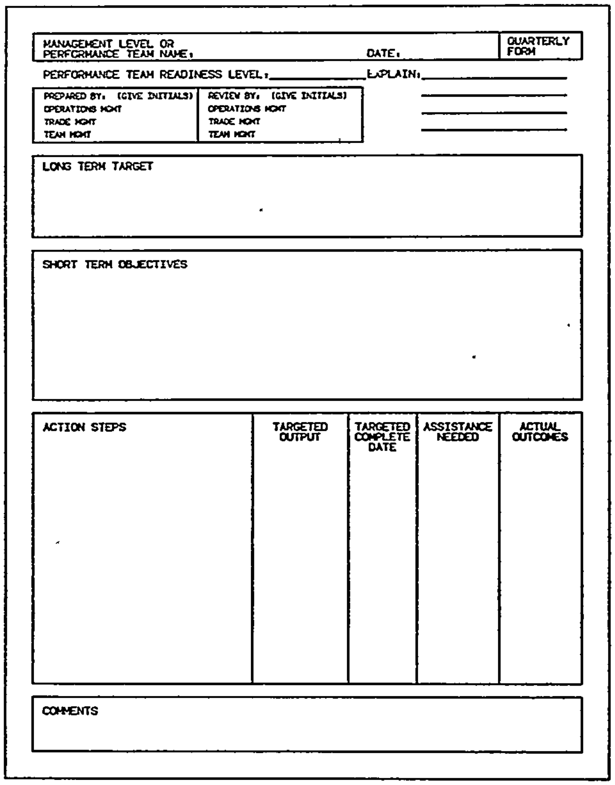
2. To document the target, objectives and action steps agreed upon in the management review process.

Specific instructions given to the teams, to complete the forms included:

Readiness Level—Readiness assessment guidelines have been established to assess a Performance Team's readiness. Identify the team's level based on the two major components of readiness, ability and motivation.

Short Term Objectives—Indicate short term objectives that can be measured and reviewed at the end of a three month period.

Action Steps—Identify specifically what particular actions will be taken in order to reach the short term objectives.



MANAGEMENT LEVEL OR PERFORMANCE TEAM NAME: DATE:

QUARTERLY FORM

PERFORMANCE TEAM READINESS LEVEL:__________ EXPLAIN:__________

PREPARED BY: (GIVE INITIALS)	REVIEW BY: (GIVE INITIALS)
OPERATIONS MGMT	OPERATIONS MGMT
TRADE MGMT	TRADE MGMT
TEAM MGMT	TEAM MGMT

LONG TERM TARGET

SHORT TERM OBJECTIVES

ACTION STEPS	TARGETED OUTPUT	TARGETED COMPLETE DATE	ASSISTANCE NEEDED	ACTUAL OUTCOMES

COMMENTS

FIGURE 1

Participants. Each Performance Team should consist of:

-a Leader—typically an Assistant Superintendant or General Foreman in the designated trade area.

-an Assistant—typically a foreman or staff person in the designated trade area

-Members—the salaried supervisors in the designated trade area.

Leaders and assistants were chosen from various departments to participate in the program. Activities involved in pursuing the objectives of this program were considered to be a normal function of the supervisor's job.

IMPLEMENTATION

Certain factors were predicted to have possible effect on the implementation of the Performance Teams. Each of these issues were addressed up front:

Management Support. As the Performance Team program was developing, management support was continually sought. Clearly, the support of each level of management was critical to the success of the program. If the participants of the Performance Teams felt that management were not in support of the program, they would be less likely to give their cooperation to the program.

The Senior Vice President, Operations was extremely supportive of the program, and was willing to "champion" the efforts. The Directors and Superintendants were kept continually involved in the program development. They previewed all training material, prior to the Performance Teams' training sessions. These review sessions were important for more than the involvement; they provided a means for acclimating this level of management to the principles on which the Performance Teams were based.

Although there were some reservations toward the program, management support appeared to be sufficient for the success of the program.

Union Support. Since the Performance Teams would be involved in measuring the productivity of the work force, union cooperation was critical. To prevent any problems as the program began, union representatives were invited to a presentation. This presentation gave an overview of the Performance Teams, and explained the importance of the program. They. were informed that the foremen would be measuring the productivity of the work force, but that this in no way reflected on the individual workers. Instead, it was a reflection of the foreman's supervisory abilities.

The union representatives were very responsive to the program, and understood that improving productivity was critical to the success of the company.

Common Understanding of the Program Goals. The goals to the program were clearly stated to all levels of management. Even more clearly understood than the goals was the underlying thought that productivity improvement was essential to the company's operations.

Production Supervision's Problem Solving Abilities. The training sessions were developed to improve production supervision's abilities. work sampling was emphasized as a technique to be used for measuring and improving productivity. A 'questioning attitude' was stressed as an integral part of their daily activities.

Awareness of Short and Long Term Results. As the program began, there was a desire for overnight changes. It was essential to portray that the program could not provide such an impact. In the short run, observing productivity improvements should be considered significant. In the longer run, effecting future bids, and developing more accurate work rates were reasonable goals. It was unfeasible to expect the development of rates as a short term goal.

The importance of not rushing for results was accepted, although there was a continued desire for a more rapid approach.

TRAINING

Performance Team training material was developed primarily to improve the participants' analytical and problem solving skills. The training material provided production supervisors with the tools to study their methods and measure productivity. This was to give production supervision the ability to:

1. Identify productive and non-productive time.
2. Reduce non-productive time.
3. Monitor performance.
4. Improve predictability of meeting schedule and manhour allowances.
5. Develop more meaningful historical data.

Many factors contributed to the development of the training material. The Methods Engineering Workshop for the Shipbuilding Industry, published by SP-8, provided a basis for development. The training classes provided "the basics", with follow-on training as the Performance Teams continued to progress.

The initial training was broken into five sessions. All Performance Team leaders and assistants were required to attend the training sessions. The following is an outline of the sessions:

Performance Team Objectives/Operations

- Performance Team Organizational Structure
- Objective Setting
- Performance Team Operations
- Start-up Sequence

Overview

- Need for Work Measurement
- Need for Methods Improvement
- General Terms and Definitions

Data Collection

- Methods Improvements
- Process Charts
- work sampling

Data Analysis

- Work Content Identification
- Self Logging
- Work Rate Development

Data Utilization

- Classification
- Application
- Performance Measurement.

As the sessions began, it appeared too much information was being presented at one time. The Data Utilization session was withheld from the training until a later date. The training continued to focus on work sampling and methods improvement. Observing the training with hind-sight, some of the training material and presentation of the material might be changed for a future application.

RESULTS

All elements appeared to have been set in place for the progress of the Performance Team Program. Each team received specific task assignments to begin their investigations. Their tasks included.

1. Identify current budgets.
2. Discuss rates being used with Planning and Estimating.
3. Conduct a work sampling to identify current productivity.
4. Identify areas for improvement.

As time passed, it became obvious that each team would progress at a different pace, and in various directions. These factors had an effect the Performance Teams' performance:

Varying Workload. During the time period in which the Performance Teams began their efforts, the production workload was diminishing. With an atypical workload, productivity could not be effectively measured.

Management Support. Active participation by management was not perceived by all Performance Team participants. A questioning attitude toward the future of the Performance Team program began to develop.

Team Guidance. The factor having the most significant impact on the teams' results was team guidance. The Performance Team program had one 'facilitator'. The direction, continued training, and program support simply could not be fully provided by one person.

The following are examples of three Performance Teams' results:

Steel Erection. Although this team was affected early by the declining workload, they were able to complete a work sampling and identify areas for improvement. The participants of this team expect to continue this type of problem solving at the onset of the next construction cycle.

Pipe On-Block. This team was also able to complete a work sampling and identify areas for improvement. They also began to analyze their productivity from various perspectives; time of day, day of the week. The information gathered by this team was used to affect their future bidding factors.

Electrical On-Board. This team was able to progress further than the other teams. Their success was attributable to:

1. An enthusiastic leader.
2. A positive departmental attitude.
3. Additional direction from the Performance Team 'facilitator'.

This team began their activities by conducting a work sampling. Although the foremen had previously recognized some of their inefficiencies, the work sampling made the information more tangible. Method changes were made on the basis of the work sampling findings.

The team continued their activities into the area of self-logging. Electricians were approached and asked to participate in the self-loggings; their participation was optional. The results from the self-loggings were helpful in identifying problem areas, but more direction would be required to have gained more accurate time-keeping through the use of this technique.

The team identified 'hook-up' as an area for significant improvement in method and productivity improvements. One of the team members had a background of industrial engineering training, and was able to conduct time studies. The results of these studies provided information for the team members to identify method improvements. The information was also used to develop input for budgeting and estimating.

The team had begun their activities by identifying their current workrates being utilized by the Estimating and Master Planning Departments. As the team developed information to effect these rates, they began to discuss this information with the other departments. They had been able to develop information which significantly affected their departmental budgets and estimates.

Another output from the team was the development of an evaluation form. This evaluation form was used to open lines of communication between the workers and their supervisors.

The feedback loop and increased involvement has begun. The department is certain they will continue their involvement in the labor management process.

Conclusion. Despite problems, the Performance Team program experienced its share of success. The Performance Team program was able to:

1. Increase production supervision's involvement in the Labor Management process.
2. Improve the supervisor's analytical problem solving skills.
3. Identify and improve work methods and productivity.
4. Improve communication between functional departments.

The program proved its concepts were a feasible approach, and variations would be required for more significant progress.

LESSONS LEARNED

Production Involvement. Performance Teams can effectively involve production supervision in the labor management process. Production supervisors are willing and able to be more involved.

Training. Specific emphasis should be placed on work sampling. The production supervisors were able to grasp this technique, using it to measure productivity, improve methods, and develop workrates.

Guidelines for conducting a work sampling should be clearly defined. As the Performance Teams progressed, the guidelines issued by Rear Admiral Horne were discussed and utilized by some of the teams. Having all teams progressing on similar guidelines would provide a basis for comparison.

Training material should be presented in segments. As the teams progress, more information should continue to be presented.

Structure. More emphasis needs to be placed on monitoring team performance, follow through is essential. Continued involvement by management is vital.

Industrial Engineering Support. The program requires continued training and guidance, outside the classroom sessions. The addition of more industrial engineers as trainers/facilitators/assistants would provide a significant improvement to the program efforts.

Implementation. A feasible timeline should be developed. Abbreviated training and start-up time will not foster the program's growth.

FUTURE IMPLEMENTATION

Participative management leads to improved productivity, as the Performance Team program indicates. The programs results validate the process of developing analytical problem solving skills to increase involvement in the labor management process.

The benefits of the Performance Team program are universal to all manufacturing environments. With industrial engineering support and top-down involvement, the program should lead toward the desired productivity improvements.

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Increasing Efficiency Through Outfit Planning No. 6

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ABSTRACT

Outfit Planning provides a means to increase productivity and schedule enhancements through zone outfitting, group technology, and prefabrication. Puget Sound Naval Shipyard has gained an understanding of outfit planning through publications by the Maritime Administration's National Shipbuilding Research Program.

In an attempt to increase efficiency, Puget Sound Naval Shipyard is using outfit planning methods to overhaul, alter, and repair U.S. Naval Ships. One project targeted for outfit planning is the forward end-electronic package on submarines. This paper will describe Puget Sound Naval Shipyard's efforts to use outfit planning concepts in developing work packages for the forward end ship alterations (shipalts).

INTRODUCTION

Puget Sound Naval Shipyard has been assigned seven overhauls of the same submarine class in the 1986 to 1990 time frame. Four of the seven submarines have five repeatable shipalts. Outfit planning/zone logic is being used to break down and divide work on these submarines into manageable packages. Breakdown of work based on zones is in contrast to traditional means of dividing work based on ships' functional systems. Because zone logic focuses on products within each specific zone, there is a shift from a system oriented methodology to one which is product oriented.

OUTFIT PLANNING GROUP

Success of outfit planning requires support and involvement from a variety of departments within the Shipyard. To coordinate the interdepartmental efforts, an outfit planning group was formed. Core members of the group include personnel from: engineering, production, supply, scheduling, and planning and estimating departments. The core group is responsible for planning and sequencing work required for the forward end shipalts. When planning a particular phase, the core group calls on the expertise of other persons and organizations to provide input and support. Lead mechanics assigned to the job become involved and have primary input before planning starts. All members outside the core group are known as "satellite" members. The group meets on an average once a week for an hour.

Two key persons of the outfit planning core group are the zone chairman and the zone manager. The zone chairman is a project engineer selected by engineering management. The zone manager is an individual from production. Selection of the chairman and manager was based on their leadership abilities and their knowledge of manufacturing and overhaul processes. While sharing same goals, the zone chairman and zone manager each have unique responsibilities.

The zone chairman's principal responsibilities include: leading group sessions, assigning tasks to group members, insuring compliance with regulatory agencies, resolving problems due to specifications or deviations, and reporting status of the project to Shipyard management. The zone manager's principal responsibilities include: identifying processes that can be grouped together, determining a work flow pattern, and sequencing work in a logical order.

The efforts of each such planning team are monitored by a few managers who are knowledge in the logic and principles of zone orientation and who are referred to as the Outfit Planning Steering Group. As the title implies, they have responsibility for reviewing current projects and processes, as well as establishing long-range plans.

The first task of the outfit planning group was to identify those shipalts contained in the forward end of the submarines and to determine effected spaces. The outfit planning group focused on the largest five shipalts. Once the group determined that the five shipalts were to occupy seven compartments, they divided those spaces into fifteen unique work zone areas. Their plan was to perform like types of work in each zone regardless of systems (e.g., all ripout work would be accomplished in response to a single zone/stage work package).

Because of the volume of work required in the forward end, the amount of work to be controlled by zone logic was systematically increased as shown in Figure 1. Phase I, noted therein, addressed all deck mounted foundations. The application of zone logic was expanded in Phase II to include all foundations i.e., bulkhead mounted and other miscellaneous types. Phase III has already started and is addressing <u>all</u> equipment and systems as well as foundations in <u>all</u> zones.

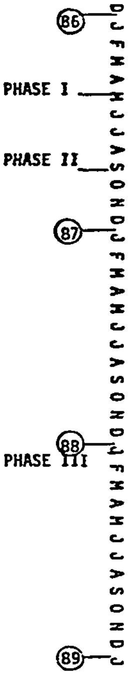


Figure 1. Goals for Work Package Development

TRADITIONAL WORK PACKAGING

Traditionally, when work was communicated to the Production Departments it was done through the job order/key operation (key op) system. Each key op identifies work to be completed on a portion of a ship's system. Each gives a list of drawings, process instructions, and references other key ops applicable to the job. Each identifies all work centers (shop number plus a numerical suffix indicating type of work) which need to be involved for a specific task, and identifies a lump sum of man-hours allocated to each work center. Scheduling of the jobs is made by a key event schedule. Each key event must be accomplished on time in order to meet projected overhaul completion dates. Key op completion dates are tied to a key event schedule. This often means that all key ops listed under any key event are given the same completion date. Control is less effective then it would be otherwise.

In response to a key op, a mechanic must gather all references listed, review each reference, understand the work to be accomplished, and go to the job site. Work for a shipalt may be on various decks in various locations. The mechanic must check for trade interferences and perform work based on work-site availability.

Outfit planning involves a new method of communicating a work package to the mechanic. The outfit planning group defines all work required within each zone during a specific stage, regardless of the system involved. The required effort is broken down by work type and is addressed in a unit work procedure. A sequence of unit work procedures is known as a work package.

UNIT WORK PROCEDURE

Unit work procedures contain between one and fourteen days worth of work. They include all information necessary for a mechanic to complete a job. This information may include: three dimensional (3-D) graphics extracted from the computer aided design system, material lists, tool requirements, and other instructions. Signature blocks permit the mechanic to certify that work was accomplished per the unit work procedure. A feedback sheet is attached, allowing mechanics to give comments or suggestions to be incorporated into future such unit work procedures.

Because unit work procedures define work by work type, more precise scheduling can be accomplished. Each unit work procedure is given a unique start and completion date. This allows closer control of work and readily identifies delayed unit work procedures.

Each unit work procedure is given a distinct identification number. From examination of the identification number, an understanding of the work to be accomplished can be obtained. Identification numbers indicate the zone, type of work, and sequence. The zone is the physical boundary work is going to be accomplished in. Type of work in this instance refers to fabrication, installation, testing, etc. Sequence refers to the order in which work is to be accomplished within a work package.

COMPUTER AIDED DESIGN

Product orientation involves more intensive planning to allow mechanics to accomplish specific tasks more efficiently. When the computer aided design (CAD) system is used, 3-D graphics can be readily extracted in any form that aids the mechanic to visually conceive goals to be accomplished. CAD, of course, is extremely useful in resolving interferences before work instructions are issued. But, CAD is labor intensive. Real benefit from the CAD system comes from repetitive use of the CAD design model.

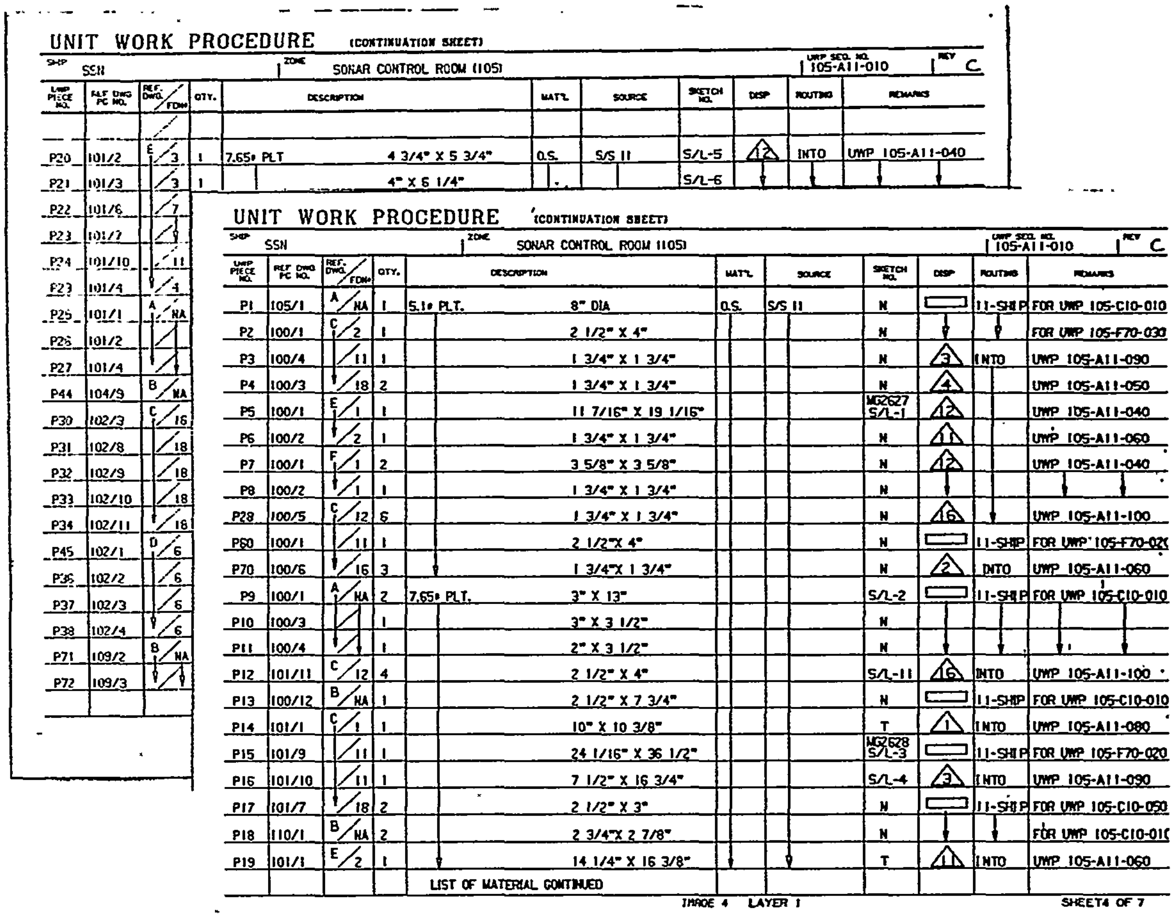
An example of where CAD modeling is not cost effective is for ripout of foundations. Customarily a unique ripout drawing is issued for each ship within a class. This means that the portion of the model for ripout work would only be used once. For this reason, other preplanning efforts were used. Instead of CAD, planning for ripout was based on a shipcheck and manual revisions to lead-yard drawings.

There are several advantages to using the CAD system. During Phase III the model will include all systems and equipment as well as hull structure. In addition to readily detecting interferences, the design model permits "layering-in" by types of work (e.g., organizing the installation of all hangers at once regardless of system).

There are 163 drawings illustrating the existing structures, new deck modifications and new foundations for the submarine class selected. These drawings had to be verified and entered into the CAD system to support Phase I and Phase II planning. While the CAD operators were entering the drawings, forty errors were identified. This is evidence that greater interaction between production and design engineering must be accomplished before design starts. Prior to outfit planning, these discrepancies would not have been identified until mechanics discovered problems during the installation phase aboard ship. When errors were identified by CAD operators, the outfit planning group took immediate action to resolve the problems.

Estimates of the savings were made by Planning and Estimating and Design Divisions. A scenario of what would have happened in each of the cases was created. The Planning and Estimating Division estimated the time mechanics would have spent resolving problems and the time involved for rework. The Planning and Estimating Division also estimated the dollar amount of material that would have been wasted due to rework. Design estimated the time which they would have spent trying to resolve drawing problems. A savings of 2,714 man-hours and 4,173 dollars in material cost was attributed to correcting drawing errors prior to starting work. These estimates do not include certain overhead costs, such as for: the mechanic's supervisor, plannermen, expanded planning yard representatives, and waterfront coordinators. It is difficult to estimate the extent of their involvement.

Emphatically, Puget Sound Naval Shipyard's experience with product orientation is disclosing an important benefit of CAD. Second to no other is planning applications, e.g., the ability to layer-in the shipalts and view all the tasks in an area regardless of the system involved, the ability to group like processes, and the ability to give the mechanic a complete and clear view of the work. Examples of the manner in which work is packaged using the outfit planning concepts can be seen in Figures 2 through 6.



UNIT WORK PROCEDURE (CONTINUATION SHEET)

SHIP SSN | ZONE SONAR CONTROL ROOM (105) | UWP SEQ. NO. 105-A11-010 | REV C

UWP PIECE NO.	REF DWG PC NO.	REF. DWG. / FDN#	QTY.	DESCRIPTION		MAT'L	SOURCE	SKETCH NO.	DISP	ROUTING	REMARKS
		/									
P20	101/2	E / 3	1	7.65# PLT	4 3/4" X 5 3/4"	O.S.	S/S II	S/L-5	△12	INTO	UWP 105-A11-040
P21	101/3	/ 3	1	↓	4" X 6 1/4"	↓	↓	S/L-6	↓	↓	↓
P22	101/6	/ 7									
P23	101/7	/ 9									
P24	101/10	/ 11									
P23	101/4	↓ / 4									
P25	101/1	A / NA									
P26	101/2	/									
P27	101/4	↓ / ↓									
P44	104/9	B / NA									
P30	102/3	C / 16									
P31	102/8	/ 18									
P32	102/9	/ 18									
P33	102/10	/ 18									
P34	102/11	↓ / 18									
P45	102/1	D / 6									
P36	102/2	/ 6									
P37	102/3	/ 6									
P38	102/4	↓ / 6									
P71	109/2	B / NA									
P72	109/3	↓ / ↓									

UNIT WORK PROCEDURE (CONTINUATION SHEET)

SHIP SSN | ZONE SONAR CONTROL ROOM (105) | UWP SEQ. NO. 105-A11-010 | REV C

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P1	105/1	A / NA	1	5.1# PLT.	8" DIA	O.S.	S/S II	N	▭	11-SHIP	FOR UWP 105-C10-010
P2	100/1	C / 2	1		2 1/2" X 4"			N	↓	↓	FOR UWP 105-F70-030
P3	100/4	/ 11	1		1 3/4" X 1 3/4"			N	△3	INTO	UWP 105-A11-090
P4	100/3	↓ / 18	2		1 3/4" X 1 3/4"			N	△4		UWP 105-A11-050
P5	100/1	E / 1	1		11 7/16" X 19 1/16"			MG2627 S/L-1	△12		UWP 105-A11-040
P6	100/2	↓ / 2	1		1 3/4" X 1 3/4"			N	△11		UWP 105-A11-060
P7	100/1	F / 1	2		3 5/8" X 3 5/8"			N	△12		UWP 105-A11-040
P8	100/2	↓ / 1	1		1 3/4" X 1 3/4"			N	↓		↓
P28	100/5	C / 12	6		1 3/4" X 1 3/4"			N	△16	↓	UWP 105-A11-100
P80	100/1	/ 11	1		2 1/2" X 4"			N	▭	11-SHIP	FOR UWP 105-F70-02(
P70	100/6	↓ / 16	3	↓	1 3/4" X 1 3/4"			N	△2	INTO	UWP 105-A11-060
P9	100/1	A / NA	2	7.65# PLT.	3" X 13"			S/L-2	▭	11-SHIP	FOR UWP 105-C10-010
P10	100/3	/	1		3" X 3 1/2"			N			
P11	100/4	↓ / ↓	1		2" X 3 1/2"			N	↓	↓	↓
P12	101/11	C / 12	4		2 1/2" X 4"			S/L-11	△16	INTO	UWP 105-A11-100
P13	100/12	B / NA	1		2 1/2" X 7 3/4"			N	▭	11-SHIP	FOR UWP 105-C10-010
P14	101/1	C / 1	1		10" X 10 3/8"			T	△1	INTO	UWP 105-A11-080
P15	101/9	/ 11	1		24 1/16" X 36 1/2"			MG2628 S/L-3	▭	11-SHIP	FOR UWP 105-F70-020
P16	101/10	/ 11	1		7 1/2" X 16 3/4"			S/L-4	△3	INTO	UWP 105-A11-090
P17	101/7	↓ / 18	2		2 1/2" X 3"			N	▭	11-SHIP	FOR UWP 105-C10-050
P18	110/1	B / NA	2		2 3/4" X 2 7/8"			N	↓	↓	FOR UWP 105-C10-01(
P19	101/1	E / 2	1	↓	14 1/4" X 16 3/8"	↓	↓	T	△11	INTO	UWP 105-A11-060
				LIST OF MATERIAL CONTINUED							

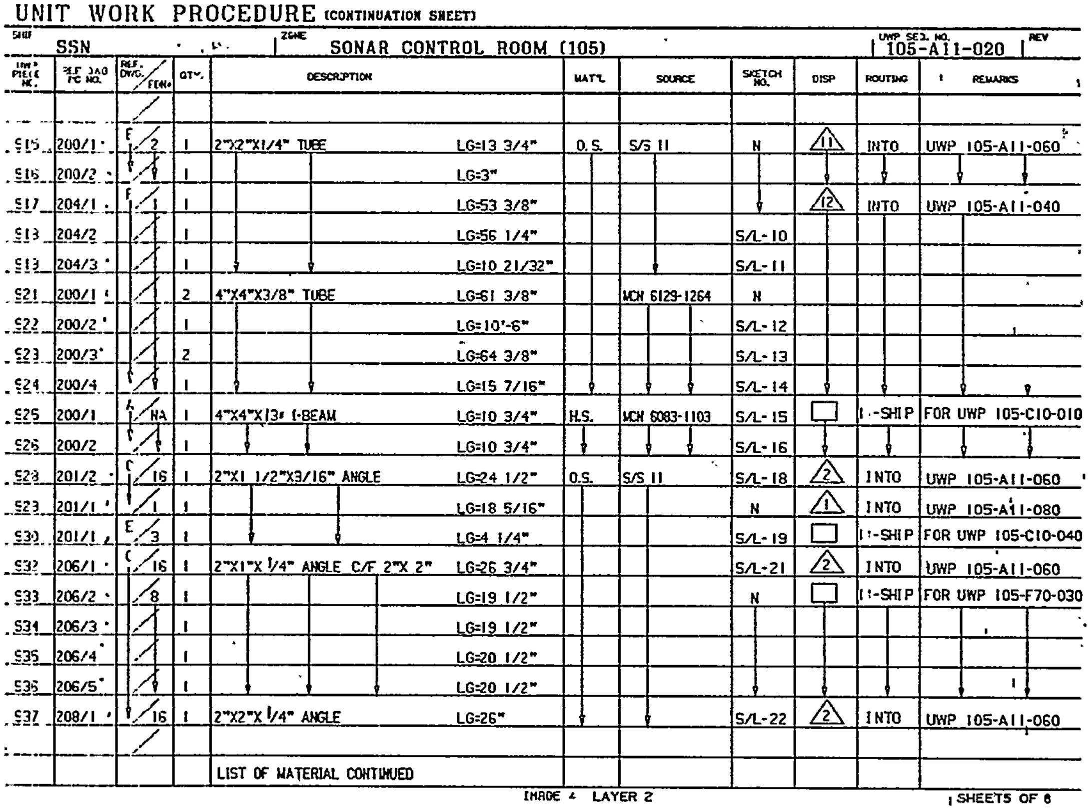
IMAGE 4 LAYER 1

SHEET4 OF 7

Figure 2. Pages from a Unit Work Procedure Issued for the Fabrication of Plate Material.

Figure 2 is an example of two pages which were extracted from a unit work procedure issued for the layout and fabrication of all plate material required for work in the sonar control room.

Once each plate is cut it is directed to an assembly, or directly to the ship. Previously, this work would have been issued under three separate job orders, referencing seven drawings.



UNIT WORK PROCEDURE (CONTINUATION SHEET)

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		/								
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S16	200/2	↓ / ↓	1	↓ LG=3"	↓	↓	↓	↓	↓	↓
S17	204/1	F / 1	1	↓ LG=53 3/8"	↓	↓	↓	△12	INTO	UWP 105-A11-040
S18	204/2	↓	1	↓ LG=56 1/4"	↓	↓	S/L-10	↓	↓	↓
S19	204/3	↓	1	↓ LG=10 21/32"	↓	↓	S/L-11	↓	↓	↓
S21	200/1	↓	2	4"X4"X3/8" TUBE LG=61 3/8"	↓	WCN 6129-1264	N	↓	↓	↓
S22	200/2	↓	1	↓ LG=10'-6"	↓	↓	S/L-12	↓	↓	↓
S23	200/3	↓	2	↓ LG=64 3/8"	↓	↓	S/L-13	↓	↓	↓
S24	200/4	↓	1	↓ LG=15 7/16"	↓	↓	S/L-14	↓	↓	↓
S25	200/1	A / NA	1	4"X4"X13# I-BEAM LG=10 3/4"	H.S.	WCN 6083-1103	S/L-15	☐	I-SHIP	FOR UWP 105-C10-010
S26	200/2	↓	1	↓ LG=10 3/4"	↓	↓	S/L-16	↓	↓	↓
S28	201/2	C / 16	1	2"X1 1/2"X3/16" ANGLE LG=24 1/2"	O.S.	S/S 11	S/L-18	△2	INTO	UWP 105-A11-060
S29	201/1	↓ / 1	1	↓ LG=18 5/16"	↓	↓	N	△1	INTO	UWP 105-A11-080
S30	201/1	E / 3	1	↓ LG=4 1/4"	↓	↓	S/L-19	☐	I-SHIP	FOR UWP 105-C10-040
S32	206/1	C / 16	1	2"X1"X 1/4" ANGLE C/F 2"X 2" LG=26 3/4"	↓	↓	S/L-21	△2	INTO	UWP 105-A11-060
S33	206/2	↓ / 8	1	↓ LG=19 1/2"	↓	↓	N	☐	I-SHIP	FOR UWP 105-F70-030
S34	206/3	↓	1	↓ LG=19 1/2"	↓	↓	↓	↓	↓	↓
S35	206/4	↓	1	↓ LG=20 1/2"	↓	↓	↓	↓	↓	↓
S36	206/5	↓	1	↓ LG=20 1/2"	↓	↓	↓	↓	↓	↓
S37	208/1	↓ / 16	1	2"X2"X 1/4" ANGLE LG=26"	↓	↓	S/L-22	△2	INTO	UWP 105-A11-060
		/								
				LIST OF MATERIAL CONTINUED						

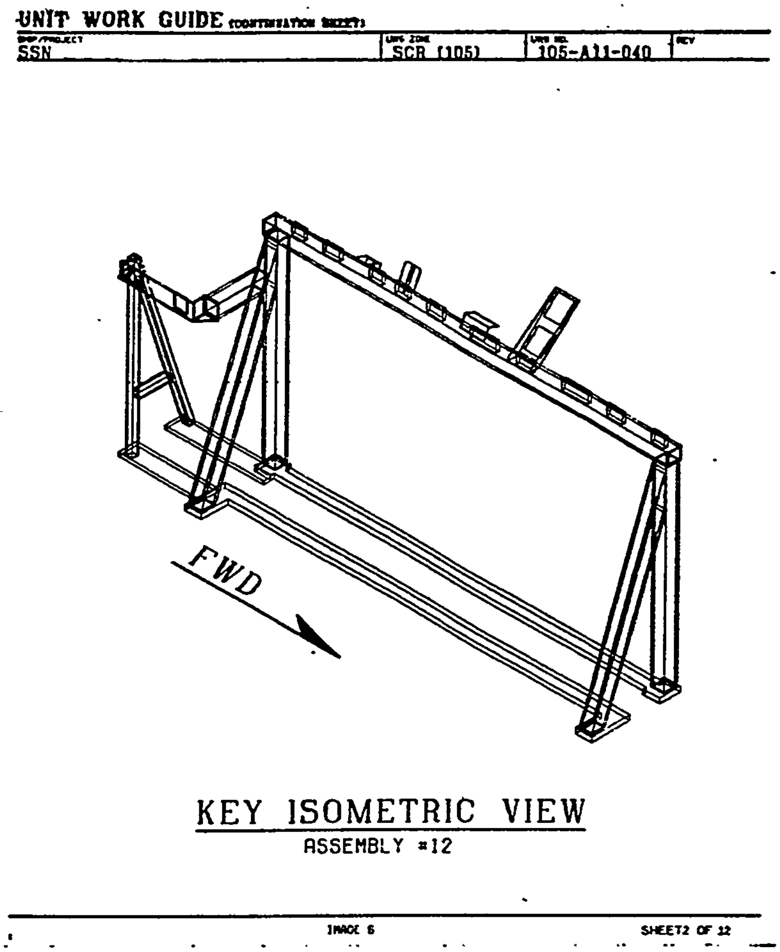
IMAGE 4 LAYER 2

SHEETS OF 6

Figure 3. Page from a Unit Work Procedure Issued for the Fabrication of Shapes.

Figure 3 is an example of a page extracted from a unit work procedure that was issued for the layout and fabrication for all shapes required for the sonar control room.

As with plate, once shapes cut they are directed to an assembly or to the ship. Prior to outfit planning, this work would have been issued under three separate job orders.



UNIT WORK GUIDE (CONTINUATION SHEET)

SHIP/PROJECT	UWG ZONE	UWG NO.	REV
SSN	SCR (105)	105-A11-040	

KEY ISOMETRIC VIEW

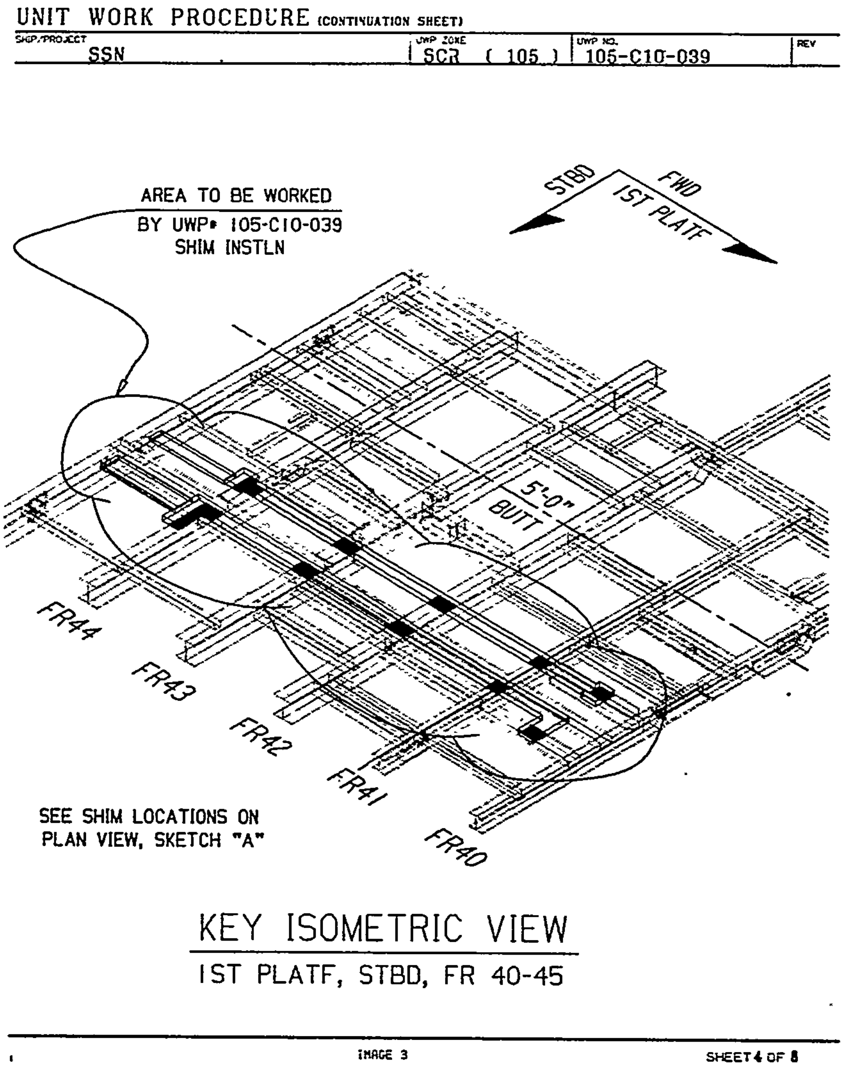
ASSEMBLY #12

IMAGE 6 SHEET 2 OF 12

Figure 4. Page from a Unit Work Procedure Issued for the Manufacture of a Foundation.

Figure 4 is a page extracted from a unit work procedure issued to manufacture a foundation for the sonar control room. The plate and shapes required to accomplish the work were provided for on the unit work procedures displayed in Figures 2 and 3.

Prior to outfit planning, this foundation would not have been manufactured as one piece as indicated. This foundation would have been manufactured in seven separate sections, under two job orders. On-board work was reduced from seven weeks to three work days i.e., product orientation permitted shifting work on-board into shops where opportunities for improving quality and productivity were enhanced.



UNIT WORK PROCEDURE (CONTINUATION SHEET)

SHIP/PROJECT	UWP ZONE	UWP NO.	REV
SSN	SCR (105)	105-C10-039	

KEY ISOMETRIC VIEW

1ST PLATF, STBD, FR 40-45

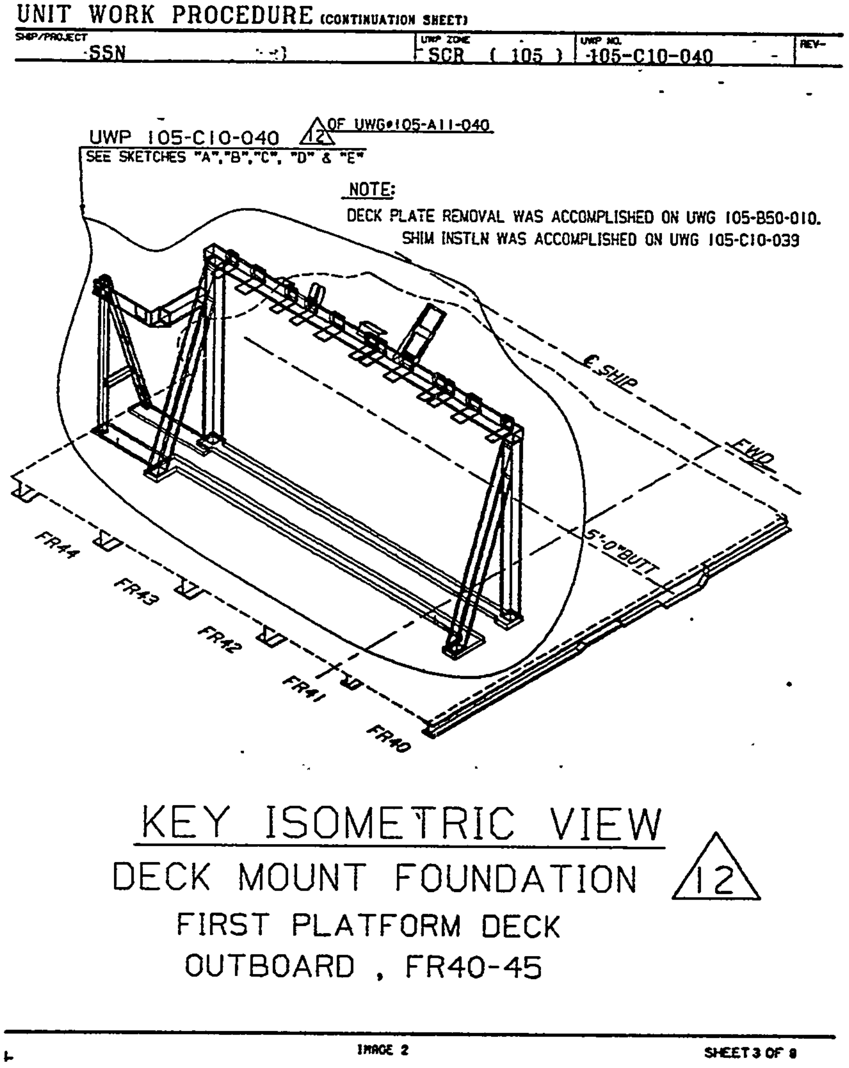
IMAGE 3

SHEET 4 OF 8

Figure 5. Page from a Unit Work Procedure Issued for the Installation of Deck Shims to Support a Foundation.

Figure 5 is an example of a page extracted from a unit work procedure that was issued for the preparation, determination, and installation of deck shims to support the foundation manufactured in Figure 4.

Prior to outfit planning, this work was covered under the same job order as the installation of the foundation.



UNIT WORK PROCEDURE (CONTINUATION SHEET)

SHIP/PROJECT SSN	UWP ZONE SCR (105)	UWP NO. 105-C10-040	REV-

UWP 105-C10-040 12 OF UWG#105-A11-040

SEE SKETCHES "A","B","C", "D" & "E"

NOTE:

DECK PLATE REMOVAL WAS ACCOMPLISHED ON UWG 105-B50-010.
SHIM INSTLN WAS ACCOMPLISHED ON UWG 105-C10-039

KEY ISOMETRIC VIEW
DECK MOUNT FOUNDATION 12
FIRST PLATFORM DECK
OUTBOARD , FR40-45

IMAGE 2

SHEET 3 OF 8

Figure 6. Page from a Unit Work Procedure Issued for the Installation of a Foundation.

Figure 6 is an example of a page extracted from a unit work procedure issued for the installation of the foundation manufactured in Figure 4. Prior to outfit planning this foundation would have been installed under two separate job orders, because it involves two shipalts. The parts to the foundation would have been shipped in seven separate sections and the mechanic would have had to install each of the sections individually onboard.

The examples shown on the previous pages point out several benefits of the outfit planning efforts currently being made. Included in the list are: 1) unprecedented coordination between design and production, 2) work is performed based on commonality, 3) work within a space is sequenced, 4) work can be readily tracked.

THE COST OF OUTFIT PLANNING

While there are many benefits to outfit planning, there is also an associated cost. Presently, a total of 18,589 man-hours has been allocated to the forward end project. The Outfit Planning Group estimates that an additional 7,500 man-hours will be needed to complete the project through Phase II. An investigation into the cost of building the CAD model and the costs of producing each unit work procedure was made. The model has been used to produce 322 original unit work procedures for four submarines undergoing modernization concurrently. The original unit work procedures were modified as necessary and applied in successive hulls so at this time there are 1,100 applications.

Based on the time duration between the start date and completion date, an estimated 6,144 man-hours were spent to construct and update the model for use on the second submarine. A total of 230 man-hours were used to update the model for use on the third submarine, and 178 man-hours were used to update the model for the fourth submarine. A six month study was conducted to determine the costs involved in the development of the unit work procedures. During the six month period, all the costs incurred in the development of unit work procedures were documented. An average of 23 man-hours was required to develop each new unit work procedure. The average time spent on the rollover of an existing unit work procedure for use on a subsequent submarine totaled 8 man-hours.

THE SUCCESS OF OUTFIT PLANNING

In order to conduct a cost-benefit analysis of this project it is necessary to compare cost incurred on equivalent magnitudes of work. This type of comparison is difficult because the work on a shipalt may vary from submarine to submarine.

When a submarine requires an upgrade of an existing system, the amount of work depends on the system currently installed and the extent of the upgrade. A comparison of the charges for shipalts which have been outfit planned to similiar shipalts without outfit planning will give an indication of the potential savings. A comparison was made of the charges incurred for major structural work on the first submarine being outfit planned, to charges incurred on previous submarines without outfit planning. This comparison indicates a 3,900 man-hour reduction over the average man-hour charges on the three previous submarines.

In addition to the installation work that was done on the first submarine, other outfit planning goals were included in the planning phase for the second submarine. There was a considerable amount of prefabrication work that was outfit planned that was not done on the first submarine. Additionally, the outfit planning group has tried to eliminate all machining aboard ship. Only the prefabrication portion of this work has been completed on the second submarine, so total cost returns are not available. Comparisons of the prefabrication work to previous submarines, indicates a savings of an additional 390 man-hours.

CONCLUSION

The outfit planning efforts currently underway at Puget Sound Naval Shipyard involve a significant change in the way work is packaged. The work so organized is in accordance with modern management techniques. Savings thus far are modest because work volumes associated with the new methods were relatively small. Learning costs and start up costs are not apt to be repeated. Outfit planning is an evolutionary step in the attempt to increase the efficiency of the Shipyard.

ACKNOWLEDGEMENTS

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The Application of Intelligent Robotic Systems and Lasers for Manufacturing

No. 7

Henry E. Watson, Visitor, Pennsylvania State University, State College, PA

ABSTRACT

The R&D programs in Manufacturing Technology at The Pennsylvania State University have a major emphasis on automation of materials processing and inspection. Two on-going research projects in these areas, that are based on the application of laser technology are (1) the Laser Articulated Robotic System (LARS), and (2) the Intelligent Robot Inspection System (IRIS). Both of these projects are supported by the U.S. Navy Manufacturing Technology Program.

The paper presents the background, current status, research results, and future plans for the LARS and IRIS.

INTRODUCTION

The application of lasers in manufacturing have been limited due to the requirements that the workpiece must be moved under a fixed beam. This process is time consuming because extensive fixturing and alignment are required to assure that the laser beam contacts the part at the proper position and orientation for the process involved.

Advances in sensor and control technology have made it possible to manipulate laser beams in space along a precise path using robots. This development has created a surge of interest in the application of lasers for materials processing and inspection, Reference 1. Accordingly, the Manufacturing Science Program has been established by the Applied Research Laboratory at The Pennsylvania State University to develop solutions to the unique problems associated with precision fabrication and inspection of components for surface and underwater vehicles.

The development of advanced welding technology for manufacturing and repair was planned to initially demonstrate the applicability of laser technology for materials processing, welding and cutting of thick sections, and then to develop articulating robotics and associated technology for controlled high speed manipulation of a laser beam throughout a large manufacturing cell.

The major thrusts of the Manufacturing Science Program is the development of equipment for automated materials processing and inspection. This requires the use of robots coupled with high powered (up to 25 kw) continuous wave CO_2 lasers for welding, cutting, heat treating, cladding, transformation hardening and glazing, and solid state lasers for measurement, References 1-7. For laser materials processing, the Laser Articulated Robotic System (LARS) is being developed. This is a large robot which, when interfaced with a high power laser, provides the capability for manipulating a beam over large distances, focusing the beam to a small spot to concentrate the energy for welding, cutting, or a larger configuration for other processes. For precision measurement, the Intelligent Robotic Inspection System (IRIS), is being developed. This is a large gantry robot equipped with laser based vision systems for precision space location and part profiling. Both these projects are funded by the U.S. Navy Manufacturing Technology Program.

In order to expand the application and acceptance of laser technology for materials processing, a survey was conducted to assess the applicability of high power lasers in manufacturing for the Navy and Army as well as for the aerospace, electric utility, automotive, and pipeline industries, Reference 8. Copies of this survey report are available upon request.

The paper presents the background, current status, research results, and future plans for the LARS and IRIS, and is organized in five main sections. Descriptions of the LARS and

IRIS projects are provided in Sections 2 and 3, respectively. Each of these two sections are, in turn, divided into several subsections. Future plans for both LARS and IRIS projects are discussed in Section 4. Summary and conclusions are presented in Section 5.

LASER ARTICULATED ROBOTIC SYSTEM (LARS)

The LARS program had its beginning in 1982 by identifying the requirements for a laser beam delivery system which later evolved into specifications for a subsequent request for proposal. The requirements are summarized in Figure 1. A contract was awarded for the development of the LARS in August 1983. The contract is divided into five phases: conceptual design, final design, system fabrication, installation and operator training, and acceptance testing. The program is currently in the fabrication phase with completion scheduled for March 1987. Upon completion the LARS will be delivered to the Westinghouse Research and Development Center in Pittsburgh and interfaced with a 15 kw CO_2 continuous wave laser for technology demonstration and transfer.

IMPORTANT PARAMETERS FOR LARS/LARS SR.

RANGE OF OPERATION:	11 FT x 11 FT x 3 FT 20 FT x 20 FT x 10 FT
MODES OF OPERATION:	MANUAL TEACH OFFLINE PROGRAM AUTOMATIC
TRACKING PRECISION:	ALONG SEAM ± 0.005 IN VERTICAL ± 0.015 IN ANGULAR CONTROL $\pm 1^{0}$
WELDING/CUTTING SPEEDS:	0-200 IN/MIN
TRACKING DEVICE:	NON-CONTACTING 200 Hz SAMPLING SPEED CLOSED LOOP REAL TIME
CAPABILITIES:	WELDING, CUTTING, HEAT TREATING, CLADDING, SURFACE TRANSFORMATION HARDENING

Figure 1

The LARS is shown in Figure 2 in its current state of development. When completed it will consist of six major subsystems including the robot, beam transport, workhead, vision, electronic control, and software. These subsystems and their components are shown in Figure 3. The principal components are described below.

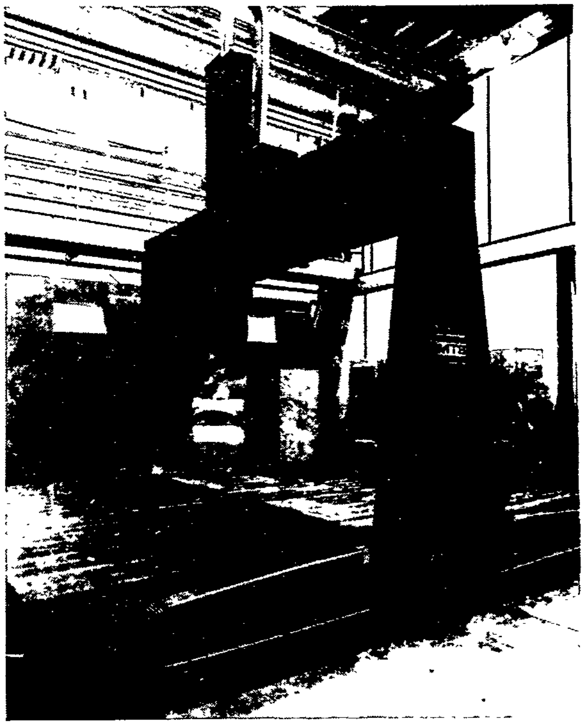
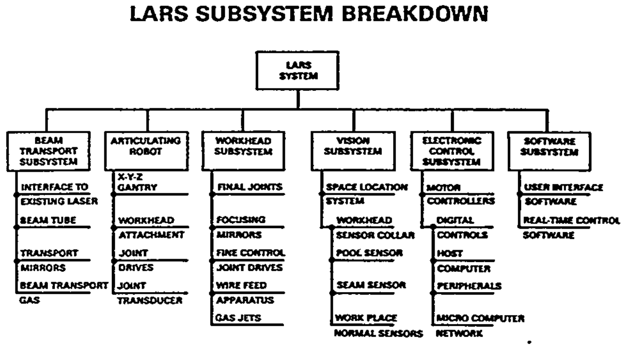


Figure 2



LARS SUBSYSTEM BREAKDOWN

Figure 3

Robot Subsystem

After considering all robot configurations, it was determined that a gantry based system was the only practical structure for this application. The initial requirement was for a system having a reach of 20 feet x 20 feet x 10 feet. To reduce the costs a prototype system will be developed first. This system will have a working volume for welding in the down-hand position of 14 feet x 14 feet x 3 feet. The gantry provides x, y, and z translation of the beam, and an articulated arm located at the lower end of the Z-axis provides the remaining degrees of freedom required to meet the requirements for random path welding and cutting. The gantry system was designed specifically for LARS since a commercially available robot meeting the requirements established for this system could not be found. The robot is designed to be as accurate as current technology permits, however, the accuracy requirements shown in Figure 1 are dynamic rather than point-to-point and relate to the position of the focused beam instead of the robot position. As a result, the beam positioning accuracy is obtained by a carefully controlled positioning mirror coordinated with a high speed vision system located in the workhead.

Workhead Subsystem

The workhead is attached to the lower end of the Z-axis of the gantry. The workhead shown in Figure 4 is an integrated system of mechanical and electromechanical components which focuses the laser beam and provides final positioning of the laser beam and process hardware at the workpiece. The workhead focuses the laser beam to a 0.040-inch diameter spot for welding and cutting using f/7 optics. In addition to focusing and beam positioning optics, the workhead contains a gas shield for plasma suppression, wire feeder and positioner, seam tracking vision components, and a gas cutting jet. While the vision system is integrated with the workhead, it is so important to the success of LARS, it will be discussed in the next section.

Vision System

The positioning requirements for the LARS include, tracking the center of a butt joint to an accuracy of ±0.005 inches, maintaining the desired standoff distance to within 0.015 inches, and controlling the angle of the incident beam with respect to the workpiece to 90° ±1°. Further, this tracking requirement must be met for random path welds throughout the working envelope without preprogramming, while operating at speeds of 200 inches per minute. For metalworking processes other than welding where there is no seam to follow, the specification requires that LARS follow a preprogrammed path to the same accuracies as that stated for welding.

The LARS vision system incorporates four vision subsystems to meet the requirements for seam following and space location. For seam following the two independent closed loop systems, fine loop and coarse loop, are utilized. The sensors and their function are shown schematically in Figure 5. The A sensor uses three linear CCD's to monitor the x, y, and z coordinates of the laser spot at the surface of the workpiece and measures the workpiece surface angle. The output of Sensor A, combined with the fine control mirror drives, provides the precision positioning of the focused laser beam.

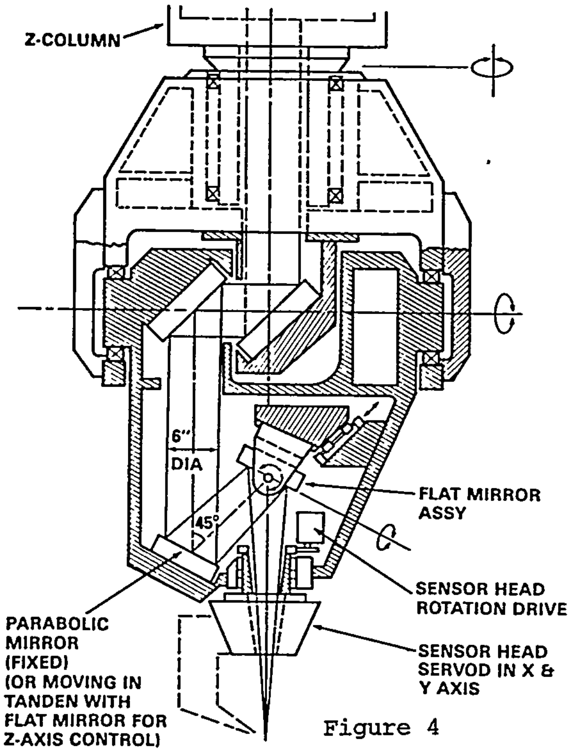
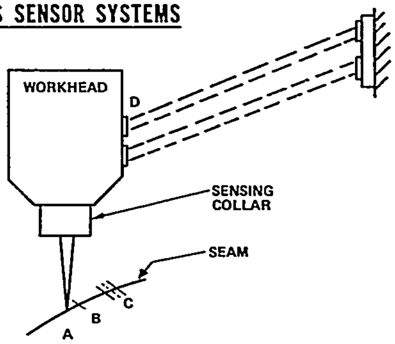


Figure 4

LARS SENSOR SYSTEMS



NAME	FUNCTION
A. BEAM SENSOR	LOCATES PUDDLE CENTER IN X, Y, Z
B. IN-CLOSE SEAM TRACKER	LOCATES SEAM Y POSITION DIRECTLY IN FRONT OF PUDDLE
C. LOOK-AHEAD SEAM TRACKER	LOCATES SEAM COORDINATES AND ANGLES ABOUT 2 INCHES IN FRONT OF PUDDLE
D. SPACE LOCATION SYSTEM	LOCATES POSITION OF WORKHEAD IN WORLD COORDINATE SYSTEM

Figure 5

Sensor B measures the y coordinate of the seam at three locations starting at 0.250 inches from the welding spot and spaced 0.750 inches apart. Sensor B finds the seam position by scanning an intense beam of light across the weld seam and monitoring the reflected light pattern. The beam scanning mechanism is an acousto-optic device which causes diffraction of the scanning laser beam when a RF signal is supplied to an acoustic transducer bonded to a crystal. By controlling the RF drive frequency of the device, the angular position of the scanning laser beam and the beam position on the workpiece can be determined with precision. The solid state light deflector is the only technique which can create a complex pattern of light in the time available. An additional benefit of this approach is its flexibility. An acousto-optic deflector is completely programmable and can be programmed to generate any sequence of light patterns within the range of operation. Sensors A and B acquire data at a 1 kHz rate and update the fine position mirror controller at 200 Hz for seam tracking. For comparison, current seam tracking systems for arc welding operate at 30 Hz maximum. The information from these two sensor systems is obtained synchronously. The desired weld pool location determined by Sensor B is compared to the actual weld pool location from Sensor A. If these positions differ, an error signal is sent to the fine position mirror controller and a correction is made.

Sensor C is the workpiece profile sensor. It measures the angular orientation of the workpiece surfaces and collects coordinate data used to determine the shape and orientation of the part ahead of the welding area. This information is provided to the robot controller at a 50 Hz rate for course robot position control and to develop data to be used during the fine position control. Sensor C also uses solid state laser beam positioners in conjunction with linear CCD's.

The space location system Sensor D, locates and tracks the position of the workhead in world coordinates for those preprogrammed metalworking operations in which no seam is available for guidance. This system is required to maintain a knowledge of the position of the robot workhead to within 0.005 inches over the working volume. Since it is not possible to obtain such accuracy using robot joint encoders, a tracking interferometric system utilizing fixed interferometers in combination with retroreflectors mounted on the workhead was selected. This sensor system will be described in detail in the IRIS description.

Control System

The control system is comprised of the computer system and precision digital interface hardware and must be capable of:

- providing very effective control accuracy over extreme control ranges by processing fine seam tracker data and using it to coordinate the position of the focused laser spot with the movement of the gantry based robot.
- coordinating the motion of a complex, multi-degree of freedom, robot with trajectories programmed from a data base, or computed on-line.
- providing on-line compensation for variations in control characteristics resulting from a wide range of workhead motions and orientations which occur during operation.

To accomplish these tasks, a hierarchical multi-processor control system will be used. A VAX 11/750 will serve as the supervisory computer to manage task planning and machine coordination. Clusters of Motorola 68000 microprocessors will serve as intelligent subsystems. Loose coupling via communication links allows the supervisory computer to control, monitor, or coordinate the operation of each multi-processor cluster.

Using this concept, the LARS control system tasks are partitioned into six subsections.:

- operator interface and system management
- coarse loop control
- coordinate conversion and servo control
- fine loop control
- safety
- task support

The tasks in each subsection will be accomplished by either one computer system or a cluster of microcomputers. Selection of a particular computer or use of special purpose hardware and software modules can be specified to suit critical or unique tasks to be performed by a particular subsection.

INTELLIGENT ROBOTIC INSPECTION SYSTEM (IRIS)

The Applied Research Laboratory has been actively involved in the design and inspection of multi-blade propulsors for underwater vehicles for many years. Unfortunately, due to the complex shape and limited space between blades, the inspection equipment can only measure to an accuracy of ±0.003 inches. As a result, it has not been possible to establish a relationship between manufacturing accuracy and performance. Recognizing this need, the Navy has decided to develop the Intelligent Robotic Inspection System (IRIS), which will utilize the enhanced vision and control technology that has already been developed for the LARS project. The contract was awarded for IRIS in January 1985 and is scheduled for delivery in December 1986.

The IRIS is essentially a robotic, laser based measuring system which will be capable of comparing actual part dimensions with design requirements to an accuracy of ±0.0005 inches. The system will be interfaced with a Computer Aided Design (CAD) system for state-of-the-art data retrieval and programming. The major technology issues which must be addressed include world coordinate and orientation measurement, non-contact part sensing, advanced robot control development, advanced user interface capabilities, and dynamic accuracy.

The IRIS is shown schematically in Figure 6. The system will consist of three major components including the mechanical, sensor, and control subsystems. These principal components will be described in the following sections.

Mechanical Subsystem

The primary mechanical components of the IRIS include the robot, a two-degree of freedom wrist assembly, the retroreflector, a granite base, a rotary table, and the robot end effector.

In contrast to the LARS, the IRIS robot will be a commercially available gantry system which provides x, y, and z translation. A highly repeatable, two-degree of freedom wrist assembly is located at the end of the Z-axis column of the robot. This wrist assembly is identical to the ones found on the more accurate coordinate measuring machines except the measuring component has been replaced with a specially designed end effector for part profiling. The retroreflector is also located on the Z-axis column. It is part of the space location system and consists of three mirror assemblies which serve to return the beam back to its source along a parallel path. The base of the IRIS will be constructed of granite to insure dimensional stability during the inspection process. Finally, a precision rotary table will be mounted on the granite base extending the effective measurement range from the original 3 foot x 3 foot x 3 foot measurement volume permitting the inspection of objects as large as 5 feet in diameter and 3 feet high.

Sensor Subsystem

In conventional measuring systems the measurement accuracy is functionally connected to the control accuracy. Since the control accuracy, which determines the accuracy of the robot or manipulation device is less than the measurement accuracy, the equipment can only be as accurate as the manipulation device for dynamic measurements. In the design of the IRIS, the measurement and control accuracy are functionally separated, therefore, the system accuracy can be as accurate as the measurement or

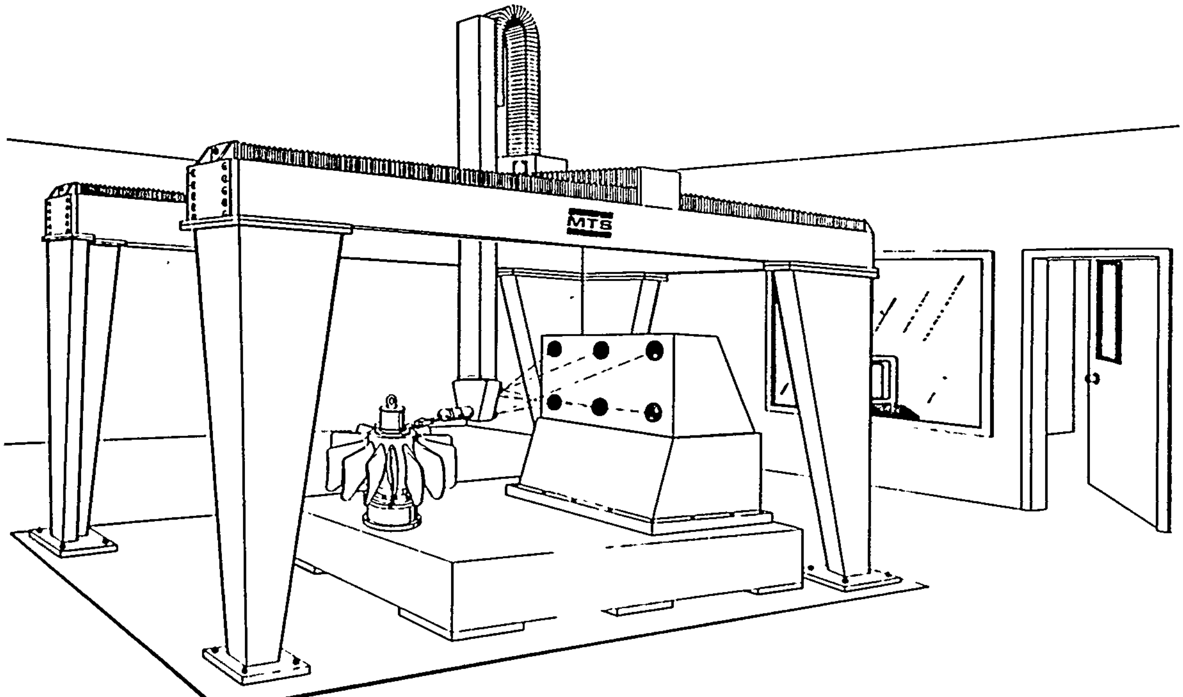


Figure 6

sensor accuracy and the accuracy can be obtained in the dynamic mode.

In order to meet the requirements for accuracy, two sensor subsystems, Figure 7, had to be developed for IRIS; the space location system (SLS), and the part sensor. The SLS consists of six laser interferometers located at one end of the granite table and three retroreflectors located on the Z-axis column. The SLS functions by measuring six distances to three points and then using this information, calculates the end effector position and orientation with respect to any predetermined coordinate system to an accuracy of 0.00025 inches.

The part sensor determines the position of the surface of the part with respect to the retroreflectors using the principle of laser triangulation for distance measurement. The part sensor shown schematically in Figure 8 consists of a solid state laser, optics, mirror, and a 3000 element linear array. The laser beam is focused by the optics, reflected to and from the part surface by the mirror, and distance measurements are determined by the position that the reflected laser beam strikes the linear array. Data is collected at a speed of 1000 Hz and the part sensor accuracy is projected to be 0.00025 inches. The part sensor is designed to pass between two propulsor blades and measure the distance normal to the part surface.

Control Subsystem

The IRIS control system has two major requirements. The system must be able to position the end effector within the work envelope with precision and the part sensor feedback must be used to monitor the location of the part being measured. In order to meet these requirements, the control system uses two position locating devices; the SLS, and the motor resolvers. These signals are summed in order to form a composite feedback signal; one from the SLS at low frequencies, and one from the motor resolver at higher frequencies. This provides the control system with a broad range of frequency response, thereby extending the usable band width of the position control loop and improving the measurement speed and accuracy of dynamic response.

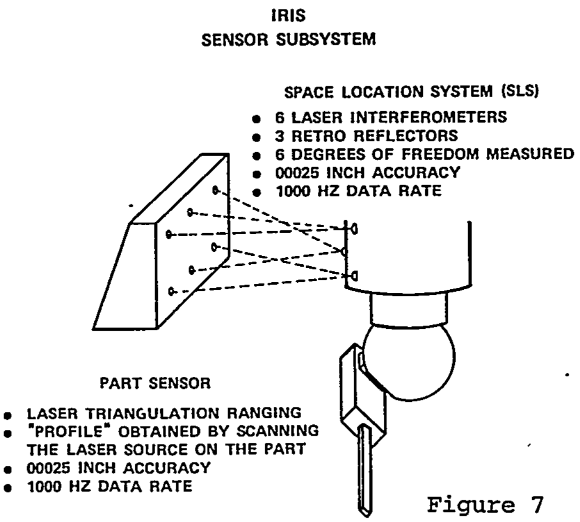
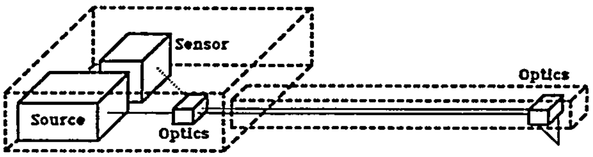
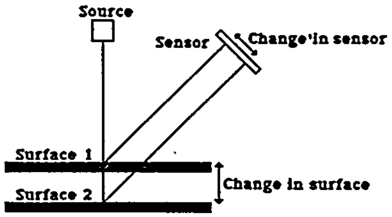


Figure 7



"Look-To-The-Side" Triangulation Part Sensor



Triangulation Figure 8

FUTURE DIRECTIONS

LARS related activities will continue in two directions; system refinement, and process development. After installation, the plan is to continue refining the system software and hardware. Equipment must be developed and integrated with the LARS which will permit coordinated control of the process parameters as well as the real time determination of weld quality. To improve autonomous functionalities of the LARS, its control system should be integrated with a knowledge-based system which is capable of making decisions in real time for high-speed laser welding, Reference 9. Additionally, new applications of laser technology must be developed for both the military and the private sector.

After installation and acceptance of the LARS at the Westinghouse Research and Development Center, the first application of this technology will be the welding of aircraft carrier launch rails to trough covers producing one-piece assemblies. This will require one and one-half inch deep welds in dissimilar materials. To assure that the work can proceed in a timely manner, Westinghouse is under contract to The Pennsylvania State University to develop and demonstrate the process for welds which will meet Navy requirements for strength and straightness. Additionally, Westinghouse and The Pennsylvania State University have been developing the process requirements for other materials which are difficult to weld, such as, high strength steels, copper, and aluminum.

Future plans for the IRIS include hardware enhancement and applications of advanced inspection technology. It is desirable to increase the accuracy and work envelope of IRIS. Higher accuracy will permit the initiation of an applications oriented precision engineering program aimed at developing a direct relationship between precision, efficiency, and manufacturing cost. This program will also require the coupling with a knowledge-based system which could autonomously determine the location of the inspection points and the amount of data required for the inspection accuracy desired.

While the IRIS is addressing a specific Navy problem, advanced multi-blade propulsor design and inspection, it is considered to be a generic inspection system capable of inspecting any part that fits within the work envelope and has a measurement data base. The IRIS will be installed in the Applied Research Laboratory, Garfield Thomas Water Tunnel facility in a "clean room" environment with precise temperature and humidity control. After installation and initial operation, an extensive program of technology transfer will be implemented.

SUMMARY AND CONCLUSION

The paper summarized the background, current status, results, and future plans for two laser technology-based research projects at the Applied Research Laboratory of The Pennsylvania State University. Both these projects, namely, the Laser Articulated Robotic System (LARS) and the Intelligent Robotic Inspection System (IRIS), are supported by the U.S. Navy Manufacturing Technology Program.

The LARS is designed for precise manipulation of high power (up to 25 kw) laser beams for welding, cutting, heat treating, cladding, surface transformation for a variety of materials including aluminum, high strength alloy steels, ceramics, and composites. Supporting research efforts include development of hardware and software for real time seam tracking, and knowledge-based systems for process planning and robot control. While the initial thrust of the LARS project was on the application of laser technology to materials processing, related technologies such as seam tracking, real time control of welding parameters, CAD/CAM interface development, and human factors will be applied to arc welding in the future.

The first application of the LARS is scheduled to be the welding of catapult launch rail trough covers and rails to produce one-piece assemblies for aircraft carriers. Other applications include component welding for ship fabrication, missile launching systems, cutting and welding of tank armor plate, and aircraft engine manufacturing.

The IRIS is a robotic, laser based measuring system which will have the capability for comparing actual component or assembly dimensions with design requirements to an accuracy of ±0.0005 inch. The inspection system is designed to have a generic measuring capability, and can be operated either by direct digital data input or from a CAD data base which precisely defines the part. During operation, a space location system consisting of laser interferometers and retroreflectors will guide the robot end effector in a prescribed path around a stationary part. A series of end effectors that will utilize laser triangulation and touch probes are planned. The laser triangulation devices are needed where high speed and/or small clearance is a consideration.

The first application of the IRIS is scheduled to be the design and certification of components for underwater vehicles.

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Submarine Tank Repair Using Outfit Planning

No. 8

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ABSTRACT

Outfit Planning and Zone Logic methods have been implemented in the Shipbuilding Industry in response to the need for increased efficiency in the construction of new ships. Efforts have been under way at Puget Sound Naval Shipyard to use Outfit Planning principles to plan and execute ship alterations on operational ships. The next logical step is to use these same principles to plan and execute overhaul and refurbishment work. This paper addresses efforts at Puget Sound Naval Shipyard to apply Outfit Planning principles to the repair of submarine tanks.

A typical submarine has approximately 60 tanks on board that perform a variety of functions such as liquid storage and control of the ship. During the overhaul period most tanks are opened, inspected, and repaired. Traditional methods of sequencing and controlling the repair functions in the tanks have not always been totally effective. Outfit Planning methods offer an alternative approach.

Outfit Planning in submarine tank repairs makes little use of prefabrication and pre-outfitting. A group-oriented approach to planning and executing work is used to bring together the right people to focus on specific phases of the work. Planning and Production personnel work together to implement usually obvious changes to streamline the work. Acting as a unit, the Group has considerable leverage to influence productivity.

The availability of computer data base management and project management software offers the possibility of developing better tools to track work status, predict work sequences, and predict work loads.

Computer Aided Design (CAD) systems are being used to model tank structure and systems to assist in the preparation of Unit Work Procedures that specify how tank work is to be accomplished. The result is task level work planning in the form of work sequences and work procedures with input from appropriate trades.

Tank repair using Outfit Planning concepts involves the use of these tools to manage and execute tank work.

INTRODUCTION

Puget Sound Naval Shipyard has been involved in using Outfit Planning and Zone Logic principles for several years (1). Initially, these efforts were focused on shipalts which involved the installation of new systems or new equipment and offered opportunities for prefabrication and pre-outfitting. Naval Shipyards also do a great deal of repair and refurbishment work on existing components. A typical submarine overhaul requires approximately 160,000 mandays of effort. About one half of that is repair work. Puget Sound Naval Shipyard is pursuing the use of the same techniques to plan and accomplish repair work.

U.S. Naval Shipyards are traditional functional organizations, i.e., people, information, and work are grouped by ships systems (2). This type of organization is best suited to the production of uniform products. A Naval Shipyard's workload, however, is characterized by a variety of products built in variable quantities. This inconsistency between organization and function results in systemic problems that inhibit productivity. Two problems characteristic of function-oriented shipyards are:

1. Poor interdepartmental communication.
2. Work packages that are too large to allow control of material, manhours, and schedule (3).

In the area of shipalt work, Outfit Planning concepts have been effective in increasing productivity through the use of ad hoc committees that focus on products within zones in lieu of systems. Since the Shipyard handles repair work much the same as shipalt work, it follows that there is benefit in applying the same Zone Logic. It is the planning methodology that is important. This is where Puget Sound Naval Shipyard is concentrating its efforts.

Historically, the Shipyard has done a good job of completing submarine tank work to support undocking, but frequently only as a result of some significant eleventh hour heroics on the part of the production workers. A typical submarine undocking is preceded by intense tank work activity to meet schedule. Since the Shipyard's performance is judged by its ability to meet undocking dates, one is left wondering if there isn't a better way to manage tank work that provides more positive assurance of schedule adherence. The recurrence of this feeling at the Shipyard management level has resulted in the formation of an Outfit Planning group to improve the tank repair process.

THE OUTFIT PLANNING GROUP

Initiation of an Outfit Planning group was accomplished by the appointment of a Group Chairman from the Planning Department and a Zone Manager from the Production Department. These two individuals organized a core group of representatives from areas of the Shipyard most involved in the tank repair process. The areas represented were:

1. Design
2. Planning and Estimating
3. Scheduling
4. Test Engineering
5. Combat Systems
6. Pipefitters
7. Shipfitters
8. Machinists
9. Sandblasters and Painters

A period of time was required to orient and educate the group members in the concepts of Zone Logic. At the beginning of the Group's activity, meetings were held twice a week. The Group familiarized itself with Outfit Planning concepts and with the activities of previously established groups while it struggled with the problem of tank repairs. Immediately there were obvious differences between this project and the shipalt projects previously done. Prefabrication and pre-outfitting are basically not involved in tank repairs. Material requirements are centered around fixing what already exists. The ship cannot as easily be broken into large blocks as is done with shipalt work. Tanks naturally define many small zones that can be treated separately or as groups. Zone boundaries must be defined for piping systems that interface with tanks so that all work relating to tank testing can be included.

It was clear that this would be a different use of the Outfit Planning concept. However, some tools were still available to the Group. A fundamental part of any Outfit Planning activity is the group-oriented approach which integrates the basic functions of planning and production. A fresh approach to old problems is more likely to develop in an atmosphere that encourages group synergy. Unit work procedures were also seen as a tool for executing repair work. A critical step for the Group was the establishment of a clear-cut objective followed by a plan of action and milestones. Having done this, the Group set to work on implementing the plan.

TANK REPAIR WORK - THE PROBLEM

The attention of the Group was initially focused on isolating the problems that result in a lack of complete control of the tank repair process. A search for problem tanks and problem tank evolutions did not expose any obvious areas where intensified efforts would improve productivity. The problem of tank repairs centers more around the multitude of tasks[1] that need to be done in order to complete the job. In general, tank work involves the following steps:

1. Take custody of the tank
2. Open tank
3. Clean
4. Inspect
5. Repair
6. Preserve
7. Close
8. Test
9. Return tank to ship custody

Consider that these nine evolutions are required for most of the approximately 60 tanks on a typical submarine and you have a minimum of 600 tasks to manage. This figure

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[1] The word "task," as used in the Outfit Planning context, is defined as an element of work, performed by a single trade or skill that can be accomplished without interruption.

does not include tasks associated with shipalt work nor does it attempt to itemize all of the inspection and repair items that might be involved. The actual number of tasks to be managed is closer to 1500. Authorization to accomplish the work, in the form of job orders, does not identify these individual tasks, but instead gives a generic description of work. Scheduling relates job orders to schedule events that they must support. All task level work list development and scheduling is done at the worker level. The Shipfitter General Foremen assigns the tank management responsibility to a mechanic who is known as a Tank Coordinator. It is that person's job to coordinate all tank work such that schedule dates are met. Tools and methods are at the option of the Tank Coordinator. In the past, some have used computers to keep lists of things to do, but the primary management tool has been the wall chart. A great deal of dependence is placed on the skills of the individual Tank Coordinator.

Based on the above, the Outfit Planning Group determined that the tank repair problem was a process oriented problem and that better management tools were needed to manage those processes. A second but related problem identified by the Group was the lack of work instructions specifically for tank repair tasks. Certainly not every task needs an instruction for each tank, but there are those that would benefit. Tasks that the Group felt would benefit from more specific instructions are:

1. Initial inspections
2. Tank testing
3. Returning tanks to ship custody

OUTFIT PLANNING TANK REPAIR WORK

Tank Repair Project Management

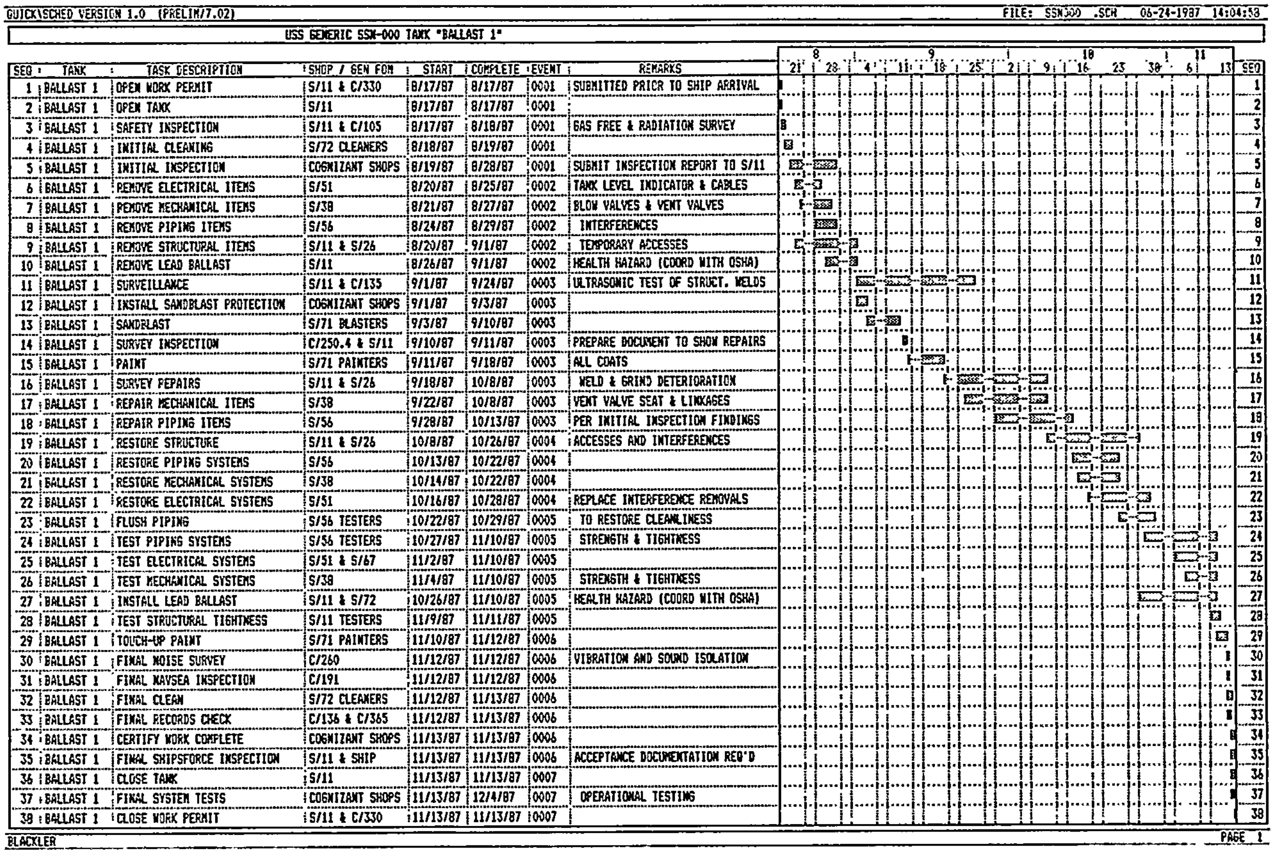
Having identified a group of problems related to a lack of tools to manage tank work, the Group set about providing some tools. The first priority was to plan and sequence tank work at the task level. Lists of work items necessary to accomplish tank work have been used for some time, but time frames for execution of the task had not been put on paper. Generation and maintenance of a schedule for 1500 tasks would be impractical if done by hand. The obvious solution was a computerized Project Management system similar to those commercially available such as MS Project, Super Project, etc. Project Management software provides for the development of a data base consisting of tasks, durations, and dates. It allows a variety of outputs such as Pert charts, Gantt charts, and resource details to be extracted. Dependencies of one task on another are accounted for.

The Outfit Planning Group decided to use a Shipyard-developed program named "Quicksched" to develop and manage the tank work data base for its first project. This program was chosen because it provided a variable format output that could be tailored to the Shipyard's needs. Data input for the first ship project was done by hand, one tank at a time. A list of repair tasks for each tank was prepared and sequenced in order of execution. In some cases, tasks were grouped together and assigned a common time frame if the sequence of execution was not important. The program software is able to identify the window for execution of a task and also the duration of the task.

In cases where sequencing was important, dependencies between tasks were entered. A sandblast sequence developed by the Outfit Planning Group was the basis for sequencing initial tasks in a tank. Previously established sequences for Special Hull Treatment application, tank testing, and other key events were used to define other task sequences and completion dates. Identification of durations for each task proved to be the most difficult part of the job. Historically, the Shipyard authorizes work in such large packages, both in manhours and in calendar time, that using cost return data to establish manhours required to complete an individual task was not possible. The Shipyard corporate knowledge about how long it takes to do work resides mostly in the heads of experienced production personnel. The Outfit Planning Group used that source to establish task durations. Figure 1 is a sample tank work sequence similar to that developed for each tank.

After completing the Quicksched data base and going through a review and revision cycle, the data base was installed on a PC computer in the dockside office of the ship's Tank Coordinator. This person is the data base custodian. At this point, the Tank Coordinator gained the following advantages:

1. Lists of tasks could be easily maintained and grouped by tank or by trade.
2. Windows for accomplishment of tasks could be easily identified.
3. The ramifications of change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USS GENERIC SSN-000 TANK "BALLAST 1"

SEQ	TANK	TASK DESCRIPTION	SHOP / GEN FON	START	COMPLETE	EVENT	REMARKS
1	BALLAST 1	OPEN WORK PERMIT	S/11 & C/330	8/17/87	8/17/87	0001	SUBMITTED PRIOR TO SHIP ARRIVAL
2	BALLAST 1	OPEN TANK	S/11	8/17/87	8/17/87	0001	
3	BALLAST 1	SAFETY INSPECTION	S/11 & C/105	8/17/87	8/18/87	0001	GAS FREE & RADIATION SURVEY
4	BALLAST 1	INITIAL CLEANING	S/72 CLEANERS	8/18/87	8/19/87	0001	
5	BALLAST 1	INITIAL INSPECTION	COGNIZANT SHOPS	8/19/87	8/28/87	0001	SUBMIT INSPECTION REPORT TO S/11
6	BALLAST 1	REMOVE ELECTRICAL ITEMS	S/51	8/20/87	8/25/87	0002	TANK LEVEL INDICATOR & CABLES
7	BALLAST 1	REMOVE MECHANICAL ITEMS	S/38	8/21/87	8/27/87	0002	BLOW VALVES & VENT VALVES
8	BALLAST 1	REMOVE PIPING ITEMS	S/56	8/24/87	8/29/87	0002	INTERFERENCES
9	BALLAST 1	REMOVE STRUCTURAL ITEMS	S/11 & S/26	8/20/87	9/1/87	0002	TEMPORARY ACCESSES
10	BALLAST 1	REMOVE LEAD BALLAST	S/11	8/26/87	9/1/87	0002	HEALTH HAZARD (COORD WITH OSHA)
11	BALLAST 1	SURVEILLANCE	S/11 & C/135	9/1/87	9/24/87	0003	ULTRASONIC TEST OF STRUCT. WELDS
12	BALLAST 1	INSTALL SANDBLAST PROTECTION	COGNIZANT SHOPS	9/1/87	9/3/87	0003	
13	BALLAST 1	SANDBLAST	S/71 BLASTERS	9/3/87	9/10/87	0003	
14	BALLAST 1	SURVEY INSPECTION	C/250.4 & S/11	9/10/87	9/11/87	0003	PREPARE DOCUMENT TO SHOW REPAIRS
15	BALLAST 1	PAINT	S/71 PAINTERS	9/11/87	9/18/87	0003	ALL COATS
16	BALLAST 1	SURVEY REPAIRS	S/11 & S/26	9/18/87	10/8/87	0003	WELD & GRIND DETERIORATION
17	BALLAST 1	REPAIR MECHANICAL ITEMS	S/38	9/22/87	10/8/87	0003	VENT VALVE SEAT & LINKAGES
18	BALLAST 1	REPAIR PIPING ITEMS	S/56	9/28/87	10/13/87	0003	PER INITIAL INSPECTION FINDINGS
19	BALLAST 1	RESTORE STRUCTURE	S/11 & S/26	10/8/87	10/26/87	0004	ACCESSES AND INTERFERENCES
20	BALLAST 1	RESTORE PIPING SYSTEMS	S/56	10/13/87	10/22/87	0004	
21	BALLAST 1	RESTORE MECHANICAL SYSTEMS	S/38	10/14/87	10/22/87	0004	
22	BALLAST 1	RESTORE ELECTRICAL SYSTEMS	S/51	10/16/87	10/28/87	0004	REPLACE INTERFERENCE REMOVALS
23	BALLAST 1	FLUSH PIPING	S/56 TESTERS	10/22/87	10/29/87	0005	TO RESTORE CLEANLINESS
24	BALLAST 1	TEST PIPING SYSTEMS	S/56 TESTERS	10/27/87	11/10/87	0005	STRENGTH & TIGHTNESS
25	BALLAST 1	TEST ELECTRICAL SYSTEMS	S/51 & S/67	11/2/87	11/10/87	0005	
26	BALLAST 1	TEST MECHANICAL SYSTEMS	S/38	11/4/87	11/10/87	0005	STRENGTH & TIGHTNESS
27	BALLAST 1	INSTALL LEAD BALLAST	S/11 & S/72	10/26/87	11/10/87	0005	HEALTH HAZARD (COORD WITH OSHA)
28	BALLAST 1	TEST STRUCTURAL TIGHTNESS	S/11 TESTERS	11/9/87	11/11/87	0005	
29	BALLAST 1	TOUCH-UP PAINT	S/71 PAINTERS	11/10/87	11/12/87	0006	
30	BALLAST 1	FINAL NOISE SURVEY	C/260	11/12/87	11/12/87	0006	VIBRATION AND SOUND ISOLATION
31	BALLAST 1	FINAL NAVSEA INSPECTION	C/191	11/12/87	11/12/87	0006	
32	BALLAST 1	FINAL CLEAN	S/72 CLEANERS	11/12/87	11/13/87	0006	
33	BALLAST 1	FINAL RECORDS CHECK	C/136 & C/365	11/12/87	11/13/87	0006	
34	BALLAST 1	CERTIFY WORK COMPLETE	COGNIZANT SHOPS	11/13/87	11/13/87	0006	
35	BALLAST 1	FINAL SHIPSFORCE INSPECTION	S/11 & SHIP	11/13/87	11/13/87	0006	ACCEPTANCE DOCUMENTATION REQ'D
36	BALLAST 1	CLOSE TANK	S/11	11/13/87	11/13/87	0007	
37	BALLAST 1	FINAL SYSTEM TESTS	COGNIZANT SHOPS	11/13/87	12/4/87	0007	OPERATIONAL TESTING
38	BALLAST 1	CLOSE WORK PERMIT	S/11 & C/330	11/13/87	11/13/87	0007	

BLACKLER PAGE 1

FIGURE 1. SAMPLE TANK REPORT

were much easier to identify.

4. The status of work was easily identified.
5. Status reports could be easily generated to suit management.
6. Critical path evolutions were highlighted by the software.
7. Corporate knowledge of "as accomplished" work sequences and durations was easier to retain.
8. Priorities for work permits to open tanks were easier to identify and provide for Ship's Force action.
9. Trade interference and competition for space were reduced.

At the date of this writing, the reaction of the top level Production management is to direct that tank repair work sequences, known as tank reports, be developed for all submarines in the Shipyard. Some of these ship overhauls were already in danger of missing schedule dates because of tank work. The tank managers for these ships adopted the tank report as a tool to minimize schedule impact. From a manager's point of view, the tank report represents a detailed plan of action to achieve schedule dates. Previously, the production working level plan to achieve schedule adherence was not all that visible to upper management. The result is a rapidly expanding program to provide project management data bases for all Shipyard tank work and all other work leading to the undocking of ships.

This Shipyard's efforts to implement project management on a large scale will impose some additional problems. The Outfit Planning Group started on a limited scale using desk top computer hardware. The purpose was to provide a tool for waterfront managers to do their jobs more effectively. Those who were involved were computer literate. The success of a computerized task management system requires dedicated personnel to provide continual attention to the data base so that current information is always available. The software must be suitable to mainframe computer systems that are likely to be in place to manage a Shipyard-wide management data base. Being restricted to PC based systems will limit the ultimate utility of the project.

Procedures and software must be made

user friendly so that special skills are not required for users to be successful. The software system used must be capable of handling large data bases, must have flexibility in output format, and must be able to communicate with other related software systems for spread sheets, data base management, and graphics production.

Finally, there exists a potential that those who monitor production will use the system to tell them if production is on track or not. If this happens on a wide scale, then the data base will come to reflect what upper management wants to hear while waterfront managers use old style methods to solve problems before upper management finds out there is a problem. This tool should be used to support tank coordinators. Management should develop its own indicators of performance that are not controlled by the people doing the work (4).

Tank Repair Unit Work Procedures

A second major area of concern to the Outfit Planning Group was the lack of specific instructions for accomplishing tank repair work. The Tank Coordinators felt that a more structured approach would cause a more uniform response on the part of all production trades and thus make the job of managing tank work easier. Initial inspection of tank systems and equipment was thought to be a good place to begin because the Shipyard has historically had problems in this area. The total extent of the repair package for a boat is not known until these inspections are done. Obviously that cannot happen until sometime after docking. The best that can be achieved is to identify the repairs as early in the overhaul as possible. This is necessary both to identify costs and to integrate the repair work into other overhaul activities. The Tank Coordinator is primarily responsible for this but must rely on other trades to inspect their systems in the tanks and report required repairs. Guidelines for these inspections either do not exist or are contained in a variety of Shipyard instructions. Consequently the effectiveness of the inspections is not consistent and required repairs are sometimes not identified until late in the overhaul.

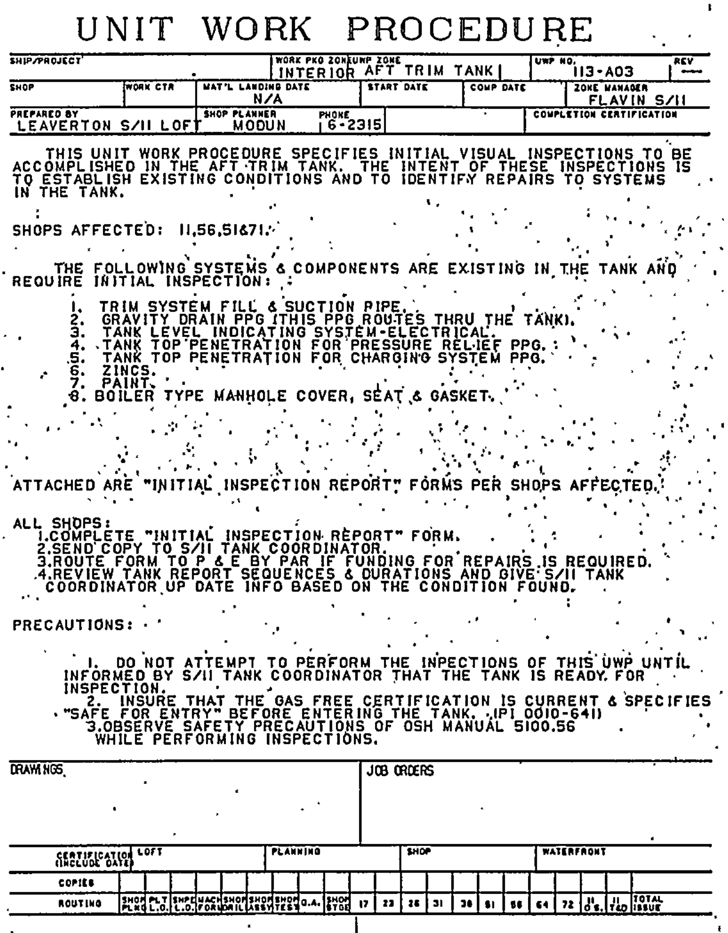
To deal with this situation, the Outfit Planning Group has initiated the development of Unit Work Procedures, as was done by previous Outfit Planning Groups for shipalts (5). These work procedures identify what must be inspected, what acceptance criteria apply, and specify a reporting procedure to be followed. The procedures are formatted so that each trade's inspections are grouped together. All inspections that can be done at that time during the overhaul are listed to insure that the necessity to reenter the tank will be reduced. In cases where location of the items to be inspected is not clear, graphics are provided to define locations. Figures 2 through 4 are excerpts from a prototype unit work procedure. The intention is to insure that all required inspections are accomplished and repairs are identified as early as possible during the overhaul.

Having the procedure defined in writing at the task level helps accomplish this because it defines the work that must be done in a relatively small package that makes it easy for production workers to sequence, manage, and report completion of tasks. When the work is completed, expenditures can be collected and reported back to Planning and Estimating to establish corporate history of costs at the task level. This information will provide a basis for better estimates for future work and will help to establish control limits for monitoring work in the future. A side benefit of using unit work procedures to specify initial inspection is that identification of required repairs is much easier in case the Shipyard and the Ship's Force disagree on what must be repaired.

Tank Structural Repairs

A related but separate project being pursued by the Tank Outfit Planning Group involves the development of improved ways for Design to communicate tank structural repairs to the shop based on Design's visual survey. Figures 5 and 6 show examples of tank structural deterioration. Narrative descriptions of the repairs have been used in the past. This method has been satisfactory but leaves much room for interpretation on the part of the Production worker and is time consuming for Design to produce. The intent is to reduce the preparation time and clarify the instruction by using a graphical approach to specify repairs. The key to this idea is to be able to rapidly generate graphics of tank structure as needed. CAD computers are a possible solution.

At present, CAD models of the aft trim tank and depth control tank structure on an SSN 637 Class submarine have been modeled on a CAD



UNIT WORK PROCEDURE

SHIP/PROJECT		WORK PKG ZONE INTERIOR	UWP ZONE AFT TRIM TANK	UWP NO. 113-A03	REV —
SHOP	WORK CTR	MAT'L LANDING DATE N/A	START DATE	COMP DATE	ZONE MANAGER FLAVIN S/11
PREPARED BY LEAVERTON S/11 LOFT	SHOP PLANNER MODUN	PHONE 6-2315		COMPLETION CERTIFICATION	

THIS UNIT WORK PROCEDURE SPECIFIES INITIAL VISUAL INSPECTIONS TO BE ACCOMPLISHED IN THE AFT TRIM TANK. THE INTENT OF THESE INSPECTIONS IS TO ESTABLISH EXISTING CONDITIONS AND TO IDENTIFY REPAIRS TO SYSTEMS IN THE TANK.

SHOPS AFFECTED: 11,56,51&71.

THE FOLLOWING SYSTEMS & COMPONENTS ARE EXISTING IN THE TANK AND REQUIRE INITIAL INSPECTION:

1. TRIM SYSTEM FILL & SUCTION PIPE.
2. GRAVITY DRAIN PPG (THIS PPG ROUTES THRU THE TANK).
3. TANK LEVEL INDICATING SYSTEM-ELECTRICAL.
4. TANK TOP PENETRATION FOR PRESSURE RELIEF PPG.
5. TANK TOP PENETRATION FOR CHARGING SYSTEM PPG.
6. ZINCS.
7. PAINT.
8. BOILER TYPE MANHOLE COVER, SEAT & GASKET.

ATTACHED ARE "INITIAL INSPECTION REPORT" FORMS PER SHOPS AFFECTED.

ALL SHOPS:
1. COMPLETE "INITIAL INSPECTION REPORT" FORM.
2. SEND COPY TO S/11 TANK COORDINATOR.
3. ROUTE FORM TO P & E BY PAR IF FUNDING FOR REPAIRS IS REQUIRED.
4. REVIEW TANK REPORT SEQUENCES & DURATIONS AND GIVE S/11 TANK COORDINATOR UP DATE INFO BASED ON THE CONDITION FOUND.

PRECAUTIONS:

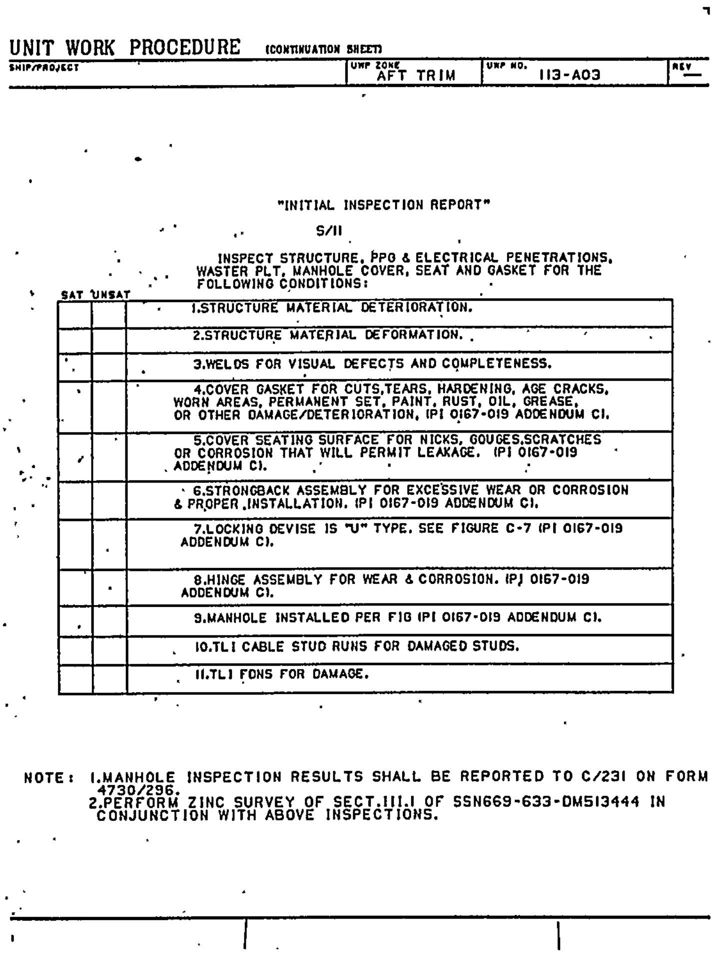
1. DO NOT ATTEMPT TO PERFORM THE INPECTIONS OF THIS UWP UNTIL INFORMED BY S/11 TANK COORDINATOR THAT THE TANK IS READY FOR INSPECTION.
2. INSURE THAT THE GAS FREE CERTIFICATION IS CURRENT & SPECIFIES "SAFE FOR ENTRY" BEFORE ENTERING THE TANK. (PI 0010-641)
3. OBSERVE SAFETY PRECAUTIONS OF OSH MANUAL 5100.56 WHILE PERFORMING INSPECTIONS.

DRAWINGS	JOB ORDERS

CERTIFICATION (INCLUDE DATE)	LOFT	PLANNING	SHOP	WATERFRONT

COPIES																				
ROUTING	SHOP PLNG	PLT L.O.	SHPE L.O.	MACH FORM	SHOP DRILL	SHOP ASSY	SHOP TEST	Q.A.	SHOP STGE	17	23	26	31	38	51	56	64	72	11 O.S.	11 T&D	TOTAL ISSUE

FIGURE 2.
SAMPLE UNIT WORK PROCEDURE



UNIT WORK PROCEDURE (CONTINUATION SHEET)

SHIP/PROJECT	UWP ZONE AFT TRIM	UWP NO. 113-A03	REV —

"INITIAL INSPECTION REPORT"

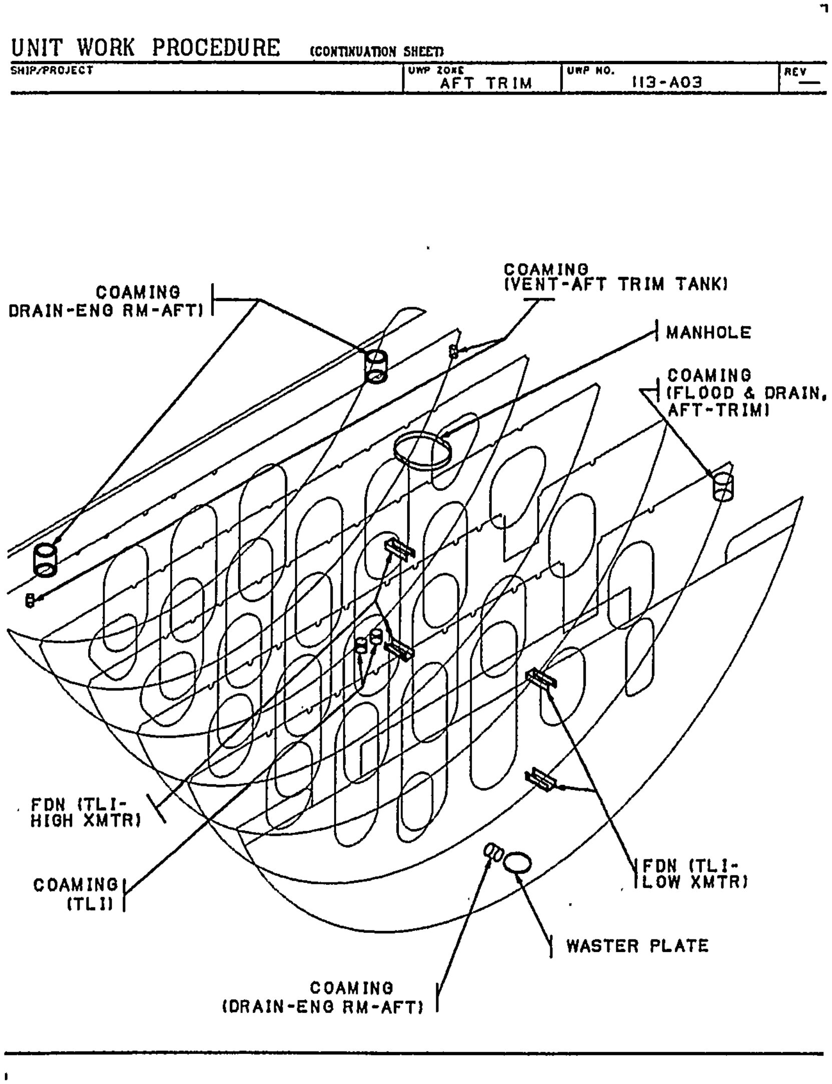
S/11

INSPECT STRUCTURE, PPG & ELECTRICAL PENETRATIONS, WASTER PLT, MANHOLE COVER, SEAT AND GASKET FOR THE FOLLOWING CONDITIONS:

SAT	UNSAT	
		1.STRUCTURE MATERIAL DETERIORATION.
		2.STRUCTURE MATERIAL DEFORMATION.
		3.WELDS FOR VISUAL DEFECTS AND COMPLETENESS.
		4.COVER GASKET FOR CUTS,TEARS, HARDENING, AGE CRACKS, WORN AREAS, PERMANENT SET, PAINT, RUST, OIL, GREASE, OR OTHER DAMAGE/DETERIORATION, (PI 0167-019 ADDENDUM C).
		5.COVER SEATING SURFACE FOR NICKS, GOUGES,SCRATCHES OR CORROSION THAT WILL PERMIT LEAKAGE. (PI 0167-019 ADDENDUM C).
		6.STRONGBACK ASSEMBLY FOR EXCESSIVE WEAR OR CORROSION & PROPER INSTALLATION. (PI 0167-019 ADDENDUM C).
		7.LOCKING DEVISE IS "U" TYPE. SEE FIGURE C-7 (PI 0167-019 ADDENDUM C).
		8.HINGE ASSEMBLY FOR WEAR & CORROSION. (PJ 0167-019 ADDENDUM C).
		9.MANHOLE INSTALLED PER FIG (PI 0167-019 ADDENDUM C).
		10.TLI CABLE STUD RUNS FOR DAMAGED STUDS.
		11.TLI FONS FOR DAMAGE.

NOTE: 1.MANHOLE INSPECTION RESULTS SHALL BE REPORTED TO C/231 ON FORM 4730/296.
2.PERFORM ZINC SURVEY OF SECT.III.1 OF SSN669-633-DM513444 IN CONJUNCTION WITH ABOVE INSPECTIONS.

FIGURE 3.
SAMPLE UNIT WORK PROCEDURE



UNIT WORK PROCEDURE (CONTINUATION SHEET)

SHIP/PROJECT	UWP ZONE	UWP NO.	REV
	AFT TRIM	113-A03	—

FIGURE 4.
SAMPLE UNIT WORK PROCEDURE

FIGURE 5.
BALLAST TANK LEAD POCKET -
HULL PLATING CORROSION
ELEVATION VIEW - LKG INBD

FIGURE 6. DIESEL EXHAUST ENCLOSURE - STRUCTURAL DETERIORATION

system and are being used to provide the graphics for specifying repairs. Use of CAD generated graphics to prepare repair instructions is resulting in an estimated document preparation time savings of about 30 to 40 percent. Time saved in locating and laying out the repair work on board ship is estimated to be about 25 percent. Cost of the CAD modeling is about 5 to 10 mandays per tank. Clearly, this method is a benefit to tank work, but is costly to implement. The positive returns on the CAD investment come from developing all potential uses for the models, such as the preparation of quality control forms, and reuse of the models on all future ships of the same class. This return can be expedited by modeling only tanks which have a high incidence of repairs. Certainly, other Shipyards can utilize the tank models for similar purposes.

CONCLUSION

To date the Shipyard has used Outfit Planning to prepare for repair work in the areas of Special Hull Treatment and Main Sea Water Bay as well as tank repairs. A large group of Shipyard workers has been involved at one time or another. The general consensus of these people is that their participation in Outfit Planning has had a positive effect on productivity. The Production workers are encouraged by their opportunity to participate in planning for work they will execute. The feeling is that getting the right personnel involved in a group-oriented planning activity is much better than the normal procedure which separates Planning and Production functions.

The Shipyard is now enjoying some of the benefits of Outfit Planning in the repair portion of its work. Among these benefits are:

1. Breakdown of communication barriers between Planning and Production and also between system-oriented Production Trades.
2. Identification of work sequences in advance of ships arrival.
3. Introduction of smarter work methods.
4. Reduction of reference material at the Production working level.

These benefits contribute to the Outfit Planning Group's short term goal of increasing tank repair efficiencies so that schedule is not impacted. Much of the early emphasis was on getting work done on time in lieu of saving money.

Breaking the benefits into dollars saved is a difficult task under the current fund management system and is premature at this time. The Shipyard's Industrial Engineering organization has undertaken studies to identify cost savings for some Outfit Planning efforts (6). A similar study will be necessary to identify and document savings from Tank Repair Outfit Planning. The authors feel that if such a study were done in the near future that a 10 to 20 percent savings in manhours would be identified in addition to a significant improvement in control of tank work.

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Implementation of Total Quality Management at Pearl Harbor Naval Shipyard

No. 9

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INTRODUCTION

Pearl Harbor Naval Shipyard is one of eight public shipyard engaged in the overhaul and repair of conventional and nuclear powered surface ships and submarines of the U.S. Navy. These ships, from their power plants to their sophisticated weapons systems, are consistently on the leading edge of technology. Work performed on these ships during an overhaul, maintenance or repair cycle requires personnel in the labor force whose skills encompass a variety of vocations -- engineers, machinists, accountants, welders, computer specialists, pipefitters, riggers, crane operators, and personnel specialists are but a few of the skills required. Of prime importance in ensuring success in the business is a management structure and philosophy dedicated to continuous improvement in quality, productivity and cost reduction.

Recognizing that increased productivity and reduced costs are end products of quality improvement, Pearl Harbor, in April 1986, elected to adopt Dr. W. E. Deming's management fundamentals. The purpose of this presentation, therefore, is to discuss the strategy and methodology which is being used to apply Dr. Deming's principles to the complex world of ship overhaul and repair.

GOAL

The goal at Pearl Harbor Naval Shipyard is to reduce costs in order to remain competitive. To achieve this goal, the shipyard has adopted the strategy directed toward "process improvement". This process management approach is based on the philosophy of Dr. W. Edwards Deming and Dr. J. M. Juran. Dr. Deming states his aim is the transformation of the American style of management. He does not tell how to make this transformation, but he provides fourteen Management Principles as a guide. It is top management's responsibility to infuse these principles functionally and operationally into the shipyard organization and to provide a plan for their implementation. A brief description of these principles is given below:

1. Constancy of purpose
2. Refusal to accept mistakes/ defects
3. Cease dependence on mass inspection
4. Single-Source Suppliers. Buy on quality, not price
5. Search for problems
6. Training for all employees
7. Leadership
8. Communication, drive out fear
9. Remove barriers between departments
10. Goals, Posters, Quotas, Slogans
11. Use statistical methods
12. Workers' right to pride of workmanship
13. Retraining
14. Top Management's Commitment

Pearl Harbor is currently in the process of internalizing and institutionalizing the Deming principles. This means shipyard managers must embrace these principles and apply them in the management of shipyard activities. Management words and actions must reflect and be consistent with these principles. Shipyard policies, procedures, instructions, and daily operations must also be consistent with this philosophy.

In recognizing past practice and management styles cannot be changed overnight, Pearl Harbor accepted the fact that this change in management attitude and behavior will take three to five years. The change process begins by generating awareness through training in the basics of the Deming Principles, problem solving techniques and statistical methods. The manager then has the opportunity to practice and apply these new ideas and techniques in his/her own environment. The restructured environment is established as part of the change process by the Shipyard Commander and the Steering Committee which has been formed to perpetuate on-going process improvement. The new structure encourages managers to spend a minimum of 10% of their time working on the problems of tomorrow. As managers participate and become more comfortable and adept with these new methods, they see the results of not only their efforts, but also of the entire shipyard's efforts to effect continuous improvement. As the goal to constantly improve becomes a way of life at Pearl Harbor, the result will be a reduction in overhaul and repair costs, and significant improvement in Pearl Harbor's competitive position and its ability to provide jobs and job security to a dedicated workforce.

MANAGEMENT'S RESPONSIBILITY

Deming point out that eighty-five percent of all problems in an organization are system problems and, therefore, are the responsibility of management. Moreover, the systems and processes that an organization uses are created and established by management. Therefore, managers must understand how to analyze systems processes and create a structure that allows all levels of the workforce to be involved in process improvement and control.

It is critical for the top management team to be a role model in the execution of its responsibilities in the transformation process. The team must change its fundamental ideas about how to manage shipyard work and its role with the people. Top management cannot delegate this responsibility; they must actively lead in helping resolve all types of shipyard problems.

Management must learn to think analytically through the process of quantifying and measuring problems. Deming's approach emphasizes making decisions based on facts. Data must be collected, analyzed, and used to identify and solve problems. Statistical process control (SPC) and other quantitative methods provide the tools necessary to collect and interpret data. Training must be provided to develop management understanding in the use of these tools and techniques. Even more important is the use and application of these tools on real problems. Guidance must be provided.

JOB SHOP BUSINESS

Many examples of the application of the Deming Philosophy come from industries where mass production and its associated repetitive processes play an important role. Examples may show a production line capable of producing 500 cars per day. Generally, most examples illustrate the repetitive nature of processes. In comparison, the ship overhaul and repair business on sophisticated Navy ships differs greatly. It may take six months to several years to overhaul a ship. Shipyards are in the <u>Job Shop</u> business. Some jobs occur only once a year, while new Ship Alterations require entirely new techniques and approaches. The job shop business requires a significant amount of planning up front to order materials, develop software, sequence work, and coordinate the trades involved. Actual work is complicated by limited space access onboard ship. But even with these differences, ship repair effectiveness can be markedly improved through process improvement, i.e., looking for ways to streamline processes.

Although much of ship overhaul and repair business is job shop in nature, there are many processes utilized repeatedly. For example, welding, machining, pipe fitting, painting, valve repairs, software development, etc.; all of these processes can be improved by reducing variability that occurs today. By understanding what causes variation in our processes, and by observing, analyzing and controlling variability, we can improve our quality and reduce our costs.

NEED

The need to improve the way Pearl Harbor manages and conducts overhaul and repair work is directly influenced by the interrelationship of the following factors:

(1) <u>High Cost</u>: Cost of overhauls and repairs have been spiraling upwards.

(2) <u>Reduced Budget</u>: The Navy's share of a reduced federal budget must be stretched over an expanded fleet.

(3) <u>Competition</u>: The public shipyards have begun competing with the private sector for Navy work. Pearl Harbor expects to competitively bid on future overhaul work packages.

(4) <u>Need for Improvement</u>: There is a great need for improvement at Pearl Harbor Naval Shipyard. It is estimated that a minimum of 15% of our

time and money is spent on rework alone. If our experience is typical of the eight public shipyards that employ approximately 60,000 people, this means that the equivalent of 9,000 or more people, that is, the equivalent of another shipyard, are spending full time doing nothing but rework. At the same time, tremendous savings can be realized by reducing work and improving processes that produce an acceptable product without rework. Although most current processes eventually produce a quality output, they are very costly, overly complex, and include too many bottlenecks and inspection points. Obviously, all processes, must be streamlined to reduce the excess fat. These two elements, reducing rework and streamlining processes, are the key areas to focus on in process improvement.

(5) The Impact of Japan: Japan has become the exemplar in the world for quality and productivity. They have excelled at being able to produce a product or a service and doing it right the first time. They have set the example for continuous improvement. Their ability to reduce variation in a process and produce uniform output has resulted in higher quality and reliability and a minimized cost by eliminating rework.

THE EVOLUTION OF QUALITY

In the 1930's, Walter Shewhart, a statistician at Bell Laboratories in New York, developed techniques to bring industrial processes into what he called "statistical control". Shewhart, through the use of statistical analysis techniques, established a method for defining the limits of inherent or random variation in a process. Once the variation was determined, process control limits were mathematically determined. From this, a process control chart could be constructed which would provide a real time measure of process variability as work was being performed. By collecting in-process measurement data at selected intervals and entering it on the control chart, the actual performance of the process could be tracked. Review of the control chart could then trigger action to adjust or modify the process if it began to deviate from the norm and thereby prevent the production of a defective product. Workers could be trained to do this charting themselves, thus giving them greater control over their jobs and allowing them to make adjustments on their own. Dr. Deming studied with Shewhart and included these theories on quality control as a basis for his own work. The theories were put into practice during World War II, and the result was our ability to produce a quality product from the assembly line without the need for 100% inspection. Because of the resulting increase in productivity, we were able to provide the forces in the field with the quantity and quality of materials needed in the war effort; a significant factor in our eventual victory. However, after the war, the high consumer demand for products placed the emphasis on quantity, not quality; therefore, the use of Shewhart's theories was no longer seen as important. Paradoxically, General McArthur was assisting Japan in the rebuilding process, and invited Deming to help with the census. While Deming was in Japan, he was also asked to present his ideas on quality to the Japanese Union of Scientists and Engineers (J.U.S.E.). The rest is history. The Japanese accepted these ideas and began massive training in statistical methods. Since 1950, the Japanese have become one of the world leaders in quality and productivity and a major competitive force in the work marketplace. It was not until the 1980 presentation in the U.S. of the NBC white paper, "If Japan Can, Why Can't We?" that American business took serious notice of Dr. W. Edwards Deming and his fourteen principles of management philosophy. Since 1980, many of the Fortune 500 companies have embraced the Deming principles and have improved their quality and productivity significantly.

The evolution of quality improvement at Pearl Harbor up until 1981, for the most part, was seen as the responsibility of the Quality Assurance Department. Like many organizations across the country, Pearl Harbor had made a token effort in support of the "Zero Defects" program in the 1970's. This program was a good example of the slogan approach to quality improvement with no plan of action nor a defined methodology on how to reach this goal. In 1981, in an attempt to apply a methodology, the shipyard initiated a Quality Circle program and within one-and-one-half years had expanded to 35 active circles. However, due to a lack of constancy of purpose, lack of management support, and changes in upper level managers, the number of active circles dropped to two in 1984. Again, due to a change in top management in 1986, the QC program was revitalized and is currently at 20 active circles. In 1984, another Quality Improvement Initiative was established to address the issue of rework. This program later became known as the Problem Recurrence Elimination Program (PREP). PREP coordinators were assigned in the various shops and departments, and a system was established to identify and record rework along with a computerized database for tracking. This program grew, gained manager and shipyard support, and is both active and very successful today. The databank is used to direct shipyard improvement efforts which have resulted in millions of dollars saved.

The current Shipyard Commander, Captain Robert Traister, arrived at Pearl Harbor Naval Shipyard in January 1986 and brought with him a background of experience at Electric Boat, Litton Industries and Puget Sound Naval Shipyard. He was familiar with the processes and problems associated with the building, overhaul, and repair of Navy ships. Although these shipyard had different strengths and weaknesses, all experienced being caught up in fighting fires on a daily basis. Unfortunately, it was his opinion that they had failed to make any significant improvement over the long range. He saw occasional successes, yet all shipyards lacked overall effective planning and coordination. They were bound up in unnecessarily costly processes. .pa However, one element of the operation which he found successful was the "tiger" or "project" team approach. These teams were made up of a relatively small number of key people with the necessary experience and background to work on a specific task. They would meet periodically on their special assignment and perform the detailed planning and then ensure the project was correctly managed during the execution phase. They were able to continuously identify unforeseen problems and then readily resolve them. This project approach is used successfully today not only at Pearl Harbor, but in all shipyards in order to focus work groups on complex tasks and evolutions. It is an example of a technique that works. Many of the factors that make this approach successful are included in the Deming Philosophy.

Captain Traister was well read in the management philosophies of Drucker, Juran, Deming and Crosby. He was absolutely convinced that "process improvement" was a necessary part of the long-term shipyard improvement equation, and he initiated a shipyard-wide effort in process management. By April of 1986, he issued written direction to all Departments and Offices making it clear that he wanted everyone in the shipyard involved in process improvement. An enclosure to this internal direction was a 55 page guide that outlined the "Management Approach to Productivity Improvement". Shortly after that, 22 top managers attended a five day course given by the University of New Hampshire entitled the "Group Approach to Problem Solving (GAPS)". Immediately following this, another group of 22 top managers attended another five day course given by the National Summit Group entitled "Quality, Productivity and Implementing SPC". Following the training, a Steering Committee of Department and Offices heads as assigned to establish and manage future process improvement policy and direction. The Steering Committee made two key decisions: (1) to hire an outside consultant for one year to assist the shipyard in its implementation efforts and (2) to develop an internal education program to train project teams and managers in the problem solving tools and techniques. The training program was to be an interim step to get the remaining shipyard managers trained and involved in process improvement until the consultant arrived. By the end of 1986, 12 interdepartmental teams and 375 managers and supervisors had been trained. The idea was that managers/supervisors were to put these tools to work in finding and solving problems in their own work area (Deming's Point Number 5: Find problems). A sub-steering committee was assigned the task of writing a solicitation to hire an outside consultant. The completion of this process took one year.

IMPLEMENTATION - PHASE I

This section describes the process improvement structure established by Captain Traister and the Steering Committee and covers the period of 1986 to 1987. Phase II begins with the arrival of the consultant in June 1987. The structure incorporates all the elements that go together to make the implementation process work; moreover, these elements integrate the ingredients of the Deming philosophy into continuous process improvement. This structure evolves and changes continually as it is refined and improved through actual use at Pearl Harbor. This paper is a description or "snapshot" of where Pearl Harbor currently is in this process. Some of these elements were already in place while others have been added since the recent emphasis on Total Quality Management (TQM) began. Due to a lack of publicity, the program has been seen as "quiet"; therefore, one drawback is that the workforce perceives fragmentation as these old programs now merge with new elements.

A description of each element is provided below.

Shipyard Commander

The Shipyard Commander, i.e., the Chief Executive Officer, is the most critical element in causing continuous process improvement to take place. He is the role model for others to follow. Without his commitment, dedication, belief, involvement, support and constant everyday pushing of the program, any effort such as this one is doomed. For example, Captain Traister has participated in all 25 training sessions conducted to date. In these sessions, he spends considerable time explaining to each class of 25 shipyard managers why this process is necessary, how it works, and gives examples of its success. In addition, he attends and chairs two one hour process review sessions each week where presentations are made on process improvements throughout the shipyard. Each week he chairs the Steering Committee, which provides direction and guidance for the TQM program. He constantly queries managers and those directly involved in improvement projects with questions such as:

> "What is the criteria?"
> "What will you measure?"
> "How will you know if you have improved?"
> "You need more data."
> "You must establish a database."
> "What is your plan to follow up?"
> "You need to break the job down into smaller pieces."
> "Why does our procedure cost more than other Shipyards?"

Managers and supervisors who have received the benefit of the training all agree that the Shipyard Commander is a critical element in Deming's "transformation". From the top down, and total process needs to be both stated <u>and</u> used repeatedly throughout the entire management structure in the shipyard.

Steering Committee

The Steering Committee's purpose is to establish policy and direction for TQM. It is chaired by the Shipyard Commander and meets weekly for an hour-and-a-half. It's members include some 25 managers, made up of Department and Office Heads in all major functions. This Committee identifies high cost processes for review and assigns interdepartmental members to work on these projects. Steering Committee activities have included viewing the Juran, Conway, and Deming video tapes, and arranging for guest speakers that are further along in implementing the Deming principles. One month was spent reviewing all process improvement projects underway in each Department. This thorough overview gave everyone an opportunity to see what is going on and to provide feedback. The Steering Committee works closely with the consultant in developing a clear understanding of Deming's 14 points. Subcommittees will be formed to study a specific number of the 14 points, and they will define them operationally and functionally within the shipyard. Through this process, the Steering Committee will become the champions of the 14 points; moreover, they will become a resource and resolver of any questions regarding these principles.

Rework

The Problem Recurrence Elimination Program (PREP) has been actively involved in identifying rework for three years. PREP is composed of 12 full time and 12 part time coordinators assigned from the various shops and departments. These coordinators have been trained in process analysis and improvement, and spearhead projects that have been identified as rework problems.

Plans for the future include ongoing documentation of discrepancies on critical submarine components and systems. These discrepancies will be documented during assembly, shop and shipboard testing. This enormous databank will be used to:

- identify problem process
- prioritize process improvement needs and efforts
- confirm effectiveness of process improvement actions
- demonstrate process control effectiveness

By continually improving shipyard repair processes, the shipyard will be able to reduce the number of problems, maintain a corporate memory databank, and get repair processes under control.

Training

Deming emphasizes a continuing training and education commitment for all employees.

The employees must understand the total assigned job, requirements, procedures and policies. Most important, the employee must be given the opportunity to apply classroom training in the workplace so that the knowledge and understanding is internalized. In other words, the employee must be qualified to do the job. Training must be continually improved and updated to meet changing requirements, and the shipyard must allocate resources to fund this training. Statistical methods are used to determine if processes are in control and if training is needed. To achieve this training goal at Pearl Harbor, an interdepartmental team was established to set up a Skills Tracking System. This system lists the skill and training requirements, dates that training was last attended, and the jobs that were worked where training was applied. This system will be used, along with the workload forecast, to determine future and on-going training requirements.

This section describes training that the shipyard developed to get started in process improvement. The purpose of this training was to train interdepartmental project teams and shipyard managers in the Deming Philosophy, problem solving, team building, and statistical methods. It was initially seen as a 3-4 month interim action before the consultant arrived; however, as it turned out, it was a one year effort. During that one year, 19 interdepartmental project teams and 600 managers were trained. Since the overview training was limited to three days, it provided only an introduction to shipyard managers on the basic concepts. It was presented in a top down approach, i.e., managers should not attend unless their supervisor had attended first. This unwritten rule was about 70% effective. Class size was limited to 20-25 people.

Subject matter included introduction, background, Deming video entitled "Road Map to Change", Shipyard Commander's presentation, working as a group, defining and understanding the problems, flow charting, cause and effect diagrams, data collection, data analysis, pareto, trend charts, histograms, scatter diagrams, control charts, solutions, and a 6 hour group application of the problem solving tools to a case study.

In addition to the above training, 6 shipyard managers were sent to a 4 day seminar given by Deming himself in May 1987.

Process Review

Currently, approximately 100 improvement projects are being tracked and monitored. This number is increasing as managers and supervisors begin to identify and attack problems in their own areas. At the present time, the Shipyard Commander, the Planning Officer, and the Production Officer hold a Process Review meeting every Wednesday and Friday between 0700 and 0800. Presentations are made on the progress of improvement projects and top management has the opportunity to provide approval, feedback, and direction at these meetings. With this meeting, the Shipyard Commander is modeling what he wants to eventually see at the shop and department level. As the number of improvement projects continues to increase, each shop and department will establish its own internal Quality Assurance Program or Quality Review Board. These Boards will be responsible for reviewing improvement projects to ensure they are progressing and receiving necessary management attention.

Interdepartmental Teams

Shipyard operations involve many complex and costly processes. These processes require input from numerous trades and codes throughout the shipyard because they cross department boundaries. These processes are further complicated by their own undocumented evolution and by the many imposed governmental regulations. The Steering Committee identifies not only the high cost processes, but also the ones which continually result or hinder productivity year after year. These processes are pinpointed as potential projects for improvement, and they represent major cost savings. Once the Steering Committee selects such a project, the next step is to nominate a project manager from the Steering Committee to be responsible for the project. The project manager serves as a link between the team and the Steering Committee, and he/she provides status to the Steering Committee on the team's progress.

The project manager selects a team leader, and the two together determine the required trades and codes that are needed to resolve the problem. Once the team members are identified, the entire team attends a three day training in the Deming Philosophy, problem solving tools, and Statistical Process Control (SPC). After completing the training, the team spends the remaining two days getting started on their project. From here on, the team averages four hours per week working on their projects. Typically, they hold two meetings per week for two hours.

These interdepartmental teams incorporate all the ingredients of the Deming Philosophy, i.e., breaking down barriers between departments, two way communication, and managers demonstrating their leadership ability by helping to remove barriers that hinder the team's progress and success. These teams become the example of how process improvement works for other shops and departments.

They are a vehicle that allows the shipyard to experience the Deming principles at work.

Nineteen Interdepartmental teams have been established at Pearl Harbor to work on the following high cost processes:

Scheduling
Steaming Deficiencies
Special Hull Treatment
System Certification
In Place Valve Repair
Electricity Usage
Discrepancy Reports
Key Operation Closure
Controlled Industrial Material
Steam Plant Cleanliness Control
Design Support Services
Material Kitting
Shift Turnover
ATMAS
Refrigeration
Skills Bank
Test Memos
BQQ5 Upgrade
Clean Van

Typically, a team will make a status presentation to the Process Review Board 1-3 months after they complete training. This gives management an opportunity to ask questions and provide feedback. The final presentation is made when the team is ready to implement their improvement action. After management's approval is received and after the changes are implemented, the team follows up to ensure that the plan of action is implemented properly. They also collect data to ensure that the improvement words and meets the desired goal. Only when the team has institutionalized the change can it step away from the project.

Departments

The Shipyard Commander has tasked each Department to identify and work on five improvement projects and to report the status to him quarterly in writing. Each department identifies high cost problems in their area and assigns team leaders and members to attack those problems. Several departments have established more than five projects. The awareness of the opportunity for fertile areas to improve becomes more and more apparent.

Managers and Supervisors

The model for individual managers and supervisors is to spend 10% of their time (four hours per week) dedicated to process improvement. This means meeting with (1) their subordinates, and/or (2) their counterparts plus managers to identify problems. This becomes a schedule and behavior that is on-going for constantly improving processes by identifying and eliminating problems one by one.

Currently, very few individual managers/supervisors are involved independently other than the projects discussed above. More and more pressure is being directed toward getting all personnel trained actively involved. Pearl Harbor has trained more than 600 managers to date and only a handful are involved in improvement projects.

This is a weak area in that managers and supervisors are not applying the tools and techniques learned in training; therefore, their ability to internalize these skills is jeopardized.

Quality Circles

The Shipyard Commander's goal is to get all the managers and supervisors trained and onboard with the Deming Philosophy and "process improvement" before addressing the workforce regarding Quality Circles. The point is that the Quality Circle program that began in 1981 had little or no management support. Before the shipyard establishes any future Quality Circle policy, all managers must first be trained and actively involved. It is important that managers and supervisors understand the Deming Philosophy and process improvement before the concept is introduced at the workforce level. Every effort must be made to eliminate lip service.

IMPLEMENTATION - PHASE II

Phase II began with the arrival of the consultant in June 1987. Up to this point, the shipyard established a system and structure to get "process improvement" underway. Although slow in development, the shipyard moved steadily and positively toward getting everyone involved. The Deming principles were addressed superficially. The video tape, "Roadmap to Change" (Deming Philosophy), had been shown to all managers and discussed briefly in the three day training.

Why a Consultant?

Deming recommends the use of a consultant and, of course, consultants recommend consultants. The shipyard made the decision early on to bring in outside assistance for the following reasons:

The payback from the expected cost savings will more than compensate for consultant's services.

Pearl Harbor lacks "hands on" experience in applying statistical methods and the Deming principles.

Consultants offer expertise, credibility, and direct "hands on" experience that will provide a faster and smoother transition.

Consultants have encountered and dealt with the barriers and pitfalls of implementation and developed strategies to minimize these problems.

The following criteria were used to evaluate the background and experience of the contractors and the personnel involved in the contract:

- teaching experience/ expertise
- problem solving and team building
- statistical process control
- Deming principles
- record of successful implementation
- size and type of organizations served
- response from references contacted

Consultant Services

In late May 1987 the contract was awarded to Process Management Institute (PMI). PMI, recommended by Dr. Deming, will provide four different specialists from their staff during the one year contractual period. The contract includes the following services.

1. Top Management

Mr. Louis Schultz, president of PMI, will present a three day seminar to top management at the shipyard. The title of his seminar is "Managing in the New World Wide Competitive Society".

Topics include:

- History of Competitiveness
- Need for Change
- Deming's Deadly Diseases
- Deming's 14 Principles
- Funnel Experiment
- Bead Box Experiment
- Consequences of Staying "As Is"
- Process for Change
- What's Required to Make It Happen
- What We Would Like to See at Pearl Harbor
- Obstacles

This seminar will initiate the contract and provide managers with an overview of their new role.

2. SPC Internal Consultants

A group of 25 people assigned from the various shops and department will receive in-depth training in statistical methods. They will be taught to apply these methods to projects within the particular shop or department where they are employed. These "internal consultants" will work with their management and project teams on improvement projects; moreover, they will become a resource in the shipyard to draw from in the application of SPC. The training they receive includes a minimum of one week in the classroom followed by several weeks of applying the SPC tools and techniques to real Shop/ Department projects.

3. Project Teams

Problem solving, team building, and SPC training will be provided for selected improvement projects. Upon completion of the training, the teams will work with the internal consultants, their Department Managers, and the Consultants in applying the skills and techniques to specific problem areas. This training covers five days and is followed by the team meeting four hours a week to work on their project.

4. Facilitation and Consultation

Continuous full-time facilitation on the application of the Deming principles, problem solving techniques, and statistical methods is required throughout the one year contract period. The consultant will work with top management, the Steering Committee, Department and Office Heads, the internal consultants, and the project teams. This hands-on application phase is a critical step for managers to internalize all aspects of the Deming Philosophy.

RESULTS AND EXAMPLES

Pearl Harbor's progress will be assessed in two areas: (1) reduction in cost of SSN 688 Class overhauls, and (2) implementation of a process management system.

SSN 688 Class Overhaul Costs

Pearl Harbor has completed two SSN 688 Class overhauls, has two currently in progress, and has two more planned for the future. Manday expenditures exceed those of other overhauling activities by the percent shown below:

SSN 688 Class Overhauls	Manday Expenditures in Excess of Other Shipyards (percent)
First (1984)	25%
Second (1985)	22%
Third (1986)	16%*
Fourth (1987)	11%*

* = Projected

The Shipyard is committed to reducing costs and the time to overhaul SSN 688 Class ships. Only by attacking the costly and time-consuming processes, project by project, and getting everyone involved can the shipyard achieve its goal. As shown by the figures above, the shipyard is making progress and still has a long way to go.

Significant Improvement Projects

Pearl Harbor's strategy on specific high cost SSN 688 Class processes is to:

(1) Identify high cost job orders by comparing our costs with the NAVSEA Cost Estimating Standard (CES) and those of other shipyards.

(2) When appropriate, break down the costs of the large complex processes into smaller segments to determine where the higher costs are originating.

(3) Assign a project team of managers close to the process to streamline it and eliminate the excess fat.

The above approach is best exemplified by the Special Hull Treatment process. The shipyard has recently completed its first of six scheduled ships. Cost figures are significantly less than original estimates, and below all other activities involved in this process. At the 70% completion stage, the second ship cost indicators suggest further significant reductions in total cost. Pearl Harbor has set an example for this process in the ship repair and overhaul industry.

Reasons for this success include:

(1) The work was packaged into nine zones that allowed accurate tracking of costs. Accurate and honest charging was achieved; this allowed the process to be controlled.

(2) A project team was established early on to improve this process. The process was flow-charted extensively to better understand how the process worked and determine where improvements could be made. Improvement actions have been implemented and significant cost reductions have been documented.

(3) People close to the process have created an on-going process improvement attitude that has developed a pride that fosters continuous improvement.

The examples below are SSN 688 Class processes that have been identified and had project teams assigned. For those that have implemented at least one improvement action, cost reductions of 10 to 100% have been documented. Taking all improvement projects into account, approximately $15 million in actual savings and $30 million in cost-avoidance have been recorded. Further cost reductions are anticipated on these processes on future ship overhauls as the shipyard maintains its commitment to continuous improvement. Eventually, problem prevention and continuous improvement will become a way of work life for all employees.

Example Project Job Order Titles

Design Services
Design Support
Fire Watch Services
Certification
Built-in Tanks
Air Conditioning
Hatches
Propulsion Lube Oil Flush
Lighting
Ship's Service Motor Generator
Oxygen System

The above projects are only a sample of the 100 to 120 improvement projects currently in progress at the shipyard.

Implementation of a Total Quality Management

The goal is to actively involve all employees in the continual pursuit of quality improvement in shipyard processes. This new management style is modeling by the Shipyard Commander and the Steering Committee downward into each Department and Shop. In the same way, the Department Head meets weekly with senior Department Managers to identify and work on quality problems under their responsibility. Problems are defined, prioritized, quantified, and flow charted. Data is collected, analyzed, and decisions are made based on facts. Causes are identified, verified, and corrective action is implemented. To ensure that the actions are implemented to their satisfaction, tracking and monitoring is initiated. Further, data is collected to ensure that improvement in the process actually occurred and that gains are held. This Departmental Management Team becomes the example and steering arm for process management to evolve downward into the middle management level. As other managers and employees see top management actively participating, and as this evolutional process continues, the entire workforce will eventually become involved and committed to continuous involvement and thereby ensure the ultimate success of the shipyard.

To date, the Steering Committee and the Process Review Board are the two driving forces molding the Process Management System in the Shipyard. Shops and Departments review their improvement projects before they are presented to the Process Review Board. Not all Department Heads and Senior Managers meet on a weekly basis. Middle management participation is still fragmented at this stage of development, and it includes involvement on interdepartmental and department projects. The current number of 100 to 120 improvement projects represents involvement of about 10-12% of shipyard employees. As yet, no concerted effort has been initiated at the workforce level. Once all managers have been trained and are actively involved, then the workforce will be addressed. Currently, 600 of the 800 shipyard managers have attended the three day basic introduction.

Areas for Improvement

As the shipyard takes advantage of the outside consultants' expertise, the following areas will be addressed in greater detail:

(1) Statistical Methods. The internal consultants will learn statistical methods in depth and begin to apply them in their shop or department.

(2) Union. The relationship between management and the union is seen as adversarial and requires considerable improvement. Steering Committee members have been appointed to discuss union concerns with anticipated changes resulting from policy to proceed with the program. It will require the union be kept well informed regarding process improvement changes that affect the workforce. Several union officers have attended the training program and have expressed agreement with the direction.

(3) Deming Principles. The Steering Committee plans to establish subcommittees to address the 14 points in detail. In particular, hard spots will be identified as they relate to the rules and regulations that exist in the Federal and Navy systems.

(4) Constancy of Purpose. In order to prevent the constancy of purpose from being jeopardized by the eventual reassignment of the Shipyard Commander in the summer of 1988, it is critical for the Steering Committee to ensure that the program survives the transitional nature of military managers at the shipyard.

CONCLUSION

People close to the implementation process inside the Shipyard see the effort moving forward very slowly; authoritative sources outside the shipyard believe the shipyard is moving too quickly. 1987-88 will be a major thrust forward as the outside consultant will be assisting the shipyard full time. Top management will tackle the 14 points in detail, and the 25 "internal consultants" managers trained in SPC will apply statistical methods in their departments. In addition, new project teams will be formed and trained by the consultant. Therefore, the expectation at this time is through the combined efforts of all these groups, the pacing between theory and practice will become more balanced.

There is no turning back. Pearl Harbor Naval Shipyard must reduce costs and be competitive to stay in business. A new management style is evolving, but not until future cost indicators are evaluated and full employee participation is realized will the extent of the success of the effort be known.

ADDITIONAL RESOURCES

Video Cassettes (Rental/Purchase)

University of Michigan
Transportation Research Institute
2901 Baxter Road
Ann Arbor, MI 48109

ATTN: AVMAST Library Coordinator
Phone: (313) 763-2465

ED18 Statistical Techniques for Quality and Productivity in the Shipbuilding Industry (Session 1)

ED19 Statistical Techniques for Quality and Productivity in the Shipbuilding Industry (Session 2)

ED20 Statistical Techniques for Quality and Productivity in the Shipbuilding Industry (Session 3)

ED21 Statistical Techniques for Quality and Productivity in the Shipbuilding Industry (Session 4)

ED22 Dimensional Accuracy Control and Statistical Methods

DE2 A Call to Arms by William Conway

DE3 Why Productivity Increases as Quality Improves

DE4 The 14 Steps Management Must Take, Part I

DE5 The 14 Steps Management Must Take, Part II: Obstacles to Success, I

DE6 Obstacles to Success, II

DE7 Uses of Control Charts

DE8 Discovery and Correction of Faults of the System, Part I

DE9 Discovery and Correction of Faults of the System, Part II

DE10 New Principles of Training and Supervision (I)

DE11 New Principles of Training and Supervision (II)

DE12 Quality and the Consumer Inspection of Incoming Materials and Products, I

DE13 Inspection of Incoming Materials and Products, II

DE14 Quality and Productivity in Service Organizations

DE15 Operational Definitions, Conformance, and Performances

DE16 Dr. Deming Discusses Quality and Productivity with Dr. Myron Tribus

DE17 William Conway, President, Relates the Nashua Corporation's Experience

DE18 Action Plans for Implementing Quality and Productivity (Part 1)

DE19 Action Plans for Implementing Quality and Productivity (Part 2)

DE20 Action Plans for Implementing Quality and Productivity (Part 3)

USN43 Quality Circle/A Time for People Building and Management Support

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Streamlining in a Competitive Environment

No. 10

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ABSTRACT

The push for streamlining the acquisition process has been complicated by other legislation such as the Competition in Contracting Act. Acquisition strategy decisions are often influenced by the real and perceived incompatibility between legislative actions. There are courses of action that can be taken to satisfy both sets of requirements and keep risks to a reasonable level.

The acquisition of a weapons system is one of the most complex management endeavors in today's society. Legislation and policy guidance frequently seem to invoke conflicting, or at least incompatible, requirements on both the Government program manager and the prime contractor. Requirements for competition, the Competition in Contracting Act (CICA), the push for streamlining, and the need for standardization and component breakout frequently seem to be at odds with one another. The problem is severe in the Navy shipbuilding community due to comparatively low production runs, complexity, and long production periods. Combine these requirements with the fact that once the shipbuilding contract is enacted the Contractor, not the Navy, is directly involved in the selection and purchase of the thousands of items of equipment that are used on board ship, and a true challenge results.

The CICA was enacted in 1984 as a means to reduce the cost of weapons system acquisitions. While much of it deals with Government procedural policies and practices, it has created uncertainty in the minds of many people as to exactly what is required with regard to competition. Summarized, CICA requires that Government contracts ensure that full and open competition takes place and the effectiveness of that competition be measured by market place response. The Federal Acquisition Regulations (FAR) also stresses the need to develop acquisition documentation with consideration for full and open competition. Legal decisions in the Federal court system have stated that the Government is obligated to encourage competition even if it increases net cost to the Government.

Much of the uncertainty focuses around satisfying the words "full and open competition" and not realizing the significance of the "market place response" factor of CICA. Many people believe that the only way to ensure full and open competition is to have a very detailed set of specification requirements that any responsible source can read, interpret and use to prepare a competitive bid. Requirements of the FAR tend to support this viewpoint. The FAR states that specifications shall be designed to promote full and open competition and that market research should be conducted to ensure that competition will not be restricted. This frequently turns the competition into a sealed bid cost competition which does not always result in the best overall value being achieved. The Government competes to obtain the best value, not just the lowest cost, and CICA was intended to clarify the point that competitive negotiation is a method of procurement no less acceptable than an award using formal advertising or sealed bids.

There are many different aspects to competition. It is imperative that the objective of the competition be defined. A detailed specification cannot be written to obtain new ideas, to sample the commercial market place, or implement emerging technology. Competition for these elements can be more flexible and open than for a well-defined commodity. As long as every contender has an equitable opportunity to present his case without prejudice, full and open competition has been achieved. The source selection process for a competition such as this is much more challenging and, obviously, cost is less of a deciding factor than technical superiority.

The Navy has had an enormous amount of recent success with competition. Shipbuilding proposals in a fixed price environment frequently come in under the Navy's cost estimate, although future claims may lead to some of those gains being given back. In Fiscal Year 1986, the Navy competed over 73 percent of its contracts at a cost of over $2 billion. Aside from aircraft carriers, and currently the Trident submarine, all Navy shipbuilding contracts are competed. Due at least in part to CICA, the Navy has set up second sources to create production competition; the CG 47 Class and the LCACs bear testament to this. This is true of non-shipbuilding Navy contracts as well, such as the Standard Missile; the Phoenix Missile; and the Tomahawk cruise missile which was split between General Dynamics and McDonnell Douglas providing for a cost reduction of 25 percent per unit. In cases where large capital investment is required, the Navy has had to provide production guarantees to entice the second source into the bidding. Legal interpretations of the CICA by the Federal court system have determined that the Government is obligated to take actions to promote competition. This has led to second sourcing of many weapon systems.

The President's Commission on Defense Management has some critical thoughts on the CICA. They believe that CICA has led to an overabundance of detailed requirements that reduces most competitions to a straight initial cost comparison, with the assumption by many that the Government must buy from the lowest bidder. The Commission believes that more commercial style competition which factors in past performance of both product and vendors, extra performance features, availability, and price needs to take place. The fear of violating the provisions of CICA has often led to increased work and risk in specification development to ensure that a quality product will be obtained, no matter what the past performance of the offerors has been. Typically, commercial companies will have a list of qualified suppliers whose performance has been sufficiently high that they are willing to waive some inspection requirements. The "full and open competition" clause of CICA does not prohibit the establishment of qualification criteria nor the evaluation of life cycle cost as opposed to initial acquisition cost. The full benefits of CICA will not be realized until the focus is placed on the quality rather than the quantity of competition.

Streamlining has been defined as any action that can be taken to reduce the cost or time to field a weapons system. The streamlining initiative also grew out of a desire to reduce the cost of weapon system acquisitions. Streamlining is a broad concept involving all facets of the acquisition process, emphasizing the critical review of all requirements and elimination of unnecessary ones, and the tailoring of the remaining requirements to satisfy needs, not wants. That is the streamlining requirement; often the perception is different -"the only streamlined specification is a two page specification, shipbuilding is different, our traditional specifications and drawing packages in detail are necessary for good competitive bidding, cut the package in half...etc." The litany goes on and on. Rather than these quantitative approaches (either increase or decrease) the focus needs to be on quality of information.

There hasn't been a Standardization in Acquisition Act as yet, but the benefits of standardization are fairly obvious. Standardization brings longer production runs and attendant reductions in cost and increases in the availability of spare parts. The entire mass production concepts of industry are based on producing large numbers of standard components and integrating them into finished products. Since the Navy buys comparatively few units, which have to last a long time, obtaining the full benefits of standardization is a major challenge. Military specifications were established to insure a high standard of quality and reliability and it was worth a premium price. Quality and reliability is as great a requirement as ever; however, significant strides in manufacturing processes and industrial consumer demand for equivalent standards have been made. While the military specification is meant to insure a standard of quality, it often freezes development of an item, and thus keeps a commercially unacceptable product in the marketplace. Further development or improvement in the product is no longer possible because it would not be in conformance with the specification. Military specifications usage should be reduced when they are not needed, and steps should be taken to improve their utility and currency when they are.

The Navy's program to use commercial type specifications or industry standards such as those promulgated by ANSI or ASTM whenever possible in lieu of military specifications is commendable and should be given top priority. The greatest way to achieve standardization is by maximum use of products from the commercial marketplace. DoD cannot duplicate the economies of scale possible in products serving a mass market, nor perpetuate the most efficient producers. Government Furnished Equipment needs to be addressed viz-a-viz true savings and standardization impact.

To a shipbuilder, Government Furnished Equipment (GFE) is hardware that he must design for and install based on technical documentation that may or may not be available when it is needed. Often the equipment is beyond the control of the Government's ship building program manager. There are very real reasons espoused for GFE such as interclass standardization, economy of scale, and implementation of emergent technologies; its acquisition process is every bit as challenging as that of the ship it operates on.

Periodically, the United States Navy invests in new classes of ships. This may be to take advantage of emerging technology, to satisfy new operational requirements and meet new threats, or to replace older ship classes going out of service. The development of a new class of ships is one area where streamlining techniques and innovative procurement strategies can be employed. One major thrust of streamlining is to take advantage of knowledge gained by industry from years of production. By carefully focusing Government requirements on needed performance in critical areas, industry will still have the flexibility to provide varying innovative solutions while still functioning in a competitive environment.

There has been an increase in the number of ship acquisitions where a Circular of Requirements (COR) is being used in lieu of the full specification and drawing package. The T-AGOR Class is a good example of this approach. The COR is broad enough to allow different hull forms such as SWATH, or a monohull or a converted monohull, as long as mission performance requirements can be met. T-AGOR proposals that satisfied the COR were submitted and evaluated and a contract was issued. A similar technique was used by the United States Coast Guard to obtain their Island Class patrol boats. In this program one of the major requirements was that the boats be a proven design, in current operation. Designs were not limited to American craft. A foreign design was selected, and American shipyards were required to obtain a license to the design and tailor it to suit the shipyard's procedures. Competitive bidding to a common baseline took place against the tailored, proven design. Cost was still the major determining factor between offerors. Strict warranty provisions written into the contract have ensured overall product quality. In both of these cases the Government had little control over the tailoring of the contract design package.

The COR approach is also being used for two step acquisition approaches where the Government has the opportunity to filter out the number of designs to be evaluated and to provide inputs. This approach was used on the MSH program and is planned for the new PXM program. While the MSH program has been cancelled for a number of reasons, the Government Accounting Office commented favorably on its streamlined acquisition policy. The PXM program plans include NAVSEA ship design standards as an integral part of the COR. The consideration of offshore designs for MHC and PXM, albeit with construction in the United States, provides the Navy with the opportunity to use foreign, international and NATO standards for ship design.

The key element in handling a streamlined acquisition such as this is the source selection process. This acquisition technique leads to different approaches being employed to satisfy the same problem. Weighing factors for improved technical and logistic performance must be developed in advance of the RFPs so they can become part of the multiple design equations to be solved. In the case of the PXM which has a cost ceiling, the true goal of the source selection is to obtain the best overall ship for the money to be invested.

The Navy's traditional specification and drawing package for shipbuilding provides a good framework for competitive bidding but requires streamlining. Overall ship configuration and machinery selection requirements are covered in sufficient detail to ensure that all responsible parties have a fair opportunity to bid. Specific ways to incorporate some of the streamlining initiatives into NAVSEA's specification and drawing packages were discussed in our last paper.[1] This package is updated during the detail design and construction phase of the acquisition cycle to reflect the current configuration of the ship and to act as a baseline for procuring the additional ships of the class.

The Navy does not introduce new classes of ships very frequently. Procurement of a number of similar ships allows the cost of detail design to be amortized over a greater number of hulls and allows the benefits of equipment and system standardization to be realized. Since the acquisition package for the follow ships of a class has been reviewed and refined, the specification and drawing package, supported by the lead yard technical documentation, is tailored for competitive bidding in a production environment. Streamlining efforts here are mostly focused on the elimination of lead ship data and testing requirements that are not necessary for the production version of the ship. This amortization of detail design over a number of hulls has led to the development of the "modified repeat" classes of ships. The CG-47 class is a "modified repeat" of the DD-963 class and the LHD from the LHA. While there was great similarity in hull form and the machinery plant, there were significant differences in the combat systems area. Still, time was greatly saved during the design phase and greater machinery standardization was realized. This approach permitted the new requirements, CG-47 and LHD, to be satisfied in a much quicker fashion than starting from scratch.

A more current example is the LSD 41 (CV) design. The ship closely parallels its parent, LSD-41, except for the decreased size of the well deck to allow greater cargo cube capacity.

Streamlining techniques used for this design were based on past practices with a new wrinkle. The LSD-41 Class has been built by two different shipbuilders. One shipbuilder was selected as the contract design agent for the variant and the other was paid to review and comment on the design so that lessons learned from both shipbuilders could be incorporated into the design. The contract design package for competitive bidding will be common to a large degree with one that has already been used to build eight ships. Saving time is also a major goal of the streamlining initiative and detail design time will be reduced since so much of the ship is identical to the current version of the class and the real ship can be used as a baseline for designing and evaluating the changes.

Ship conversions and modernizations have long been a prime area for the use of CORs and work packages. In most cases major engineering design and systems integration is not required and there is a live ship to prepare a detailed package against. The T-AKR program used a streamlined COR approach that was reviewed by six different shipyards and comments were integrated by the Navy. The competitive package was successfully prosecuted and the six ships were delivered early and under budget. The conversion of the T-ACS crane ships was handled by the development of a commercial style work package which itemized in detail the work to be performed in converting each ship. Again the streamlining benefits were in the area of time savings - work was able to commence almost immediately upon the ships' arrival in the yard.

While ships are the largest single item procured by NAVSEA, the equipments and systems contained in those ships that have to be repaired and replaced during a ship's life are a major cost element. The selection and competitive acquisition of most shipboard equipment is the responsibility of the shipbuilder. While the Navy invokes the top level performance requirements, the shipbuilder satisfies those requirements with hardware. The fixed price environment of most shipbuilding contracts today makes competition for price benefits of paramount importance to the shipbuilder. Because price is such an overriding factor in this environment the Navy frequently believes it must rely on detailed military specifications to ensure product quality. This is the exact situation the Packard Commission was talking about when it addressed the negative impacts of CICA.

The Navy has a list of qualified suppliers for some of its equipments in its Qualified Products List program. This program, however, is limited to equipments that have testing periods in excess of thirty days, require uncommon quality inspection equipment, or are directly related to personnel survival or emergency life saving. This is an expensive program for the Navy to administer due to the cost of testing required, but quality products are ensured. This program does not, however, cover the majority of the vast amount of contractor furnished equipment on board.

One major requirement invoked on a shipbuilder for component acquisition deals with NAVSEA's Standard Components List. This document is a compilation of commercial components or equipments which are installed in at least one ship of the fleet. It is provided as an aid in the selection of components, but the Government does not warranty that any of the equipments listed

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[1] C.H. Piersall, Jr. and C. Sinche, "Streamlining of Navy Procurement Specifications", Ship Production Symposium, 1986

provide satisfactory performance; some of them may actually be classed as "bad actors." It might be better to develop a preferred sources list to accompany each new ship class acquisition package. As long as there are multiple vendors for each piece of major equipment, and alternate sources are not forbidden, a preferred sources list could streamline the acquisition, aid in interclass standardization, and correspond to the intent and letter of the CICA.

The truth is standardization is not achieved just because something is made GFE. There is more often than not, a "better" modification to the hardware which then renders it inconsistent and incompatible with the documentation.

Large quantity buys by the Contractor offers the greater opportunity for standardization in that there is no incentive for the contractor to procure different for subsequent ships than for the original. Where a different builder is constructing follow ships, the major equipments and systems from the lead ship can be specified by the Government to be purchased for all ships of the class under procurement. Only a strong resistance to change modifications insures standardization, regardless of the procuring activity.

Since the Government competes the initial contract for system design and development competition becomes a non-issue until a stable production baseline is reached when second sourcing becomes practicable. The use of a streamlined acquisition package in the early phases of selecting a solution for an operational need is virtually mandatory.

SUMMARY

The emphasis on acquisition streamlining is fairly recent even if some of the techniques predate the initiatives. As in all new endeavors lessons are learned and techniques refined. From our perspective there are a few significant lessons that have already become apparent.

1. Requirements for future production baselines must be defined up front at the start of the acquisition process.
2. The source selection criteria and process need to be defined up front and agreed to by the major players in the acquisition hierarchy.
3. Streamlined does not automatically mean shorter documents or fewer references. It means starting with a zero base and specifying only that which is essential to performance and supportability.
4. The overall focus must stay on the bottom line; cost to produce and operate and time to field.

Competition has long been a way of life in the shipbuilding industry, both for shipbuilders and major equipment vendors, whereas the thrust for streamlining has been more recent. The current environment, with the Navy providing virtually the entire shipbuilding market, makes competition all the more intense. It is an environment creating big winners and big losers. A long term shipbuilding program such as the CG-47, DDG-51, SSN-688 or LSD-41 and its variants guarantees a stable base for a shipyard to grow on, and to maintain strong engineering base plan for the future. There is a strong parallel in the effects on the producers of major equipments that get selected as the class or Navy standard. They also achieve a steady backlog of work to enable them to invest in becoming more efficient. The Navy also gains as a result of increased standardization between ships of a class and the corresponding decrease in logistic efforts.

What happens to the losers, however? They are frozen out from the long term work associated with major shipbuilding programs, and the competition for repair and conversion work of the ship classes with fewer ships becomes even more intense. Without the relative guarantee of a stable workload, investment in productivity increases becomes riskier, if not impossible. This situation puts the industrial mobilization base of the United States in a vulnerable position.

There are some possible remedies to the situation. Team or consortium bidding and shared production has become commonplace in the aircraft industry as a way to mitigate the all or nothing situation in competitive bidding. A similar approach could be used in shipbuilding. Two or more yards bidding as a team for a long term Navy program could well produce tangible time and cost savings. A more universally usable detail design package could be developed and equipment ordering and scheduling could be distributed and coordinated, thus minimizing the requirements for personnel surges and relocations. At one time a Gulf Coast shipyard built the bow and stern sections for Great Lakes ore carriers and sailed them to the lakes where they were mated with large midbody sections produced at another shipyard. This may be an extreme case of shared production, but having one yard integrate the main parts of the combat system on all ships of a class while splitting HM&E

production could be a realistic scenario.

To achieve standardization and preserve the industrial base for quick mobilization, the Navy needs to continue to develop additional standard equipment. For the Navy to obtain the maximum benefits from competition, larger production runs and improved spare parts availability will be required. The standard equipment must be compatible with industry based standards - in effect, a militarized version of a commercial product or purely commercial when possible. To obtain the maximum benefits from the streamlining initiatives, the Government must remain flexible and innovative in the acquisition process to satisfy specific needs and not become locked into methodology without necessity. Incorporating all of the policy guidance is a major challenge, but if consideration is given to when the various guidance elements are applied during the acquisition process, it is possible to reap significant benefits.

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Implementing Technology—Viewing Management's Task in Today's U.S. Shipbuilding Industry

No. 11

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ABSTRACT

Competitiveness (foreign and domestic) is continuing to present formidable challenges to management in the U.S. shipbuilding industry. The implementation of advanced technologies, especially software technologies, requires a special understanding by management. Based on material from two National Shipbuilding Research Program workshops, a view of the socio-technical goals and objectives for shipyard management are presented.

INTRODUCTION

This paper is based on work that was done by the author, and others, during two workshops held in Ann Arbor, Michigan in late summer and fall of 1986. The workshops, entitled *Implementation of Advanced Technology in the U.S. Shipbuilding Industry*, were based on the premise that the technology gap that exists today between U.S. shipyards and their overseas competitors is one that is caused primarily by software technologies. The direction and sponsorship of these workshops was provided by the Ship Production Committee's Design/Production Integration Panel (SP-4) and the Education and Training Panel (SP-9) of the National Shipbuilding Research Program. The process of implementing change, which was the focus of the workshops, provides a framework for viewing management's goals and objectives in dealing with the socio-technical organization of today.

Like other manufacturing industries in the U.S., the shipbuilding industry has had many advances in production techniques over the last twenty years. That period signalled the awakening of the shipbuilding industry to better methods of building the product and to the challenge of incorporating the associated technologies. Complicating this task, the new technology must be incorporated in a time of shrinking market demand that forces a compression of time and money resources.

It has therefore become the task of the entire organization, led by management, to deal with change. The goal is to transform the manufacturing process to promote market share growth while maintaining, and more ideally, enhancing the quality of the product. The technologies associated with this transformation have been identified as primarily "software" in nature.

A definition of software technology, the technology transfer process, and the structural elements of the production operation follow in the next two sections. Secondly, a discussion of resistance to change leads to modeling management's evolution toward the goal of being "externally supportive" to production operations. The emerging role of marketing and the product-oriented organizational structure are discussed. Finally, a road map for change is suggested through the development of company-wide quality control.

DEFINING SOFTWARE TECHNOLOGY

A global definition of technology (from anthropology) is that technology is the body of knowledge available to a civilization--knowledge that is of use in fashioning implements, practicing manual arts and skills, and extracting or collecting materials. A working definition of advanced technology (for the purposes of this paper) is that it is simply any existing process not commonly utilized, that improves production productivity: i.e., make it sooner, make it faster, make it better, reduce the cost, and meet legal requirements of work place safety and product liability.[1]

The subject of technology can be broken down a number of different ways. In discussing production manufacturing technology, it is most convenient to separate it into hardware and software.

Hardware
  Machines
  Tools
  Materials
  Facilities

Software
  Procedures
  Workers' Skills
  Techniques
  Organization of Work

New hardware technologies continue to become available (a new burning machine, CAD/CAM tools, etc.) and will continue to improve productivity; however, each piece of hardware must have its associated software interface into the production process. This supporting interface, which can be responsible for realizing the full benefits of a piece of hardware, is too often an after thought. It has been proposed that because software technologies have taken on a subordinate roll, they are considered to be the primary cause of the competitive gap between the U.S. shipbuilding industry and its foreign counterparts.[2] The advanced software technologies that must be brought into the mainstream of decisions include:

- quality control,
- planning,
- production control,
- production engineering,
- design for production,
- product work breakdown at the design stage,
- standardization of the product,
- progressive management techniques,
- standardization of procedures,
- material control, and
- management information systems.

THE TECHNOLOGY TRANSFER PROCESS

To survive in today's market, there must be a transfer of advanced technology. This transfer can be viewed as having four distinct stages:

1) Initial Awareness,
2) Evaluation,
3) Adoption, and
4) implementation (including follow-up).

Fundamental changes resulting from the implementation of technology (hardware or software) affect the organizational structure, communication patterns, reporting relationships, work rules and job definitions, new attitudes and positions, etc., within the shipyard.

The introduction of a software technology (e.g., the move from viewing the ship as the product to the concept of group technology that requires an interim product focus) is especially difficult since it is less tangible then a new machine or building basin. Thus, it is often not clear what has changed and/or to what degree the organization has been affected. These unknowns typically retard the implementation process. The delay in realizing benefits from a project (or worse, the actual failure of a program) leads to management frustration with unrealized goals and objectives.

The resulting disruption from attempts at technology emplacement often has the most undesirable result of all: a "backlash" reaction against further endeavors at technology implementation and a deeper entrenchment of the traditionalists within the organization. The first three stages of technology transfer can happen with minimum disruption to the firm; however, to avoid the "backlash" reaction during or after stage 4, management must appreciate the extent to which a new production concept affects the structural elements of the production operation.

THE STRUCTURAL ELEMENTS OF PRODUCTION

A useful generalized framework for production operations has been outlined by Steven Wheelwright at the Stanford University Graduate School of Business[3] and is shown in Figure 1 below. This framework relates the organizational scope to the external and internal environment factors within which the firm must operate.

The Structural Elements of Production

	Structure ("Hardware")	Infrastructure ("Software")
MACRO (COUNTRY)	1. GOVERNMENT Fiscal/Tax Policies Monetary Policies Trade Policies Industrial Policies	2. SOCIETY Culture Traditions Religion Values Social Behavior
MICRO (COMPANY)	3. FACILITIES Plant & Equipment Decisions *Site,Location *Technology Vertical Integration	4. POLICY & PROCEDURES Workforce Policies Management Selection & Development Organization Structure

Figure 1: The Structural Elements of Production
Adapted from Wheelwright, Reference [3]

The first two quadrants represent the external environment that affects the organization. Quadrant 1 depicts the external "industrial policy" hardware, while quadrant 2 deals with the infrastructure software aspects (culture, traditions, and social behaviors) of workers and consumers.

The last two quadrants represent the more traditional company level (internal environment) view of production operations. Quadrants 3 and 4 divide the internal environment factors into the hardware and software resources of the production operation.

Management responds to change by controlling the resources in the internal and external environment depicted in all four quadrants. The management responsible for production operations within the company has control (for the most part) only over those hardware and software resources listed in quadrants 3 and 4. Quadrants 1 & 2 are not to be ignored (as they often are); they must be well defined by executive management to avoid conflicts between the macro- and micro-management of the organization.

Wheelwright states that there are usually three driving forces creating the necessity for change and for improvement of production operations: a need for

(1)greater capacity,
(2)new products, and
(3)profitability.

The short term solutions of yesterday signal a change in production hardware when one of the above forces is out of control: that is, pumping resources (typically in a reactionary mode) into quadrant 3.

However, the increased competition and higher cost of capital today requires long-term solutions that address all of the structural elements of the production operation. The changing of quadrants 3 and 4 in harmony requires that the organization use a "socio-technical systems" approach to management.

The Organization as a System

The term "socio-technical" system is used to describe the systems approach to the organization based on the theory that the technological system works only within the context of the worker's social system. A systems approach in general denotes an approach that recognizes that an alteration of a part of the system, alters the whole.[4]

When an organization uses the socio-technical systems management approach, analysis of the productivity of both the social system and the technical system must take place with a recognition of the interdependence of the two. The social system is examined to determine and improve organizational roles and their interrelationships. The technical system is analyzed to obtain maximum benefit from the machines, tools, materials, techniques, procedures, and skills used to do the work.

There is an increasing use of the socio-technical systems approach to organizations in the U.S. manufacturing industry. The fundamental change required by the traditional organization is a long, complex, and expensive procedure. The two major roadblocks to such change are the incongruous managerial system already in place, and the basic human tendency to resist change. The benefits of overcoming these roadblocks and implementing the change result in an organization that is flexible and highly motivated, and one which provides satisfaction to its work force.[5]

RESISTANCE TO CHANGE

Roadblock #1—The Incongruous Managerial System

The over-simplification of work, and the vertical orientation of departments that resulted from the management theory implemented in the early 1900s, left workers alienated from the organization. Productivity improvements traditionally focused on the technical system, as described earlier, without regard for necessary changes in the social system (e.g., in job roles or organization design).

The process of implementing change is an especially difficult one to accomplish in the traditional organization. The company is organized in a number of autonomous businesses, each with responsibility to its own results and its own contributions to the total company. Many firms have reached a point of dividing up the work so that they now suffer from communication blockage—analogous to the onset of osteoarthritis in the human body.[6] This is depicted in Figure 2 below: the horizontal lines represent the layers of management and the vertical lines the division of the functional departments. At each crossing, communication blockage occurs both vertically and horizontally.

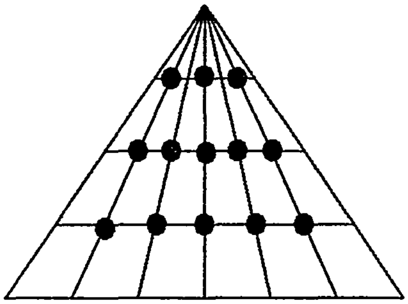


Figure 2: Communication Blocks

Workers in a traditional organization are living in their own narrowly defined "arthritic boxes"--at all levels of the organization, across departments, divisions, and segments of production. It has been programmed into these organizations that, if "I do my job - you do yours," the work of the company would get done. Over time, the functions and levels become so separated that they often send conflicting objectives or tasks up and down the "functional chimneys".[7]

For manufacturing and production organizations communication problems are compounded by this highly hierarchical organizational structure as two distinct levels have evolved: operations managers and technical specialists.[8] Add to this the complex product (such as a pre-outfitted ship subassembly) that must move across the functional departments, and the result is that everyone in production operations becomes protective and concerned about keeping track of his/her own "rice bowl", rather than the company as a whole.

The system itself, not the personnel, is at fault for creating this protectionist environment. Executive management directs the operations managers to meet certain requirements. Operations managers then specify to the technical specialists what needs to be done to meet these requirements. However, because of the evolution of specialization that has separated business administration from production, management is out of touch with production capabilities—yet it is directing what, when, and how to produce the product. (It should be noted that this separation has been supported to a large extent by academia teaching that "a good manager does not need to understand what he/she manages", and engineering curriculums that do not address management development skills).

The technical specialists in production (Production Engineering, Industrial Engineering, Materials, and Information Systems) work only toward meeting the requirements and expectations set forth from above. There is no encouragement or impetus to improve the system in general. Executive management vision focuses only on what has been presented to them. For the most part, these are problem areas where performance has fallen below expectations. There is no room for improvements to the system because of what Peter Drucker refers to as the lack of "entrepreneurial practices".

> "...problems have to be paid attention to...but if they are the only thing being discussed, opportunities will die of neglect. In fact the business and its managers, focusing on the "problems," are likely to brush aside the unexpected success [an innovation source] as an intrusion on their time and attention."[9]

The entrepreneurial organization is defined by Drucker as one capable of searching for change (new technologies), responding, and finally exploiting (implementing) the change as an opportunity. If the structure of the organization does not support entrepreneurship and innovation, ultimately, production will strive to maintain short-term flexibility and take a conservative stance on most issues.

Roadblock #2--Human Tendency to Resist Change

The second major roadblock to change is often referred to as the basic "human nature" tendency to resist any change. Rosabeth Kanter, author of "The Change Masters", describes the ten most common reasons for this resistance:[10]

1. **Loss of Control** - the feeling of "ownership" being threatened.
2. **Excess Uncertainty** - not knowing if the next step is into the abyss.
3. **Surprise, Surprise!** - decisions sprung on people without groundwork or preparation.
4. **The "Difference" Effect** - habits and routines are broken.
5. **Loss of Face** - admitting that the way things were done in the past was wrong.
6. **Concerns About Future Competence** - personnel questioning their skill levels and whether they will fit in.
7. **Ripple Effects** - impacts outside the project or even outside the job.
8. **More Work** - more work that is not usually recognized may be required.
9. **Past Resentments** - a past gripe against the organization may cause resistance to change regardless of what the change is.
10. **The Threat is Real** - change usually results in some winners and some losers.

Implementation of technology requires that these reasons for resistance to change be recognized and manipulated in such a way that the forces of change are all moving toward the organizational goal of transforming the production operation.

A model that describes the forces of fundamental change was developed by R. Beckard in the late 1960s. Paraphrasing his model[11], one can describe resistance to change (R) to be a function of three factors: dissatisfaction with the present (D), a vision of what is possible (V), and the first steps in reaching the vision (F). For change to occur, the product of these three factors must be greater than the resistance to change.

$$D \times V \times F > R$$

Although, dissatisfaction-with-the-present (D) can be of great magnitude in the traditional organization, its cause is usually not agreed upon. Additionally, the autocratic style of management that prevails in the traditional organization does not support team vision (V) and first steps (F).

Participative management within the socio-technically oriented organization is the means for developing factors that produce change in the right proportions (i.e., allowing for a common employee data base about: (1) how everyone in the organization sees the past and why a change is needed, (2) what the future could be and what is preferred, and (3) what steps can be agreed upon in order to effect change.)

However, as many U.S. manufacturing firms have discovered, using the words "socio-tech", "participative management", or "quality circle" is not enough. Organizational change (in terms of people, attitudes, and structure) must take place.

DIRECTIONS FOR MANAGEMENT

Managing the transition of organizational change requires the development of a strategy. A detailed examination of the external and internal environment must be made. The vision of where management thinking regarding where the production operation is headed must be visualized. A model of the evolution of management thinking provides basic goals and objectives for developing a transition strategy.

The evolution of management thinking regarding production operations is suggested in a four-stage model[12] and depicted in Figure 3.

In stage 1, executive management is considered internally neutral. "Fire-fighting" is the order of the day as problems that stem from current production operations are minimized, and the function of management is to be flexible and in a reactive mode.

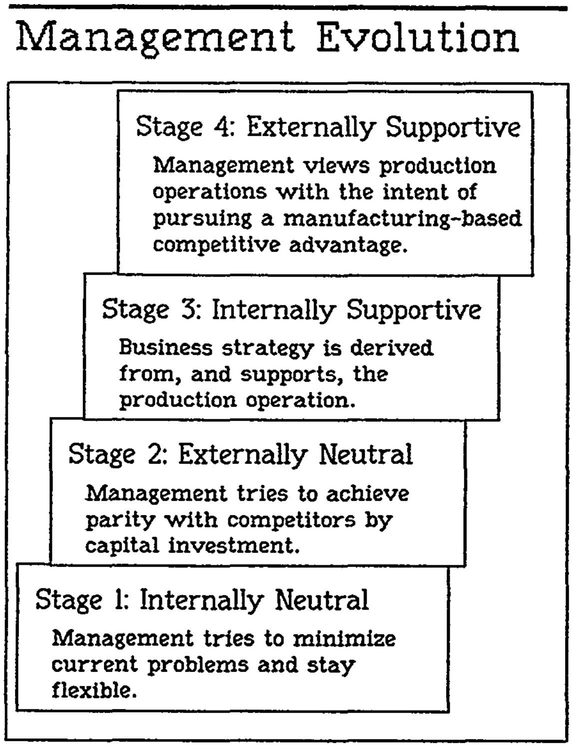


Figure 3: Stages of Management Evolution Regarding the Production Operation

In stage 2, management is externally neutral. Capital investment is used to try to achieve parity with competitors, and the role of production (as in stage 1) is essentially neutral.

In stage 3, management has moved into being internally supportive. Production operations has direct input into the business strategy by providing a screening of the decisions that are to be made. The role of production, however, is one that is derived after the other functions have developed their strategies and determined the macro-direction of the enterprise. The black books of estimating and planning are still intact.

The similarity between stages 1-3 is that production operations management itself is responsible for any improvements in moving from one stage to the next. As stated earlier, the lack of "entrepreneurial practices" does not provide the impetus to change. Production maintains a subordinate voice within the organization.

The final and fourth stage is referred to as externally supportive. At this level, general management changes its interface and views of the production operation with the intent of pursuing a manufacturing-based competitive advantage. Production operations now has a pro-active role in identifying and charting the course so that new technologies (hardware and software) can be applied in an integrated and systematic fashion.

The questions that management must answer for their particular organization are: "What is required to bring about a socio-technical system resulting in an externally supportive management?" "Is the functional organizational structure that has evolved, so backward that a drastic overhaul of the organizational chart is required?" If yes, "can the organization survive the impact of such change in today's shrinking shipbuilding market?" "Will such change only result in new lines and intersections for the communication 'arthritis' to take hold?" "What might be the alternatives and underlying objectives of needed change?"

THE ORGANIZATIONAL BINDER

One of the underlying objectives, as stated earlier, is the elimination of the communication blockages in the organization: i.e., the need for an organizational binder. In the following sections, three (not necessarily separate) directions for shipyard management are suggested: the emerging role of the marketing function, the product-oriented organization, and company-wide quality control.

The Role of Marketing

In support of the workshops that were the impetus for this paper, a Delphi survey was conducted to identify the major areas of change for the industry.[13] 74% percent of the survey respondents indicated that the functional role of marketing would change significantly in the next ten years. The following pro-active changes were stressed by the majority of these respondents:

* marketing will need to further develop the technical knowledge of ship production and shipyard capabilities,
* marketing will need to have intimate knowledge of customer performance requirements,
* marketing will be linked to technology development (R&D function) and strategic business planning,
* marketing will be more innovative and entrepreneurial.

Richard Bagozzi, Stanford University Graduate School of Business, explains this changing role of marketing as one of moving from a separate and parallel function to an integrative function that binds the rest of the organization together. In addition, marketing is taking on the role of providing strategic direction for the organization. This is a change from the mid-70s when finance, production, and engineering dictated strategy.

Marketing is assuming this emerging role as the forces driving the organization are changing--from financial and procurement considerations having center stage to fickle consumers, aggressive competitors, and an economy that no longer grows with prosperity unabated. A technically competent marketing department will allow the firm to impact these new driving forces.[14]

As will be discussed later in the section on company-wide quality control, the successful organization today is able to instill the "voice of the customer" throughout the organization. A marketing function that understands the firm's constraints allows for maximized opportunities by adapting these constraints to the customer requirements--something that has been lost in the specialization of the traditional organization.

Changing the Organizational Chart

Movement away from the functional organization is movement toward its counterpart: the product-oriented organization. R. Chirillo explains this in the NSRP report, "Shipyard Organization and Management Development":

> "Functional organizations, as an organization type, are best when a firm makes only one or a few products and where technology does not change. The traditionalists in shipbuilding look simplistically at the entire ship as the end product of the shipyard." The product-oriented organization, on the other hand is "...a structure based on a Product Work Breakdown Structure and Group Technology which permits diversification...aimed at interim products...that makes it possible for large firms to cope with technological change and multiple markets."[15]

The product-oriented organizational structure is depicted in Figure 4 for the IHI Kure Shipyard in Japan.

Choosing to shift to the product-oriented organization is dependent on many factors (product mix, volume, size, etc.) and the extent of the change will be different for each shipyard. The socio-technical systems approach to management suggests that the development of a shipyard's social system (the organizational chart) should complement the shipyard's technical system (the organization of work) for the full benefits of the technologies to be realized. The product-oriented system seems inevitable as the shipyards move into full implementation of group technology and zone-by-stage construction/repair.

The product-oriented organization provides a vision of what has worked. It is supported by a combination of the evolving management sciences; however, the key to realizing the full return on technology implementation will not be answered by change in the organizational chart alone. More fundamentally, full return is realized in the ability of the infrastructure to fully support what one IHI shipbuilding consultant referred to as the "passing of the baton."

Engineering does not redo what planning and estimating had guessed at. Production does not get the work done "in spite of engineering." The pay-off is in the elimination of the intangible rework that goes on everyday, rework that seems to be synonymous with a functional organization building a complex product.

This fundamental concept of the baton and the need for an organizational binder brings us to the newly established concept of quality that a manufacturing and production facility must understand to compete on the world market. The road map to the externally supportive management is clearly marked by what the Japanese refer to as company-wide quality control.

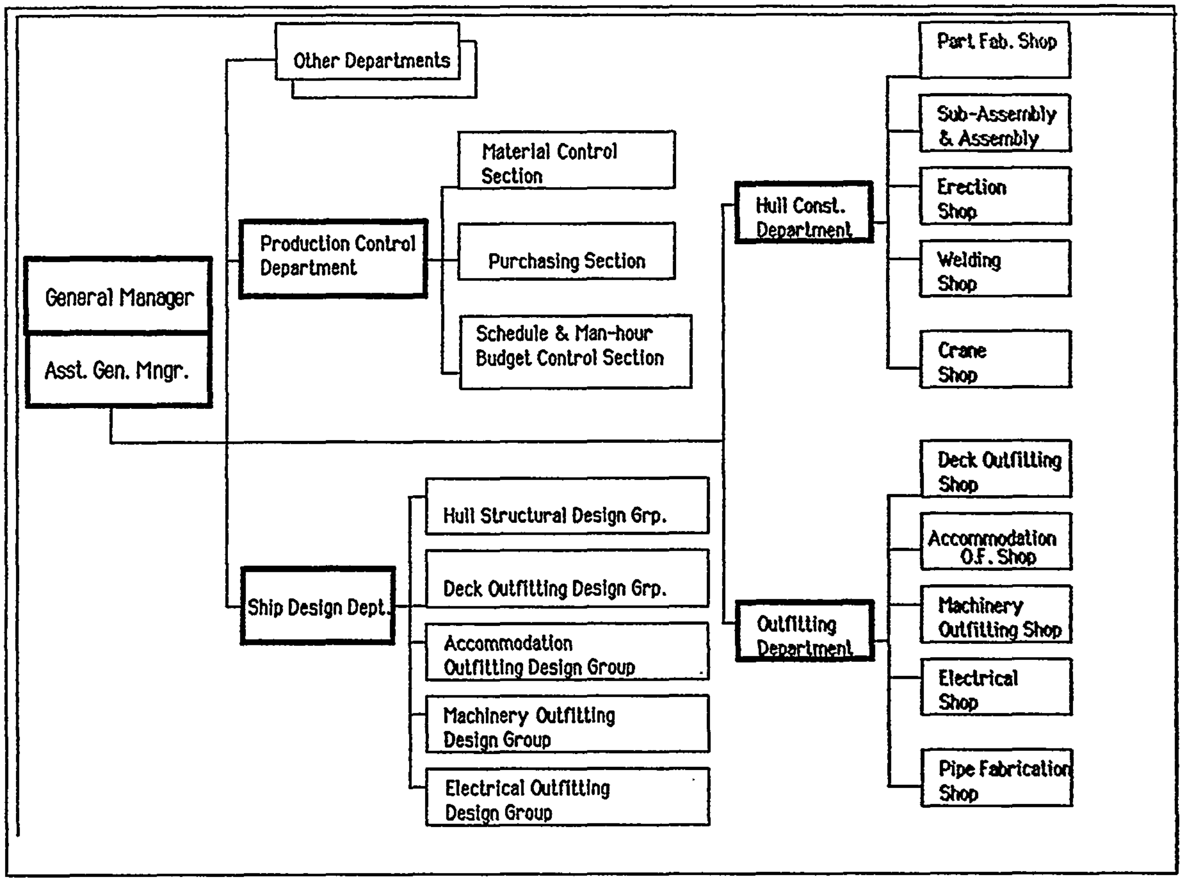


Figure 4: Product-oriented Organization for the IHI Kure Shipyard, circa 1982.
Source: Chirillo, Reference [14] page 21

COMPANY-WIDE QUALITY CONTROL

The Japanese Industrial Standard Z8101-1981 specifies quality control as: "a system of means to economically produce goods or services which satisfy customers' requirements...Implementing quality control effectively necessitates the cooperation of all people in the company, involving top management, managers, supervisors, and workers in all areas of corporate activities such as market research, research and development, product planning, design, preparations for production, purchasing, vendor management, manufacturing, inspection, sales and after-services, as well as financial control, personnel administration, and training and education. Quality control carried out in this manner is called *company-wide quality control*."[16]

The impact that company wide quality control (CWQC) has on the productivity of an organization is well documented, both inside and outside the shipbuilding industry. The evolution of the quality function has been modeled by L. Sullivan of the American Supplier Institute as having seven stages. This model is depicted in Figure 5.

Complete installation of CWQC refers to an organization that has moved from *manufacturing quality control* (inspection after production and/or statistical process control during production) to *product and process development quality control*. The result is that all operations are driven by the "voice of the customer". The impact on the organization is improved productivity and quality at reduced cost, and ultimately, competitiveness.

As depicted in Figure 5, Sullivan views U.S. manufacturing as somewhere in the first three stages of development. The U.S. shipbuilding industry, for the most part, can only be considered to be in stages 1 and 2.

It is the development of the humanistic side of quality that separates the U.S. concept of Total Quality Control and the Japanese style of CWQC:

> "In traditional U.S. quality literature, 'cost of quality' refers to the cost of assuring conformance and of managing

and correcting non-conforming material. In the CWQC definition, cost is the loss to society which is determined by design cost, efficiencies in manufacturing, assembly, sales, service, customer ownership, and the contribution to society."[17]

The stages of CWQC that go beyond the U.S. technologies provide the following:

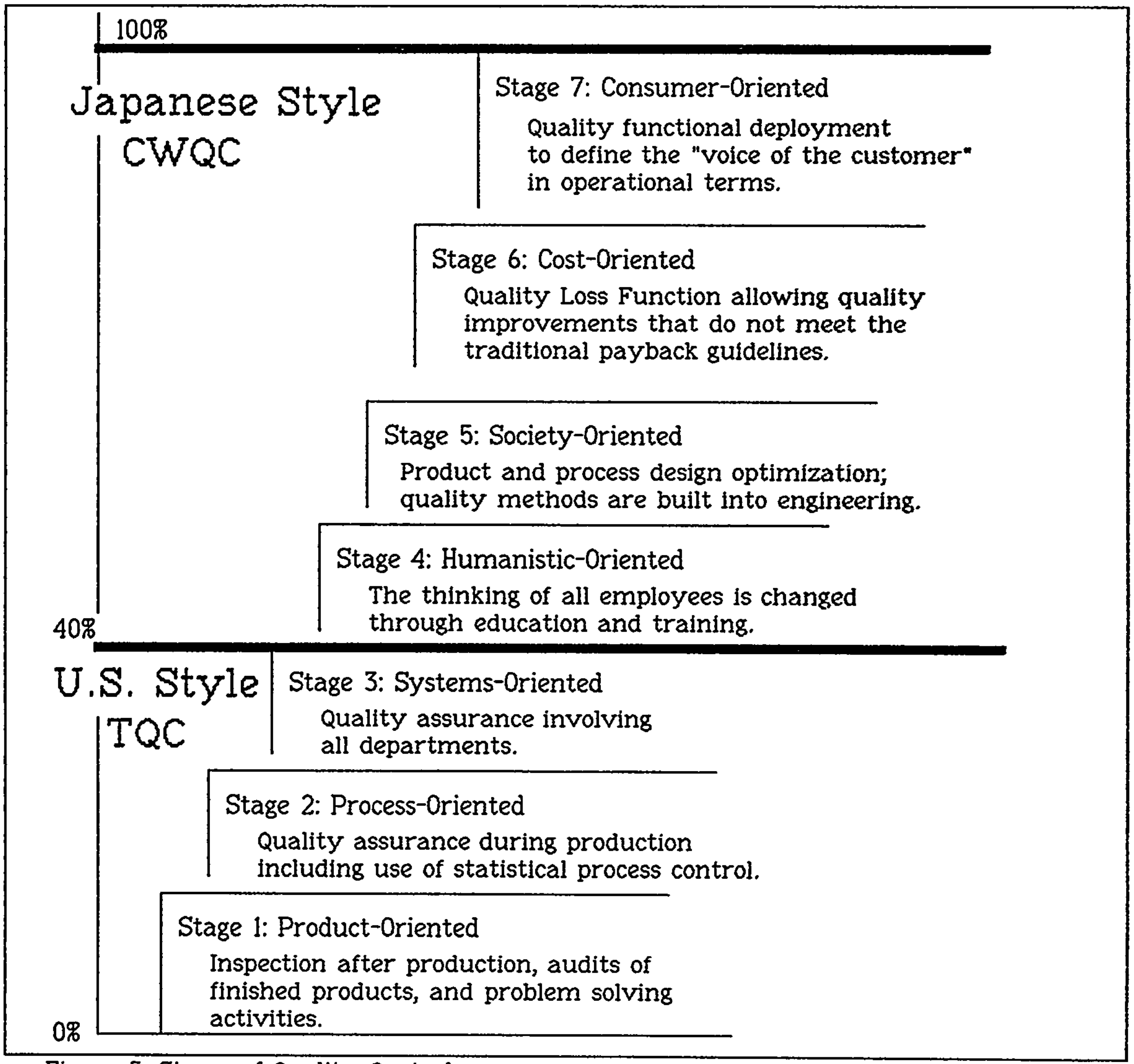
* Statistical process control to separate common causes of variability from special causes in such a way that the process can be changed to reduce variability.

* Education of the workforce that changes the way people think and recognizes process improvement flowing automatically from personal improvement.

* Society-oriented product and process design that builds quality into the engineering process.

* Cost-oriented loss function allowing quality improvements that do not meet the traditional payback guidelines.

* Quality functional deployment to define the "voice of the customer" (internal and external) in operational terms.



Stage 7: Consumer-Oriented
Quality functional deployment to define the "voice of the customer" in operational terms.

Stage 6: Cost-Oriented
Quality Loss Function allowing quality improvements that do not meet the traditional payback guidelines.

Stage 5: Society-Oriented
Product and process design optimization; quality methods are built into engineering.

Stage 4: Humanistic-Oriented
The thinking of all employees is changed through education and training.

Stage 3: Systems-Oriented
Quality assurance involving all departments.

Stage 2: Process-Oriented
Quality assurance during production including use of statistical process control.

Stage 1: Product-Oriented
Inspection after production, audits of finished products, and problem solving activities.

Figure 5: Stages of Quality Control

The management evolution model (depicted in Figure 3) and the socio-technical systems approach suggest that an externally supportive management is required so that new technologies can be applied in an integrated and systematic fashion. To get to this externally supportive stage, a breakdown of the product and process into an integrated mapping is necessary to provide continuous support for the shipyard in its development of organizational strategy. CWQC can provide such a framework through the systematic depiction of the "voice of the customer."

EPILOGUE

To the management on the front lines of today's shipbuilding industry the chord that may be struck by this discussion is that, "it is all easier said than done." This is no doubt true.

Steven Wheelwright notes that:

> "...whether one is looking at production planning and materials control, human resource management, or plant supervision, the critical tasks for the future are all very similar. These functions cannot be segmented and isolated, but must be integrated. Moreover, while these functions involve many small, seemingly minor day-to-day decisions, the cumulative effect of these decisions can indeed be substantial. Finally, it appears that when competitive advantage is based on such infrastructural arrangements in production operations, it becomes extremely difficult for competitors to imitate, because there are no short cuts to putting in place the infrastructures needed to realize these results."[18]

What is intended by this discussion is to affirm the need for top management's commitment, vision, planning and execution in the effective transformation of the the shipyard production process. In this continuous struggle to "get organized", new technology implementation must be done in a systematic fashion that avoids islands of efficiency. As stated by Peter Drucker, effectiveness and efficiency have a special relationship: "Efficiency means doing things right. Effectiveness means doing the right things. Doing the wrong thing efficiently is worse than useless. It can be very harmful."[19]

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Why Standards Programs Fail

No. 12

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ABSTRACT

Why Do Standards Programs Fail?

A general review of the failings of Standards Programs, with particular reference to shipyard programs. This review is focused on the reasons why some programs fail and others succeed.

Consideration is given to both the people aspects and the technical aspects. Comparison is made of theory and practice in Standards Programs, and how at times they appear to conflict.

Eight basic rules are given for successful Standards Programs. They apply whether you are installing a program, maintaining a program, or trying to revitalize a deteriorated program. It is stressed that failure to follow these rules is the main reason "Why Standards Programs Fail."

3 BASIC QUESTIONS
RE: PERFORMANCE STANDARDS

I. ARE THEY OF ANY VALUE?

II. WHY DO THEY FAIL?

III. WHEN DO THEY FAIL?

I. Are Performance Standards of Any Value?

(a) If they are of no value, the reasons for failure are irrelevant. They then are an unnecessary expense, should be cheerfully relegated to the wastebasket, and we do not need to consider why they fail.

(b) But if they are of value, what causes their destruction? What are the primary reasons for the large percentage of failures?

II. Why Do Performance Standards Fail?

(a) Are people the reason? Is it upper management, middle management or front-line management? Are the unions responsible, or the workers? Is it the staff -- production engineers, industrial engineers, human resource personnel? What role do the financial and marketing people play in the failure or success of Standards Programs.

(b) Are techniques the reason? Which standards techniques are apt to cause failures? Which ones are apt to succeed? How can you select the one most likely-to-succeed for a specific operation?

III. When Do Performance Standards Fail?

What are the early warning symptoms? Which symptoms are incurable? Which symptoms indicate curable problems? Which symptoms are readily curable?

ARE PERFORMANCE STANDARDS OF ANY VALUE?

The theoretical answer is "yes." In theory, Performance Standards help your planners do a better job of having good Planning Standards for (a) cost estimating; (b) production scheduling; (c) crew scheduling, etc. In theory, Performance Standards help production managers and foremen do a better job of (a) identifying and correcting poor productivity habits and inefficiencies by workers and crews; (b) avoiding bottlenecks; (c) evaluating and training employees, etc. Performance Standards, in theory, also help engineers (a) evaluate alternate methods, equipment and tooling; (b) provide factual basis for cost and savings calculations, etc.

Most important, Performance Standards - "in theory" - provide upper management and controllers with factual tools for cost control, budgeting, profit optimization and competitive operations.

IN THEORY? HOW ABOUT IN REAL LIFE?

The facts in real life often are:

1. Performance Standards don't exist.

-- or --

2. Performance Standards are suspect. The standards are not considered realistic; they are not in convenient format for use; they are confusing and not easily understood.

-- or --

3. The potential users are not aware that standards exist in a useable format.

-- or --

4. The potential users are not experienced in the use of Performance Standards. As a result, they don't use the standards or they use them incorrectly.

For the above reasons many shipyards have dropped or cut back their Standards Programs because they were not cost effective.

ARE PERFORMANCE STANDARDS COST EFFECTIVE? MAYBE?

Standards may be of value. But standards are not worth having if the Standards Programs cost more than they save. This can occur. Why? It can occur because

1. the Standards Plan as designed and implemented did not provide for effective use of the standards.

-- or --

2. the plan called for Performance Standards in areas where standards could not logically be cost effective.

-- or --

3. the Standards Plan was poorly designed and implemented so that seting the standards was time consuming and far too costly.

Too often, companies do not actually know whether their Standards Plan is or ever was cost effective. The following set of statistics in Table I represents the results we have been able to glean from a study of 210 locations that did track their Standards Programs savings and costs.

RESULTS OF 210
STANDARDS PROGRAMS

- **GOOD PLANS**
  25% - 50% NET SAVINGS.
- **AVERAGE PLANS**
  10% - 20% NET SAVINGS.
- **POOR PLANS**
  10% - 20% NET LOSS.

TABLE I

Variables Affecting Cost Effectiveness

The most important variable in the cost effectiveness of Performance Standards is in the improved productivity that can be achieved from their use. Table II shows the changes in productivity apt to occur from the use of Performance Standards.

PRODUCTIVITY/
VARYING OPERATING CONDITIONS
Based on over 1000 Productivity Audits and Work Measurement Installations.

PERFORMANCE MEASUREMENT	SUPERVISION POOR	SUPERVISION AVERAGE	SUPERVISION GOOD
MEASURED	60% to 80%	70% to 90%	80% to 95%
UNMEASURED	30% to 70%	50% to 75%	60% to 85%

TABLE II

The second variable that directly affects cost effectiveness is the time and cost of having Performance Standards. The actual times for setting Performance Standards can vary from immediately to seemingly forever. The costs can vary from low cost to exorbitant.

Why the great discrepancy in time and cost of setting standards? The most frequent reason is in the standards setting techniques. The difference can be startling as evidenced by the averages shown in Table III.

TYPE OF OPERATION	POOR TECHNIQUES	GOOD TECHNIQUES
Machining		
- up to 30 min. cycle	1 hour to 4 hours	5 to 10 minutes
- up to 10 hr. cycle	over 10 hours	5 to 30 minutes
Assembly		
- up to 30 min. cycle	4 to 8 hours	5 to 15 minutes
- up to 8 hour cycle	8 to 24 hours	15 to 60 minutes
- over 8 hours	1 week to forever	1 to 4 hours

TABLE III

There is a general rule of thumb that the manpower needed for good standards setting -- in areas appropriate for standards -- is:

1. one standards setter per 50 employees covered by standards in job shop or custom shop operations.

2. one standards setter per 100 employees covered by standards in production shop operations.

These would appear to be reasonable time and costs for standards setting,

IF there are good results from having standards.

DO YOU HAVE STANDARDS? YES ! !

You can bet your next launching that your yard has Performance Standards for all or practically all production activities. The only real question about the standards is: Are they derived from an official Standards Program or have they been derived at will -- by different people with different philosophies, skills and experiences?

If you doubt this statement: "A Performance Standard exists, formal or informal, for practically every activity in your operations," check that conclusion the next time you are out in the yard. Ask the first person you see how long a specific job should take. The answer will probably cover the following range:

- "I don't know, but the planners are sure off by a mile."
- "The last time we did it, it took about a day and a half."
- "I don't know, but I think it will take the rest of the afternoon."
- "The time for that job, about three per shift, is right on the money."

The question, in essence then, is not "Do you have Standards?" but "How good are the Standards?" The answer can be extremely important to your Company.

Predicted time values (whether you call them planning times, estimating times, guesses or engineered standards) can be extremely important to the competitive success of your Company and the job satisfaction of your employees.

Peter Drucker says it best:

> *"WITHOUT PRODUCTIVITY OBJECTIVES, A BUSINESS DOES NOT HAVE DIRECTION.*
>
> *WITHOUT PRODUCTIVITY MEASUREMENT, IT DOES NOT HAVE CONTROL"*

TIME, PRODUCTIVITY AND COST EXPECTATIONS

Table IV shows the multiplier effect on unit costs by dropping from 100% to 90% to 70% productivity. It shows clearly why a Company with 70% productivity may have a tough job competing.

PRODUCTIVITY EFFECTS ON UNIT COSTS

Productivity	Std.	Good	Poor
%	100%	90%	70%
Units Produced	100	90	70
TOTAL COSTS			
(a) D.L.Payroll @ $10/Hr.	$1000	$1000	$1000
Production O.H.			
@ 30% D.L. Payroll	$ 300	$ 300	$ 300
@ $7/D.L. Hour	700	700	700
@ $5/Unit Output	500	450	350
@ $1000/Hour	1000	1000	1000
General Overhead @ $2000/Hour	$2000	$2000	$2000
(b) Total Labor & Overhead	$5500	$5450	$5350
UNIT COSTS			
(a) D.L. COSTS	$10.00	$11.11	$14.29
Comparison	par	$ 1.11 extra	$ 4.29 extra
(b) D.L. plus OVERHEAD	$55.00	$60.56	$76.43
Comparison	par	$ 5.56 extra	$21.43 extra

TABLE IV

The practical effect on all aspects of your Company's operations from good productivity based on realistic standards is enormous. This is true regardless of the importance of labor costs in relationship to your overall competitive position.

Productivity is the engine that drives the ship. Poor productivity affects more than the direct labor costs.

Poor productivity can dramatically delay delivery schedules, tie up capital, play havoc with your unit costs and ruin your yard's competitive reputation.

We have seen many operations where productivity has been as low as 30% to 40%. Some of you have probably seen comparable poor performance, or at least down to a 50% to 60% productivity level.

If Time, Productivity and Cost Expectations can have such a large effect on the competitive position of your operations, what can you do to make your Standard Program successful?

The answer is basic. There is no mystery to it. The solution is so simple there is no fun in solving it.

All that is required for a good, cost-effective Performance Standards Program is common sense and hard work. That is not any fun. It does not solve any of the mysteries of the universe, it just merely makes money for the shipyard that uses it.

REALISTIC STANDARDS ARE POSSIBLE FOR LONG CYCLE WORK

Let's look at the reasons why most upper management, operations management, staff personnel, and foremen do not and will not believe it. Most of them have been exposed directly or indirectly to programs where the Performance Standards

1. were of no value.
2. if of any value, the value was not apparent.
3. had been of value but the value had deteriorated.

Whose Fault? No-one's/Everyone's!

All that's required to correct the situation is common sense and hard work. Common Sense? Yes, elementary common sense. If you are going to use a cost-effective Standards Program, you must plan for it. You must

1. pick a program appropriate to your needs.
2. pick techniques appropriate to your needs and your operations.
3. keep it simple. Install slowly so that problems are solved as you progress rather than buried in the muck of turmoil from trying to install the standards everywhere at once.
4. keep everyone informed. Upper management, middle management, staff, foremen, employees and if you are blessed with a union, the union officials.

Hard work? You better believe it! Worth the effort? Let's consider the probabilities.

The Work Probabilities shown in Table V seem to repeatedly exist in operations with "soft standards,". with deteriorated Standards Programs, or no Standards Programs.

Soft standards are apt to be found in operations

(a) where there is no structured plan to establish realistic standards, or

(b) where realistic standards have been allowed to deteriorate.

WORK PROBABILITIES IN OPERATIONS WITH SOFT STANDARDS

* 50% by wrong people.
* 40% done wrong way.
* 30% doesn't need to be done.

TABLE V

Correcting the problem is no easy task, but the results are "well worth the candle."

RULES FOR SUCCESSFUL STANDARDS

Rule I. Comparable Yardsticks

Let's modify the term "Performance Standards" to identify the desired relationship between Planning Times and Performance Standards. A good Planning Program and a good Performance Standards Program require that the times are comparable, modified only by the changes that take effect between calculating the Planning Times and calculating the Performance Standards. From here on, let's talk about Planning Standards as encompassing both aspects. They should. Otherwise we have the old gag: (1) "Here's how we plan the work," and (2) "Here's how we work the plan." That joke is too often true. In which case, neither group interferes with the other, nor gives a damn about the other, nor helps the other.

Having Planning Time Estimates comparable to Performance Standards does not mean that they have to be in the same degree of detail. Planning, production, and engineering, each should have the say on the amount of detail they need. But it would seem essential that all operate from comparable yardsticks.

Rule II. Select Appropriate Techniques

The techniques used in establishing the Performance Standards should fit the uses to which they will be applied and the type of operations to which they apply. If accuracy needed is ±30%, there is no need -- in fact it is stupidity -- to try to set the standards with ±5% accuracy. Likewise, if the need is for ±10% accuracy, then there is no excuse for using sloppy techniques that cannot be maintained within ±10%.

It is quite common for the Production Department to need a greater degree of accuracy in the Performance Standards than that required in Planning Estimates. As stated above, this is no problem as long as the performance levels are comparable.

A common mistake in selecting Performance Standards techniques is failure to allow for the range in tolerance and in techniques required by different needs in different types of operations. Table VI shows the range of accuracy customarily realized with the four most common Performance Standards techniques.

PERFORMANCE TECHNIQUES	WHEN SET	CUSTOMARY TRENDS
Historical Records	± 30%	20% tight to 60% loose
Reasonable Expectancies	± 20%	10% tight to 45% loose
Stop-Watch Studies	± 10%	5% tight to 35% loose
Pre-Determined Times	± 5%	5% tight to 20% loose

TABLE VI

Selecting techniques appropriate to the need can save a great deal of grief.

Rule III. Plan Your "Frame Work"

The second most common mistake in establishing Performance Standards Programs is failure to plan ahead. The best way to set Performance Standards for operations that are complex and long-cycled (days and weeks instead of hours) is to get some overall settings with approximate accuracy. Then refine the time estimates -- where necessary -- with supporting details and greater accuracy.

This is contrary to common experience. Most industrial engineers build Performance Standards with great detail, with great accuracy, whether needed or not.

I believe most of you who are involved in building or overhauling ships, will achieve optimum progress if you begin with the overall structure and approximate times. Then plan out different techniques as needed for different departments and operations.

A "common sense" pragmatic approach as outlined above is the easiest way for long-cycle operations to install a cost-effective, long-lasting Planning Standards Program.

Do it the right way, the easy way. In our firm's 40 years of specialization in Performance Standards, we've learned the right way by doing things the hard way -- again and again. With that confession before you, I feel quite free to say that the following statistics in Table VII on the average Engineering Department are typical in this country and abroad.

IF YOUR ENGINEERING IS AVERAGE:

- 80% DONE THE HARD WAY.
- 40% IS UNNECESSARY.
- 20% DONE BY WRONG PEOPLE

TABLE VII

Rule IV. Hard Work

Planning Standards to be effective must be believed.

Planning Standards to be believed must be consistent, must be understood. The following techniques help achieve these results:

1. "Systems Standard Data."
2. "Family Grouping."
3. Training. Include industrial engineers, process engineers, planners, production managers,

foremen and industrial relations plus anyone else who is interested.

4. Communication.

There are many factors that influence the reliability and maintainability of the integrity and cost effectiveness of your Planning Standards.

The tangible factors are:

1. Formats used for setting Standards.
2. Methods Specifications.
3. Competitive Needs.
4. Work Sampling.

It is essential that the formats used for standards setting and the supporting data for the time values are convenient to

- use,
  - understand,
    - validate.

The following intangible factors also strongly influence Planning Standards integrity and cost effectiveness:

1. Management Controls.
2. Management Experience.
3. Line and Staff Knowledge.
4. Union Knowledge.

The three modifying forces that have the strongest influence on the quality of a yard's Planning Standards Program usually are:

1. Competitive Needs.
2. Methods Specifications.
3. Management Experience.

Rule V. Win, Don't Lose, from Your Computer Use

The big advantage to using Computerized Planning Standards is that computers (a) take a great deal of the drudgery out of the work; (b) do the detail consistently and legibly; (c) provide the answers rapidly in a multitude of formats that can be aimed to fit your specific requirements; and (d) can be programmed to be a highly useful tool for fact-finding and productivity improvement.

The last is one of the most important features of a good Computerized Standards Systems. Properly programmed and implemented, the software system can massage the information to greatly improve operating performance. For example, the computer system can readily

1. Rank by performance - help the poor performers.
2. Rank by jobs - identify problem areas.
3. Rank by families - identify and validate good Planning Standards along with the need to correct defective Planning Standards.

However, you can lose from use of computers also. There are three important dangers to protect against in Computerized Planning Standards Systems:

1. Computerized Planning Standards must be applied in a practical manner, so that they are understandable
   - by everyone involved,
   - including line supervisors and hourly workers.
2. Good Planning Standards take a lot of hard floor work that cannot be replaced by a computer.
3. Too often, Computerized Planning Standards are seen as a cure-all. Industrial engineers and management often forget about the floor once Computerized Planning Standards are introduced.

Today's software systems for Computerized Standards are cost effective. There are a multitude of good, moderately priced computer programs available for Computerized Planning Standards. They run on micros, minis, and mainframes. Our firm, for example, works in tandem with five different software developers on seven different Computerized Standards Systems that operate on microcomputers and can be uploaded to mainframes. These systems range from very basic and low priced ($4,000 to $7,000) to more sophisticated systems at higher prices (up to $39,500.)

By careful review of available software, you should be able to find one that fits your needs and your pocketbook. Before buying, be sure you identify the reports you want. These should be the reports you need, not your Christmas wish list. Computers can generate enough paperwork to sink a small tugboat and you. Then look at sample printouts. Pro-forma (preliminary samples), not actual, are satisfactory if the software supplier warrants that the actuals will match the samples.

Rule VI. Make Your Planning Standards Programs Bilingual

Bilingual? No, I do not mean different languages. I mean two types of Performance Measurement. I am specifically referring to using both Planning Time Standards and Planning Cost Standards. The difference is important.

If you really want an on-going program with effective Planning Standards and competitive productivity, install bilingual Performance Measurement Programs. Both are essential. Table VIII outlines the reasons why.

MOTIVATION OF PRODUCTION AND STAFF PERSONNEL

Negative and Positive Performance Measurement

1. Supervisors measured by:
    * Productivity comparisons - puts 'em on the other side.
    * Cost comparisons - your side.
2. Staff measured by:
    * Coverage - take shortcuts.
    * Grievances - avoid work.
    * Cost comparisons - encourages foremen cooperation and management style thinking.

TABLE VIII

If you want your Bilingual Performance Measurement Programs to be effective, the person measured must understand and believe the figures.

I recommend measuring the employees by work done and time taken. Those are factual things they can see, understand and believe. Please do not try to measure employees by things they cannot see, understand, and believe. In most cases, that rules out cost comparisons.

I do not recommend measuring foremen and staff by the identical yardsticks used for measuring employees. Table VIII explains why. If time and space permitted, I could give you case histories by the barrel of problems such identical measurement has caused.

Instead, take my word based on forty years of working with Productivity Improvement Programs worldwide: use Cost and Profit Comparisons to measure supervision and staff. Sure, I know most of them also do not understand or believe your cost figures. Perhaps even some of your Accounting Department people don't. But if you look carefully, you can find ways of making the crucial Planning Cost Standards clear, understandable and believable to individual foremen and individual staff personnel for their specific areas of responsibility.

One favor: use the basic approach followed in Standard Cost Programs. See Table IX. Alternate approaches cause trouble in cost effective measurement of supervision and staff personnel.

**3 - PHASE
STANDARD COST CONTROLS
FOR BETTER MANAGEMENT**

. FROZEN STANDARD COSTS FOR INVENTORY & BASE TARGET

. CURRENT STANDARD COSTS FOR MARKETING

. ACTUAL COSTS -- THE BOTTOM LINE !

Table IX

Rule VII. Involve The Front Line Supervisor

Your front-line supervision must be an integral part of the Planning Standards Program if it is to succeed.

The typical supervisor is untrained -- uninformed -- unimpressed. Does Table X reflect your yard? If so, your yard has unnecessary troubles.

IF YOUR SUPERVISION IS AVERAGE:

* 75% OF OPERATORS NOT INSTRUCTED.
* 50% OF SUPERVISORS UNSKILLED INSTRUCTORS.
* 25% OF OPERATORS, IF INSTRUCTED, COULD DOUBLE OUTPUT.

TABLE X

Don't blame your supervision if this condition exists. It is management's fault. Involve your supervisors and train them. Give them the knowledge; give them the responsibility; give them a pat on the back when they do a good job.

Make them feel good -- catch them doing something right. If you give recognition for good performance, if you give training on how to be a good supervisor, you will be amazed at how many good supervisors - how many diamonds in the rough - you have in your shipyard.

There are many benefits from involving front-line supervision. What's the best source of knowledge about what the actual methods are, how the work is actually done in your yard? No, it's not management. It's not engineers. It's not planners. It's not the foremen. It's the employees. But who is the second best source? It's the foremen.

The time required to do a job depends on the method used. That's basic. And if you want the Performance Standards to be somewhat correct, involve the foreman. Find out the methods actually used. Get suggestions on how to improve the methods. And get the foreman involved in putting the improvements into effect. Everyone benefits, except your competitors.

Also, now that the foreman is involved, has participated and understands how the Performance Standards are based on the methods, he is apt to be more supportive. He is not as apt to sabotage the standards by telling his team, "Look what those *!#@!* came up with now." You may even get some respect.

Rule VIII. Explain to Your Employees

You know, they are people too. The employees are the ones most concerned about job security. Where do they go when your yard closes down? They do not have the mobility or the resources management and staff have. Employees have a vital interest in your Company's success. They will respond enthusiastically to good Productivity Improvement Plans, particularly if you keep them informed and give the good ones recognition.

Most employees are proud of doing a full day's work. They want to know how to do their work, and when they have performed well against realistic targets. It's not much fun bowling or playing golf, if you don't know what to shoot for.

Many times, all that is necessary for a 20% or greater jump in productivity is:

1. replace soft standards with realistic standards.
2. validate the realistic standards with the foremen.
3. explain the reasons for the changes to foremen and employees.
4. brag about the better performance, give recognition for good methods suggestions and good productivity.
5. don't complain, don't criticize about the past.

Base your action on the 99% of your people who are good, honest, dedicated employees. Forget the 1% who don't care. Work with the 99% who do. Give them recognition when they do good work.

And, if you are blessed with a Union, recognize -- and let the Union recognize -- that they do not have the right to run your yard. Keep reminding them that "The Company must exist for the Union to exist, but the Union does not need to exist for the Company to exist."

Don't let the Union shoot itself by sinking the Company.

WHY AND WHEN DO STANDARDS PROGRAMS FAIL?

Failure to follow the above eight rules are the most common reasons why Standards Programs fail. They start to fail the moment those rules are forgotten. The Standards Programs start to revive the moment those rules are reintroduced.

WHAT CAN YOU DO TO REVITALIZE OR INSTALL A COST-EFFECTIVE PLANNING STANDARDS PROGRAM?

First, make an audit of where you are. An audit should encompass both technical and personnel aspects.

I. From a technical viewpoint:

- A. Audit the techniques used to establish your Planning Standards. As a by-product, identify the techniques that should be used.
- B. Do a Work Sampling Study to evaluate your current productivity and opportunity for productivity improvement.
- C. Compare the Work Sampling results with reported productivity figures. That will highlight opportunities for improvement in your present Planning Standards.

D. Compare specified processes and methods with actual including facilities layout, equipment specifications and quality specifications. That will highlight further opportunities for improvement in production and in Planning Standards.

E. Compare actual time and production recording practices with specified procedures. That will highlight opportunities for simplification and improvement in paperwork.

II. From a personnel viewpoint:

Make a confidential sampling of operator attitude, foremen attitude, staff attitude and management attitude. These sampling surveys will reveal:

A. Opportunities for improvement in Productivity and Planning.

B. Areas of support for, and opposition to, improvement.

C. The types of approaches most apt to succeed.

Don't be overly surprised if you find that the operator attitudes compare very positively with the other attitudes.

III. Take action.

YOU CAN WIN --

- IN PLANNING STANDARDS, AND

- IN PRODUCTIVITY IMPROVEMENT

The answers are simple. They are basic and they are tough. It is up to you in upper management or with aspirations to be in upper management.

You must lead. Let me close with two slogans. One slogan is from Great Britain when they ruled the waves:

> *"THERE ARE NO POOR SAILORS,*
> *JUST POOR OFFICERS ! !"*

In our work worldwide, we run into too many operations where Table XI is appropriate.

MANAGEMENT AWARENESS

- * 80% DON'T KNOW SHOULD COSTS.
- * 50% DON'T KNOW ACTUAL COSTS.
- * 30% LACK NEEDED MARKETING DATA.

-- -- --

- * 100% EXPECT STOCKHOLDER APPROVAL.

TABLE XI

If that's true in your operations, let's correct that cost knowledge on the double. There is an old Viking slogan:

> *"THE VISION OF THE CHIEF*
> *SETS THE SPEED OF THE SHIP."*

VISION IS IMPAIRED BY LACK OF FACTS.

THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
601 Pavonia Avenue, Jersey City, NJ 07306
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Development of an Intelligent System for Flame Straightening Panel Structures—Devices and Algorithms to be Used with Robots

No. 13

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ABSTRACT

Distortions which occur during the assembly of steel panel structures can be removed by flame straightening. This has been used for a number of years in the shipbuilding industry. Correct skill to perform this technique is acquired by many years of experience. The industry is concerned now about the decreasing number of skilled workers.

What is needed to improve the situation is to develop a robot capable of not necessarily replacing a human worker but helping a human worker. This paper discusses results obtained thus far in a research program of which the ultimate objective is to develop an intelligent machine capable of performing flame straightening on a deck of a ship superstructure. Discussions are given on (a) a concept of an algorithm to determine heating conditions, and (b) sensors needed for "in-process" sensing and controlling the robot movements.

INTRODUCTION

The flame straightening method has been used for many years to remove distortions of a welded structure. An oxyacetylene torch is usually used as a heat source to produce counter distortions to remove distortion that exists. Many years of experience are normally required to master the skill of distortion removal. The skill has been handed down from generation to generation.

Researchers in the academic community also have tried to study the technology of distortion removal. They have succeeded in studying mechanisms of flame straightening and flame forming in simple cases[1,2,3,4,5]. However, in most cases their research has been limited within laboratories. This is because it is extremely difficult, if not impossible, to simulate in a laboratory the complex situations of a real structure.

On the basis of recent developments of robotic technologies together with artificial intelligence (AI), sensing technologies, and small but powerful computers, the authors believe that there is a good possibility to fill the gap between a laboratory and a factory. Information collected on site in an actual structure should be useful for researchers in developing mathematical models for studying distortion removal. This will improve the level of academic research and its relevance to industry. From the industrial manager's viewpoint, the number of workers experienced in flame straightening is decreasing causing serious concern over the availability of skilled workers in the future. New technologies related to AI including expert systems may be able to fill the void created by the lack of experienced workers. The authors believe that now is the appropriate time to develop a robot capable of flame straightening.

This paper describes current R & D efforts for developing a flame straightening robot. Since the efforts have not been completed, this paper should be regarded to be a preliminary report. The robot being developed will not replace the experienced worker, since it requires human supervision. However, one worker will be able to supervise several robots. The robot should be able to perform the following:

(1) Move by itself on a deck of a ship superstructure (See Figure 1)
(2) Remove most of the residual distortions in panels on the deck.

The robot being developed will not be automatic nor a stand alone robot, but an "intelligent aid" robot designed to help the worker by reducing his labor and increasing his productivity. The idea was initiated in a Japanese shipyard that needed a practical machine which could be developed with today's technology and introduced quickly into production, not a dream for the future.

In order to meet these requirements, the authors have decided that the robot being developed should be capable of:

(1) Recognizing its own location
(2) Measuring distortion
(3) Deciding how and where to apply

the heat

(4) Learning from a previous operation.

Again, the robot will not be able to perform these functions unassisted by the worker. It will still need human supervision. The degrees of automatization and mechanization in the system are described in this paper.

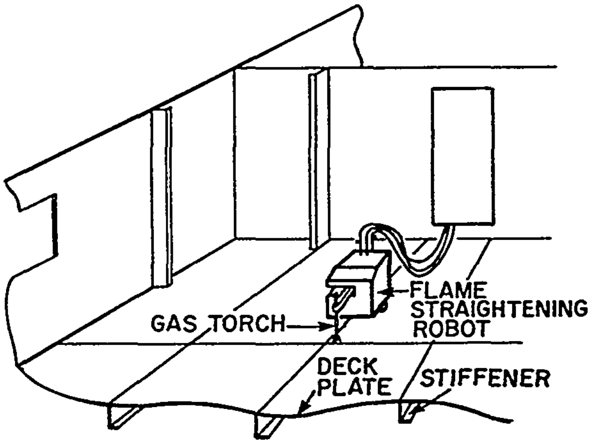


Fig. 1 Conceptual figure showing a flame straightening robot removing distortion of a deck panel of a superstructure

DISTORTIONS IN DECK STRUCTURES

This section discusses typical uses of the robot being studied: The type of structure and typical distortions.

A deck of a superstructure consists of stiffened panels. Stiffeners are welded on the bottom side of the deck which is the ceiling of the deck below. Aspect ratios of the panels are larger than two in most cases. Since a superstructure must be light and does not support large external loads, it is made of thin plates on the order of several millimeters.

Figure 2 shows typical distortions of a panel structure. Two major causes of the distortions are:

(a) Angular distortions produced at fillet welds between stiffeners and the plate

(b) Buckling distortion of the plate due to compressive residual stresses in the plate.

Regarding residual stresses, they are produced not only by welding but also by flame cutting that is used to cut large plates into specified sizes. The distortions may also be produced by joint mismatch and other causes.

Since the robot must rest on the horizontal surface of a deck, straightening can only be performed from above the deck. It is not feasible even for a human operator to apply the heat to a ceiling (unless he is 9 feet tall and tools are weightless). So flame straightening must be accomplished from one side of the deck. This is more difficult than straightening from both sides.

In addition, the work must be performed in an unpleasant environment. It is humid, hot, dirty, noisy, and wet on the floor because of the gas heating and water spraying. Uses of robots should provide some relief to workers.

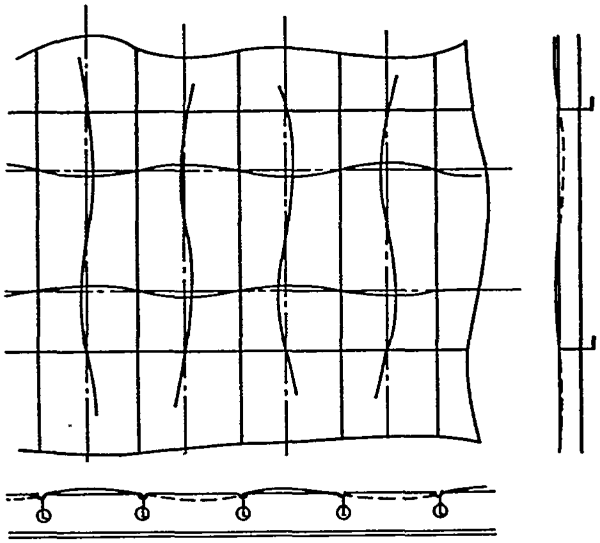


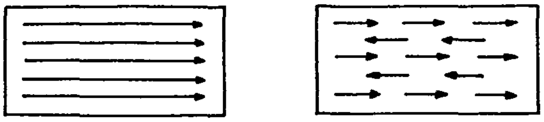
Fig. 2 Typical distortions of a panel structure

FLAME STRAIGHTENING METHODS

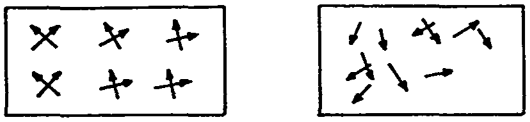
There are several different types of flame straightening methods, as shown in Figure 3. They are classified into two major groups: (1) line heating and (2) spot heating. In line heating, an operator moves a torch linearly. In spot heating, a torch stays at one location for a few seconds and moves away. The former is basically used to remove angular distortions and the latter to remove buckling type distortions, which are caused by in-plane forces. Each group of heating, shown in Figure 3, is applied to a specific type of structure and shape of residual distortions.

The heat source is usually an oxyacetylene flame. The highest temperature reaches 3000 degrees centigrade. The flame heating is usually followed by water spraying to avoid excessive heating and to cool down the structure quickly. It has been noted that the procedure used in one factory may be different from that used in another, depending upon the worker's preference. The process is more of an art than a technological operation.

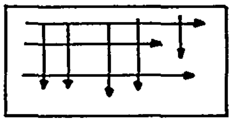
Parameters which are adjusted in the operation include torch traveling speed, torch height, water spray intensity, relative location of water spray to the heat source, angle of the flame with respect to the structure surface, etc. These are intended to change the



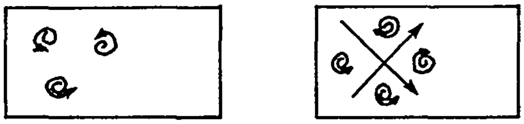
LINE HEATING USED FOR MOST FAIRING WORK



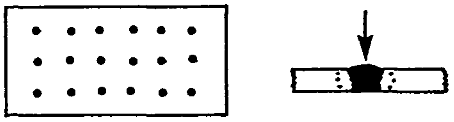
PINE LEAF HEATING FOR PANELS



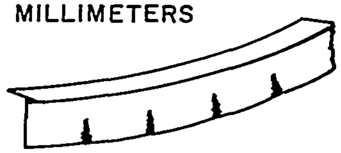
CROSS HEATING



VARIATIONS OF ABOVE



SPOT HEATING FOR PLATE THINNER THAN ~5 MILLIMETERS



TRIANGULAR HEATING FOR STIFFENERS

Fig. 3 Various methods of flame straightening

temperature distribution of the structure being treated. The selection of a proper torch tip size is also important. An experienced worker chooses the best tip for a specific structure and its material. The gas flow rate and gas pressure are not regarded as adjustable parameters, since they are usually optimized for the lowest operational cost.

Previous researchers found that water spray reduces the effectiveness of flame heating [3,5]. Thus, less angular distortion is removed when water spray is applied during flame heating. However, there are three major reasons to use water spray as follows:

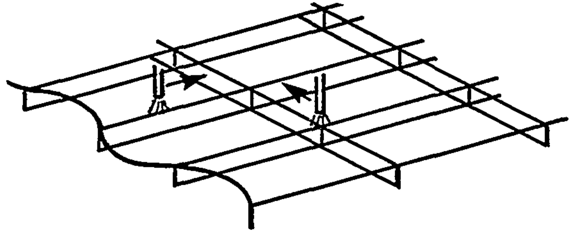
(1) Water spray increases the productivity because it cools down the structure quickly so that the next operation can start without a long waiting time.
(2) If a mistake is made in the flame heating operation, the operator can cool down the material immediately.
(3) In the case of spot heating, excessive heating of a plate can be prevented by water spraying.

In many cases, the distortion cannot be removed by a single heating operation because there is a temperature limitation above which materials are degraded. Depending on the amount of distortion, the heating must be repeated so that the distortion is removed gradually while the temperature of the material is maintained below this critical limit. For the subsequent operation, the operator has to wait until the material cools down. Otherwise, the material shows different movements which are unpredictable. Water spray is necessary to shorten this waiting period.

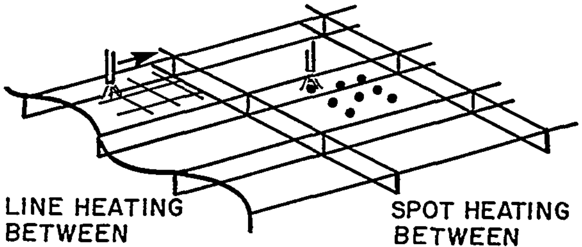
An experienced operator knows how the structure moves during heating. While he performs the operation, he watches the movements of the structure. If he finds something wrong, he stops heating immediately and sprays water all over the structure.

In the case of spot heating, of which the major objective is to reduce in-plane forces, the temperature deviation through the plate thickness must be kept to a minimum. If the temperature difference is large, additional out-of-plane deformations will occur and this process will not remove the distortions. Unfortunately, both sides of the plate cannot be heated at the same time to give the symmetrical temperature distributions needed through the thickness of the material. Also, gas torches distribute the high temperature gas into large areas. Water spray minimizes this undesirable heating. Thus, a water spray nozzle will be installed on the robot to minimize the undesirable heat input and spreading.

Three heating patterns have been selected to be used with the robot. They include (see Figure 4):



LINE HEATING ON STIFFENERS (LOS)



LINE HEATING BETWEEN STIFFENERS (LBS)

SPOT HEATING BETWEEN STIFFENERS (SBS)

Fig. 4 Three heating patterns selected to be used with the robot

(1) Line heating on stiffener lines (LOS)
(2) Line heating between stiffeners (LBS)
(3) Spot heating between stiffeners (SBS).

Combinations of these heating patterns have been used for many years in Japanese shipyards for removing distortions of panel structures. Almost all types of distortions can be removed by proper combinations of the three heating patterns. Algorithms to apply these three methods are described later.

CAPABILITIES OF A HUMAN OPERATOR VERSUS CAPABILITIES OF A ROBOT

In order to develop an intelligent system, we must know what a human operator does in a shipyard. An experienced flame straightening operator must be able to:

(1) manipulate the tools of his trade
(2) use the best techniques for a given type of distortion
(3) learn from past experiences
(4) make the correct decision in a new situation.

First of all, he must have the ability to move a torch maintaining constant conditions such as the speed and the torch tip height. He may have to occasionally check the gas pressure and flow rate. Secondly, he must know how and where to apply the heat to remove a specific type of deformation. He makes the decision based on past experience. Thirdly, he learns from his past experiences. He memorizes conditions that give good results and bad results. He makes fewer mistakes as he gains experience. Fourthly, he must have the ability to handle a new situation not encountered before. The worker must be able to choose the correct technique with a minimum amount of trial and error. The experienced worker can solve flame straightening problems faster than a novice worker. This is because he has a lot of data based on his experience and he knows how to improve his performance by using this data.

At the present time, even the most sophisticated robot does not have all of these abilities. The authors think that it is impossible with the present state-of-the-art technology to replace the human operator.. Then, what is a robot capable of doing today? A robot can easily perform the first function of manipulating flame straightening tools by incorporating feed-back control systems. To perform functions two, three, and four is more difficult. A system having these functions, which have been intensely studied for several years, should be called an "expert system." The intelligence that this robot will need is discussed in the next section.

ALGORITHMS FOR HEATING OPERATIONS

A noticeable feature in this research is "in-process sensing." Data collected by in-process sensing are used to modify coefficients in equations which give the relationship between the torch velocity and the amount of distortion removal. This is the most important point in this research. Because of this feature, it can apply theories found in a laboratory to a structure in actual situations. Coefficients modified according to the data are supposed to include actual conditions.

The term "in-process" is somewhat different from "in-process" used in other fields. For example, during the welding operation, data like voltage, current, and diameter of the molten metal pool are collected in real time. On the contrary in flame heating, while the gas flame heats panels, nothing is measured in real time except the location of the stiffener line. Measurements of distortion are not usually carried out during the heating process. Since a change of the state in one panel may affect a neighboring panel, measurements of distortion during flame heating may not be useful. Distortion measurements must be taken after all heating is completed. The flame heating process is not finished until the deformations of the entire deck are removed. It may take a few hours or even a few days. In this sense, any measurements during the flame heating operation can be called "in-process sensing."

An algorithm is shown in Figure 5. Before applying any flame heating, deformation measurements are taken along the entire deck. Flame heating patterns and other parameters are determined once the displacement distributions are known. To ensure that the material's critical temperature is not exceeded, the torch traveling speed must be faster than the minimum heating velocity. The first heating operation is carried out using these determined conditions.

After the first heating, deformations are measured again to calculate values of removed deformations, and coefficients in the equations are modified using the actual data. (See Appendix for details.) Then a second heating is performed. The deformations are measured and compared to the allowable values. If they are not within allowable values, the heating is repeated until the conditions are satisfied.

It may take three or four heating operations to reduce deformations to allowable values. If maximum deformation limits are not achieved by four heating operations, the robot judges that the task is too difficult and leaves it to a human operator.

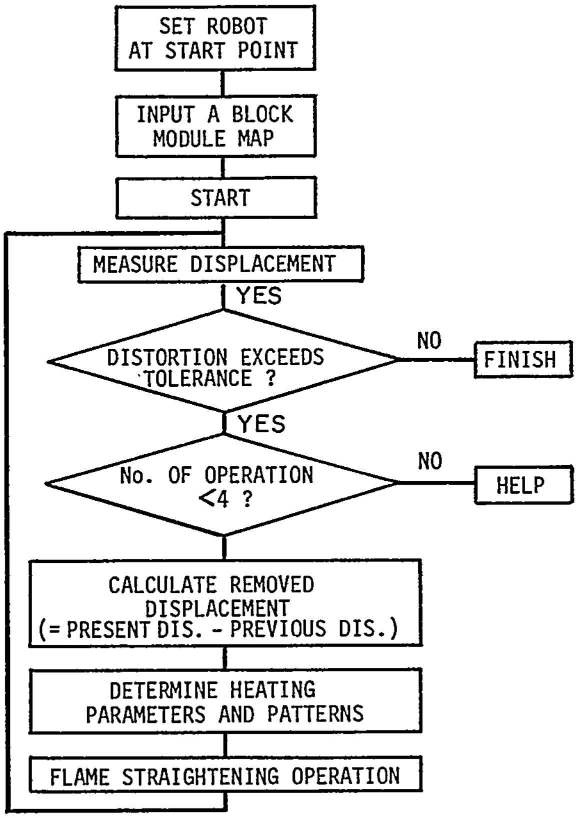


Fig. 5 An algorithm of flame straightening operation

The equations calculating the plate displacements are based on an assumption that the removed displacement corresponds linearly to a free angular distortion[6]. The free angular distortion is defined in Figure 6. The plate has no constraint with regards to angular distortion. The relationship between the free angular distortion and the torch velocity is obtained in experiments completed before the robot's operation. The experimental data is input into the computer that controls the robot.

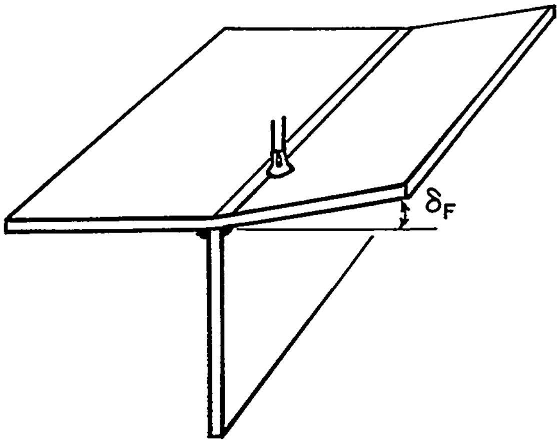


Fig. 6 Free angular distortion

As mentioned before, three heating patterns are selected to be used by the robot:

1. (1) Line heating on the stiffener line (LOS) (See Figure 4)
2. (2) Line heating between the stiffener lines (LBS) (See Figure 4)
3. (3) Spot heating between the stiffener lines (SBS) (See Figure 4).

LOS is for the angular distortion caused by fillet welding. It produces counter distortion against the residual angular distortion. In principle if the displacement is convex, this is not applied. LBS is applied to an area where the displacement is convex. This produces a local concaved distortion to reduce the deformation as shown in Figure 7. The pattern is like a lattice.

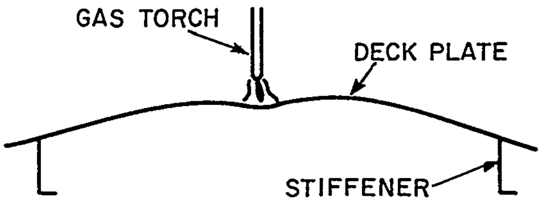


Fig. 7 Distortions due to LBS

SBS reduces in-plane-forces causing positive displacements. This is applied between the lattice lines of LBS.

After the panel displacement measurements are completed and this data is input into the robot's computer, the computer decides which pattern to use on each part of the panel

SENSING SYSTEMS

A sensing system is indispensable for an intelligent machine. A sensing device should be durable in a dirty, dusty, humid, warm, and noisy environment. If possible, a non-contact sensing system is preferred since the surface of the plate is wet. In flame straightening, a robot must have a sensing system to detect the following:

1. (1) Location of a stiffener line
2. (2) Out-of-plane displacements of panels.

A stiffener line must be recognized by the robot as it moves across the deck. The robot uses the stiffener line as a reference for its own location and for the location to apply heating. The stiffener line is also used as a reference line for displacement measurements.

As a sensing method for locating stiffener lines, the following four methods have been studied:

1. (1) Magnetic field difference caused by plastic strains due to the welding on the other side of the plate. This is detected by an

electromagnetic detector

(2) Detection of thickness difference using ultrasonics.

(3) Sound difference produced by hitting the plate surface and detected by microphones

(4) Color difference between the painted part and the burned-paint part due to the heat of welding on the other side of the plate. This is detected by vision sensors.

The electromagnetic detector that was studied could penetrate only a few millimeters in thickness. Usual thicknesses of plates used in ship superstructures range from 6 to 8 mm, which are too thick for this method.

When an ultrasonic method is used for determining a stiffener line, echoes are affected by the presence of the weld metal (fillet weld) between the plate and the stiffener. A probe must make contact with the surface, which may be dirty and wet due to water spray. It is extremely difficult to maintain good contacts between the probe and the surface under such conditions, and therefore is not acceptable.

When the plate surface is hit by a small hammer, an FFT (Fast Fourier Transform) analyzer is needed to locate a stiffener. This analysis is too time consuming for the computer to carry out in real time.

A human operator locates stiffeners by recognizing color changes in the paint. If there is a weldment on the other side of the plate, the heat penetrates through the thickness and burns the paint on the surface. Figure 8 shows an example.

Fig. 8 Welding mark on deck

As long as a robot works on the superstructure, plate thickness is thin enough to produce this color change. Details of a vision system are described in a later section.

Out-of-plane displacements can be measured using linear transducers. The transducer's leg needs to be in continuous contact with the plate surface. Since the electronic transducer for this instrument is placed above an indicator leg, it is protected from the environments. The accuracy of the device may be 0.2 to 0.4 mm which is sufficient for this purpose.

In addition to the above mentioned two measurements (i.e., the location of a stiffener line and the out-of-plane displacement of a panel), temperature distributions may have to be measured during heating. For mild steel, there is a critical torch velocity below which the material is degraded because of the high peak temperature. It can be determined in advance by experiments using a simple structural element. The peak temperature is checked by referring to the critical velocity. Therefore, temperature measurement is not necessary during heating of mild steels.

In the case of high strength steels, on the other hand, the temperature must be carefully checked so that not only the peak temperature condition but also cooling down temperature conditions are satisfied. Water spray is not allowed as a general rule. This strict condition makes flame straightening very difficult. In this research the material is assumed to be only mild steel. Further discussions on this subject will be given in a later part of this paper (Future Work).

Vision Systems

The most practical sensor that can be used by a robot to detect a stiffener line is an image sensor (7). In a shipyard a human operator uses his eyes to detect the stiffener position. As shown in Figure 8, there is a color change on the surface. This color change is called "welding mark" in this paper. It can be recognized by a TV camera.

Figure 9 shows a fundamental measurement system using a TV camera. The camera monitors the panel surface and detects the welding marks. The original image before data processing (Image I) is shown in Figure 10-A. Identification of the spots from the image is important. There are many methods to obtain the contours of the spots, however, processing the whole flame image takes a long time. PCVISION (8) by Imaging Technology Incorporated, a TV camera, and an image processing system were used to estimate the performance of the sensor system. The image processing unit used 8086 CPU(9). It took over 30 sec. to process the whole image flame. This is too long to be used in real time control without modifications. To improve the processing time, it has been decided that only crucial and best portions of the

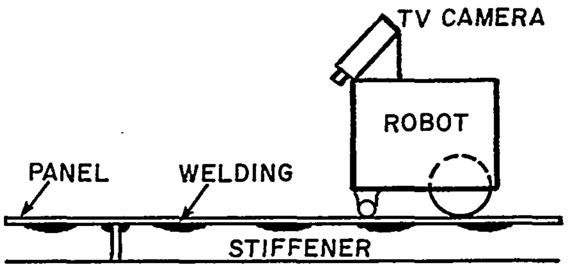


Fig. 9 TV camera and robot

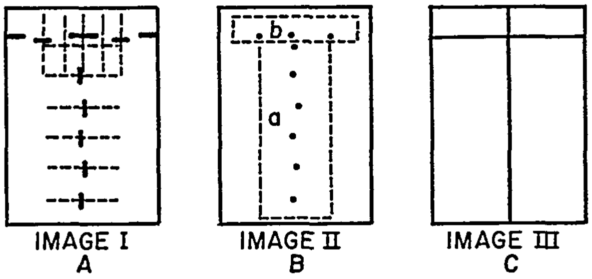


Fig. 10 Image processing of welding marks

image to be processed. The welding is done intermittently as shown in Figure 8. Dotted lines in Figure 10-A represent the image processed area and the area of contour-strengthening operations done to detect the stiffener line. The image in Figure 10-B is obtained after the data processing.

The image has two zones which are called Zone a and Zone b. Zone a is for a stiffener sitting along the moving direction of the robot. Zone b is for a stiffener sitting transversely across the moving direction of the robot. In both zones, the stiffener line is determined by interpolation.

Figure 10-C shows the image after the interpolation. Two lines represent locations of the stiffeners. The relative position of the robot is calculated from data of the crossing point of the stiffeners. This information is used to control the robot movement.

The image signal processing is described further in detail (10). An image taken by a TV camera is converted into digital signals and stored in a frame memory. The PCVISION has 256x256 frame memory for each image and each pixel has 8bit data. An original image has continuous signals and noises. Using filtering technique, the original image is changed to a binary image. Discrete Fourier Transformation is used for reduction of noise. When high and low frequencies are rejected from the original image, the processed image becomes smooth. The derivative of the frame helps the detection of the edge. However, in the experiment at MIT, it was not used. Lighting conditions were so good that the edge was easily detected. After getting the smooth image, a binary image is obtained by defining the threshold value.

When using the TV camera as shown in Figure 9, the shape of the image is distorted because of the perspective effect. Figure 11 shows the image of the welded panel taken by the TV camera. Although all welds have the same length, L; L1,L2, and L3 appear to have different lengths (L1>L2>L3.)

As described before, processed lines must be chosen to reduce computation time. Figure 12 shows the relationship of the space between the processed lines and possibility of detection. When the space distance is 2L and the processed lines are between the welding marks (right side of the figure), it is impossible to detect the welding marks. On the contrary, if the space distance is L, the welding marks can be detected under any conditions. Considering that the stiffener line may not be perpendicular to the process line, if the robot is not moving parallel to the stiffener line, the space distance must be set shorter than L.

In order to detect the stiffener line transverse to the robot's moving direction, another arrangement of process lines is necessary as shown in Figure 13. If the robot fails to find the transverse stiffener, it will stop the operations by checking the map of the stiffeners given by an operator in advance.

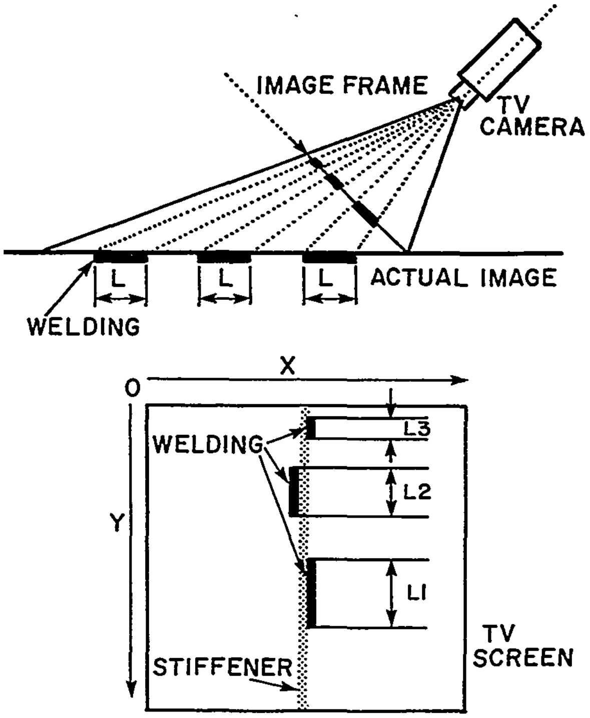


Fig. 11 Image of welding mark

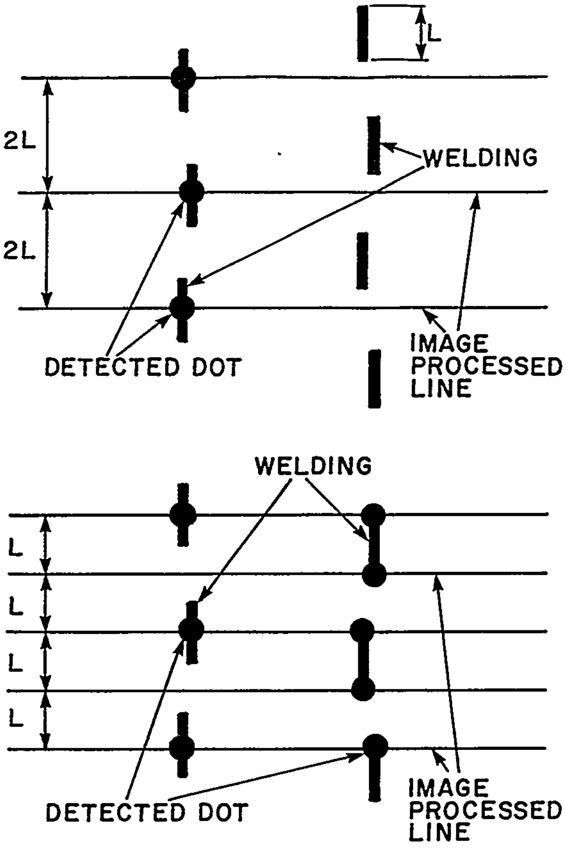


Fig. 12 Length between processed lines

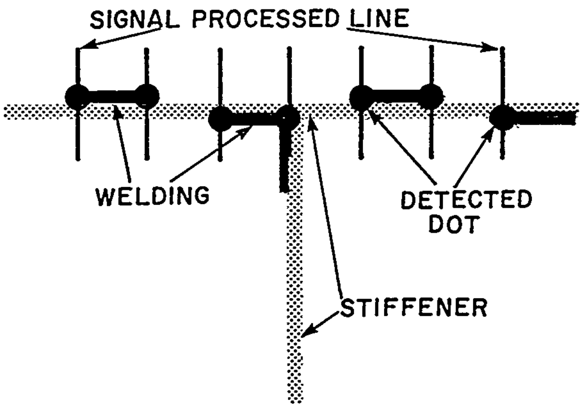


Fig. 13 Perpendicular stiffener detection

Tests On A Vision System

Experiments using a simple structural element were carried out at the MIT Welding Systems Lab. Figure 14 shows a plate having welding marks on the surface and a CCD camera. Thickness of the plate was 1/4 in. Length of the welding bead was 3 in. and spacing between the beads was 3 in. in longitudinal direction and 1/4 in. in transverse direction.

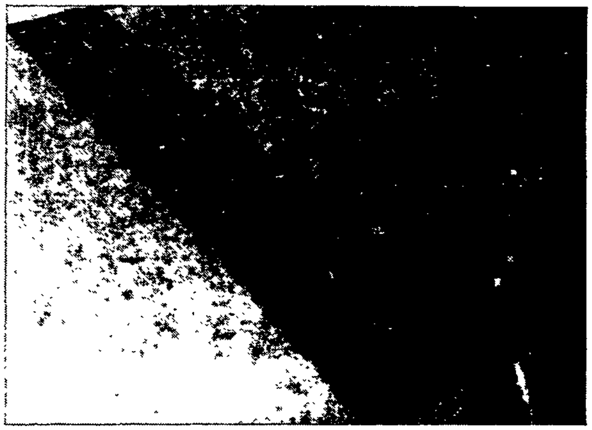


Fig. 14 CCD camera and welding mark

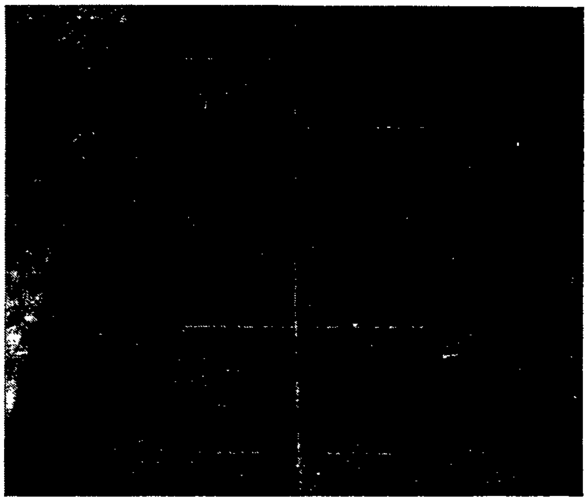


Fig. 15 Imaginary stiffener line

The CCD TV camera was set about one foot above the plate surface. Figure 15 gives five image processing lines and calculated center of the welding marks on the monitor screen. A center line of an imaginary stiffener was then calculated and drawn on the screen using the least square method between the welding mark centers. (See Figure 15.) Processing time was about 0.3 seconds which is fast enough to be used in real time control of the robot movement.

FUTURE WORK

The authors believe that there are three major tasks to be performed in the future, as follows:

(1) Verification of the algorithm
(2) Integration of robot hard- and soft-wares including displacement measuring sensors, vision systems, driving mechanisms, torch movement control, etc.
(3) Develop appropriate methods for removing distortion in materials other than low carbon steel, including high-strength steels,

and aluminum alloys. The current research is focused on mild steel only.

The algorithm described before must be verified by experiments using a test piece (model) consisting of more than one panel in order to investigate interactions between neighboring panels. Model sizes must be as close to the actual structural dimensions as possible, since a scale effect is unknown with regard to a heat source. This kind of experiment does not perfectly simulate every condition that could occur in an actual structure, however, if the algorithm is not effective on a model structure, it will never be valid on an actual ship structure. In the end, field tests must be conducted on the actual deck of a ship superstructure.

The interaction of the robot soft- and hard-wares should be completed before a field test. Mechanisms and their movements can be checked using the model structure. The remaining sensing system to be developed is a displacement measuring system. One candidate was mentioned in a former section (Sensing System). The robot's computer must be capable of vision system data processing, displacement data processing, determining heating pattern and conditions, controlling driving motors, and controlling torch movement. All of the hard-wares and system components should be integrated into the total system so as to enable the robot to move and perform the operations smoothly.

As demands for reducing structural weights have been increasing, higher strength steels are used for structural materials to utilize thinner plates. Usually, such materials require more stringent temperature controls. It would be extremely difficult to measure surface temperatures on the plate if a gas flame is used as the heat source. An alternate heating method is an electromagnetic induction since there is no high temperature gas (from gas flame) interfering with the temperature monitoring. This heat source should be investigated further. New straightening methods and conditions may have to be established for materials other than conventional mild steel, even if gas flame is used as the heat source.

Even if the above mentioned three tasks are completed, there are other problems to be solved by R & D engineers, production engineers, and structural designers, before this robot can be used for production.

R & D engineers and production engineers have to cooperate to change the present production sites into robot friendly environments. For examples: (1) how to organize gas and water hoses so that the robot movements are not disturbed, (2) how to keep gas and water pressure constant, (3) how to check gas and water flow rates, (4) how to handle three robots, (5) what kind of safety regulations are necessary, and so. Gas and water pressure, from main distribution piping, are not constant, but depend upon consumption in the factory at that moment. Therefore, gas and water supply for flame heating must be independent of the main supply lines. The deck floor should be as clean as possible. The surface must be painted with an appropriate paint so that weld marks can be visually sensed. Lighting may be required for proper TV camera operation.

Not only the production site but also structural design may have to be changed in order to utilize the robot. The welding size may have to be standardized to enable the robot to perform tasks easily. A special welding configuration may need to be adopted to give reference points for robot vision.

It is very important to recognize that this robot does not behave like a human and needs a friendly environment. In order to develop and use the most efficient and practical robotic system, there must be good communication between all related engineers and the working flame straghtening experts.

CONCLUSIONS

There are two areas of difficulty in developing a flame straightening robot. One is developing an algorithm for removing the residual distortion in the panels. The other is developing a sensing system to detect stiffener line location.

The algorithm presented in this paper has to be verified in the field. The most noticeable feature in this algorithm is "in-process sensing" during the flame straightening operation. The data collected by "in-process sensing" is used for modifying the relationship between the torch traveling speed and the amount of distortion removal. The robot's performance is improved by referring to this up-dated relationship in order to determine the torch traveling speed for the next operation.

A vision sensor is adopted to locate stiffener lines. It uses a TV camera aided by a computer to find welding marks on the deck plate. With this visual sensing system, the robot moves along the deck and performs flame straightening operations. Some basic elements of the system have been evaluated in the laboratory.

It will take one or two years to complete the R & D program. After assembly of the hardware, the robot will be tested using a model. Further modifications may be required during the field test.

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APPENDIX

Before a flame straightening operation is performed on a deck structure, experiments need to be conducted on unrestrained samples of material to determine the relationship between free angular distortions and torch traveling speeds. An example of the result is shown in Figure A-1. Vc is the minimum velocity limit. The torch must travel faster than this speed, or damage/degradation of the material will occur. A reduction rate from one pass to the next pass is also determined in the experiment by heating on the same line as the previous pass. (See Figure A-2). Test pieces must have the same material and the same weld dimensions of the actual structure. The experimental results are then input into a computer on the robot.

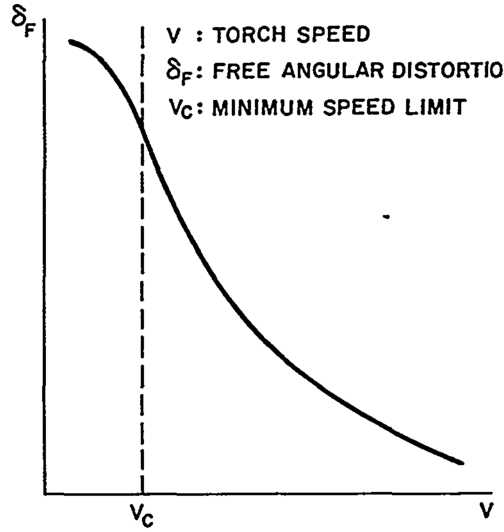

Fig. A-1 Torch speed and free angular distortion

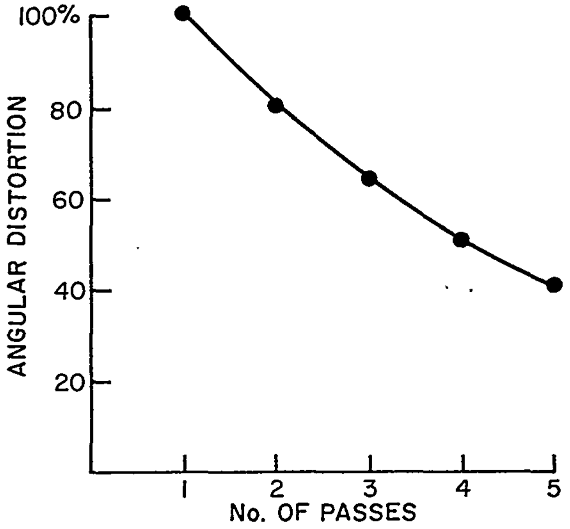

Fig. A-2 Reduction rate due to superimposing

For a simple example, suppose that the four panels shown in Figure A-3 are assigned to a robot. As the robot moves along the panels, indicated by arrows in Figure A-3, the distortion pattern shown in Figure A-4 is obtained. The computer of the robot determines heating patterns and torch velocities for the removal of distortion based on this measured distortion. For the given distortion, a heating pattern as shown in Figure A-5 may be used. SBS and LBS are applied to the positive displacement region. LOS is applied to the negative displacement region.

Torch velocities and the periods of spot heating are assigned according to experimental data and opinions of experienced human operators. A 20% removal from the original distortion may be sufficient for the first operation.

After the first heating operation, displacements are measured again. Assume that the displacement distributions shown in Figure A-6 are obtained in this second measurement. To obtain the amount of distortion removed during the first flame heating operation, the values of distortion measured after the flame heating are subtracted from those values measured prior to the first heating. (See Figure A-7.) For example, in panel P1, after the first flame heating pass, distortion removal of -4 mm(9-13) and +3 mm(-8-(-11)) were accomplished. The remaining displacements are 9 mm in negative region and 8 mm in positive region. The robot is now programmed to remove 50% of the remaining distortion (i.e., 4.5 mm negative and 4.0 mm positive).

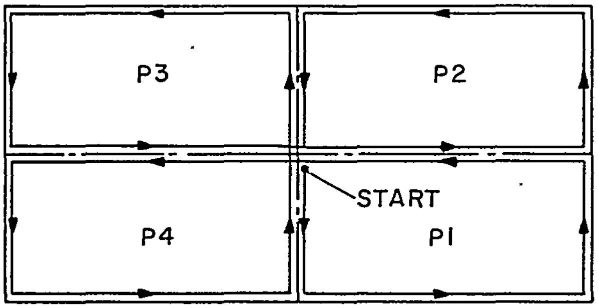

Fig. A-3 Panel arrangement and robot pass for displacement measuring

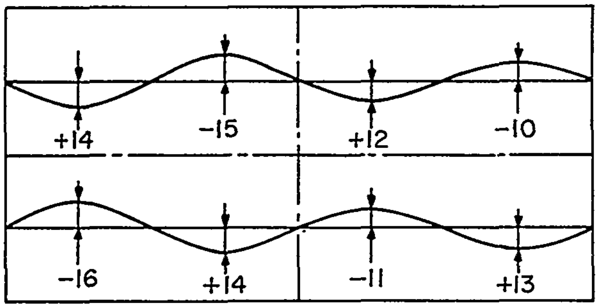

Fig. A-4 Displacement distribution prior to heating

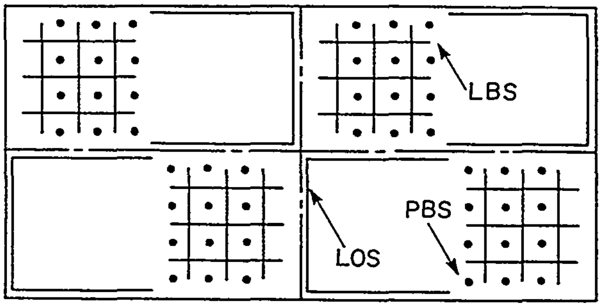

Fig. A-5 Heating pattern

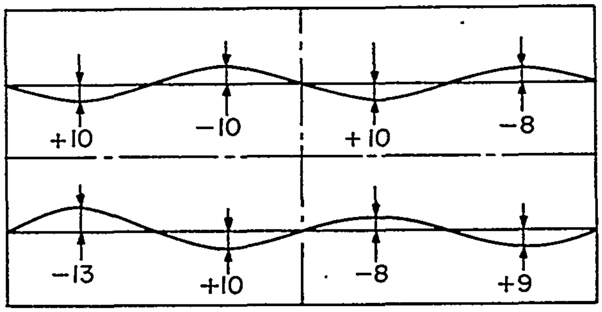

Fig. A-6 Displacement distribution after the heating operation

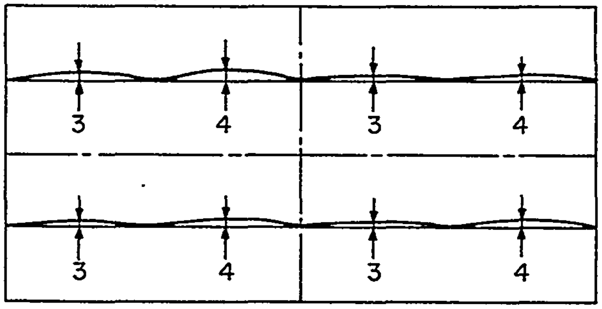

Fig. A-7 Removed displacement

During the first heating operation, VLos1 removed 4 mm and VLbs1 with SBS removed 3 mm of distortion. In order to remove 4.5 mm in the negative region and 4.0 mm in the positive region, the necessary free angular distortions are δ Los1x4.5/4 for negative and δ Lbs1x4/3 for positive. (See Figure A-8.) Velocities are, therefore, VLos2 for negative and VLbs2 for positive. This calculation is based on the assumption that the amount of distortion removed is linearly related to the given free angular distortion. Velocities for other panels are determined in the same manner

Heating and measuring operations are repeated until the distortion is reduced to allowable values. If any problems that the robot is not able to handle occur, the robot stops the operation and waits for human instruction. A panel having a strong singularity may be left for treatment by a human operator.

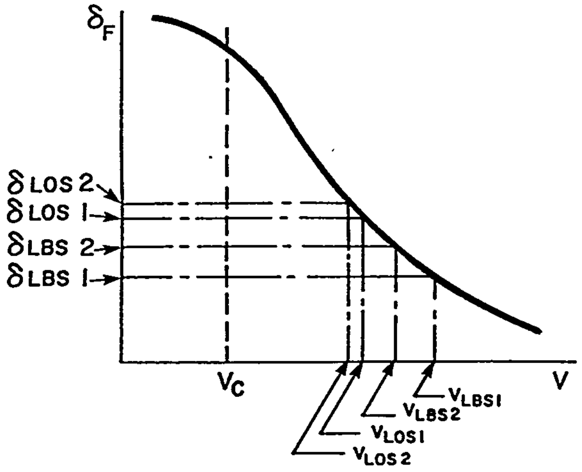

Fig. A-8 Velocities for the next operation

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Computer Aided Process Planning—A Path to Just-in-Time Manufacturing for Shipyards

No. 14

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ABSTRACT

The use of computers to improve the productivity of U.S. shipyards has never been as successful as hoped for by the designers. Many applications were simply the conversion of an existing process to a computerized process.

The manufacturing data base required for the successful application of Computer Aided Process Planning (CAPP) to the shipyard environment requires a "back to basics" approach. An approach that can lead to control of the processes occurring in the fabrication and assembly shops of a shipyard. The manufacturing data base will not provide management feedback designed for the financial segment of the shipyard (although it can be converted to be fully applicable) it provides "real time" manufacturing data that the shop floor manager can utilize in his day to day decisions - not historical data on how his shop did last week or last month.

The computer is only a tool to be used to organize the mountains of manufacturing data into useful information for today's shop manager on a "real time" basis. The use of group technology to collect similar products, the use of parameters to clearly identify work content, the use of real time efficiency rates to project capacity and realistic schedules and the use of bar codes to input "real time" data are all tools that are part of the process. Tools for the shop floor manager of tomorrow.

INTRODUCTION

"Just-in-time" manufacturing for U.S. Shipyards is considered by many to be an impossible goal. Computer Aided Process Planning can change that into reality for many areas in the shipyard. It does require that engineers utilize group technology to identify similar interim products, planners gather better work content information based on parameters, schedulers develop and use "real time" efficiency rate information, shop managers establish process lanes to produce similar interim products using standard processes, and cost administrators gather data based on the processes occurring in each process lane. Yes, interim products, group technology, work content, parameters, efficiency rates and process lanes are new terms that today's shipyard managers must become familiar with. However, the technologies associated with these new terms are not new. They utilize concepts developed in the 1930's such as "group technology". Drawings of similar interim products resemble the drawings used during the "stick built" era of shipbuilding. Parameters and efficiency rates result from the utilization of the basic building blocks of which shipbuilding has been composed. It is a "back to basics" exercise to get control of the activities occurring in the shipyard: the application of old technologies such as statistical quality control and new technologies such as personal computers to improve the efficiency of the shipbuilding process, and to achieve "Just-in-time" manufacturing in the U.S. Shipbuilding Industry.

INTERIM PRODUCT/CONSTRUCTION PROCESS DEFINITION

The implementation of Computer Aided Process Planning (CAPP) requires that the following factors be established in the manufacturing environment:

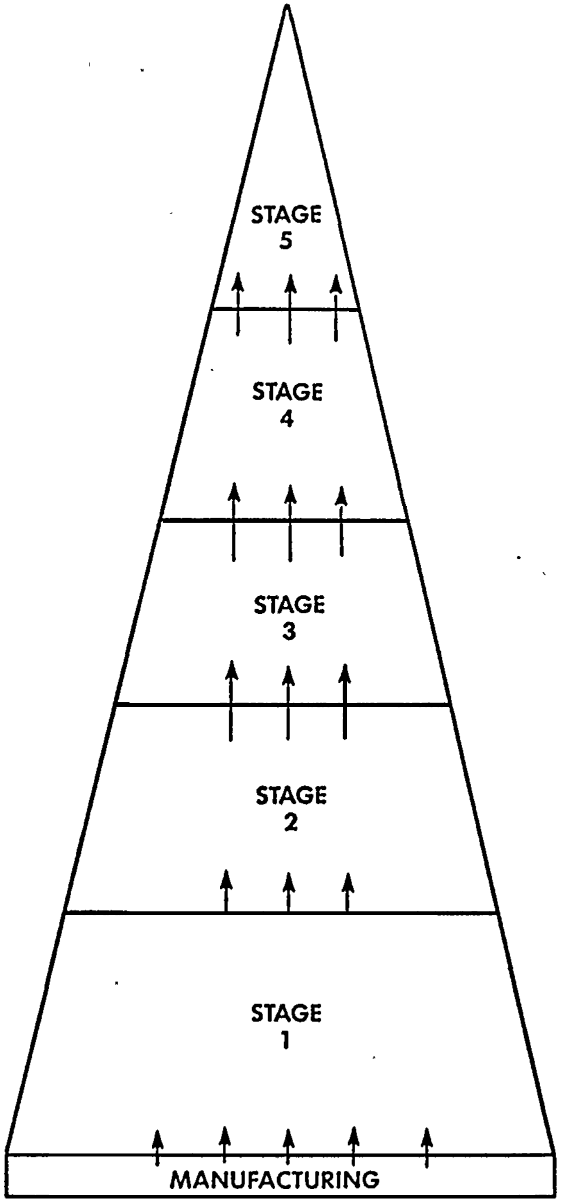
- A consistent vocabulary
- A clear identification of processes
- A clear identification of products
- A simple work content measurement tool
- A measurable definition of shop process lane capacity.

A lack of understanding of these factors could cause the majority of U.S. shipbuilders to believe that automated process planning can only be applied to multiple ship construction programs and perhaps then only to a limited extent where unit similarity and series production can be applied. This opinion is reinforced through constraints imposed by the layout of fabrication shops and through the macro-level view of shipbuilding processes which obscures product/process similarities that exist on the micro-level. Consequently, the implementation of any automated process planning system in a shipyard environment must be preceded by the development of a model that addresses each of these factors and by a training program which explains the model and the logic used to develop it. Once the model is developed, the manufacturing data can be quantified, training can occur and automated process planning can be implemented in the shipbuilding industry. This has already been done in many machine shop-type industries, such as cylindrical shaft and gear manufacturers.

Frank Logan, in his paper "The Five Stages to Automated Process Planning," describes the stages of process .planning using a triangle with manufacturing data as the base upon to which build the manufacturing processes. (see Figure 1). During the initial development of CAPP for shipyards it was discovered that the only type of shop which had repeatable manufacturing data available was the machine shop where the majority of time is expended in machine operations. Machine shops also benefit from the significant amount of work which has been done to develop set-up time parameters. Consequently, the majority of existing CAPP systems are designed for machine shop applications. The U.S. Army Missile Command System, CMPP, is an example of such a system.

Existing machine shop CAPP systems organize the manufacturing data in a logical, structured manner which is easily related to the design, planning, budgeting and scheduling processes. Figure 2 illustrates the basic concept. Classification of individual parts into families of parts with similar attributes early in the design process is a key element of a philosophy developed in the 1930's known as Group Technology (GT). In the "stick building" era of shipbuilding, GT concepts were applied in shipyards as similar interim products were grouped on separate drawings, such as web frames, stiffeners, and shell plates. Similar materials were consequently grouped on each drawing and the assembly process followed a similar, logical pattern using each of the drawings in each stage of construction. With the advent of unit construction, the assembler was forced to deal with all of the drawings at one time since each unit was only a small part of each drawing. The evolution continued and the unit drawing was developed to support the assembly shop personnel. In order to facilitate material control, raw materials were also grouped by unit. This resulted in small pieces of raw material having to be handled by fabrication shops to support the unit assembly process. Unfortunately this has also resulted in the groupings of fabricated items by unit with the result that there are only one or a few in each unit. This naturally reduced efficiencies in the structural fabrication shop and in most of the other fabrication shops as well. CAPP and its inherent requirement to organize manufacturing data in a logical, structured manner can have the effect of bringing the shipbuilding industry full circle. Fabrication shops will once again see World War II type drawings for groups of similar interim products with the added dimension of organizing such drawings based on a schedule window added to achieve "just-in-time" manufacturing.

The recognition of the interim product similarities allows the fabrication shop to group such interim products and fabricate them using a process lanes approach. The resulting repetition of similar work provides learning curve savings. In addition, the processes for each process lane remain relatively constant and the processes can be analyzed for productivity improvement through the use of



AUTOMATIC PROCESS PLANNING DRIVEN BY COMPLEX PART CODING AND MANUFACTURING LOGIC DECODING CAPABILITIES WITH LINKS TO CAD.

SEMI-AUTOMATIC PROCESS PLANNING DRIVEN BY SIMPLE CODING SYSTEMS WITH MANUAL ENTRY OF SOME DATA, E.G., DIMENSIONS.

FEATURE (ATTRIBUTE) DRIVE PROCESS PLANNING FROM GROUPS KEYWORDS AND SIMPLE AUTOMATIC SELECTION OF BASE PARAMETERS.

ENTRY LEVEL INTERACTIVE COMPUTER-AIDED TIME ESTIMATING AND METHODS PLANNING USING QUESTIONS AND/OR PARAMETER DRIVEN MANUFACTURING LOGIC.WHICH HAS DIRECT ACCESS TO TIME/COST STANDARD DATABASE.

TRADITIONAL MANUAL PROCESS PLANNING USING PERSONAL EXPERIENCE TO DERIVE MANUFACTURING LOGIC AND EXTRACT TIME/COST STANDARD DATA AND WRITE OUT MANUFACTURING INFORMATION.

FIG . 1 THE FIVE STAGES OF PROCESS PLANNING

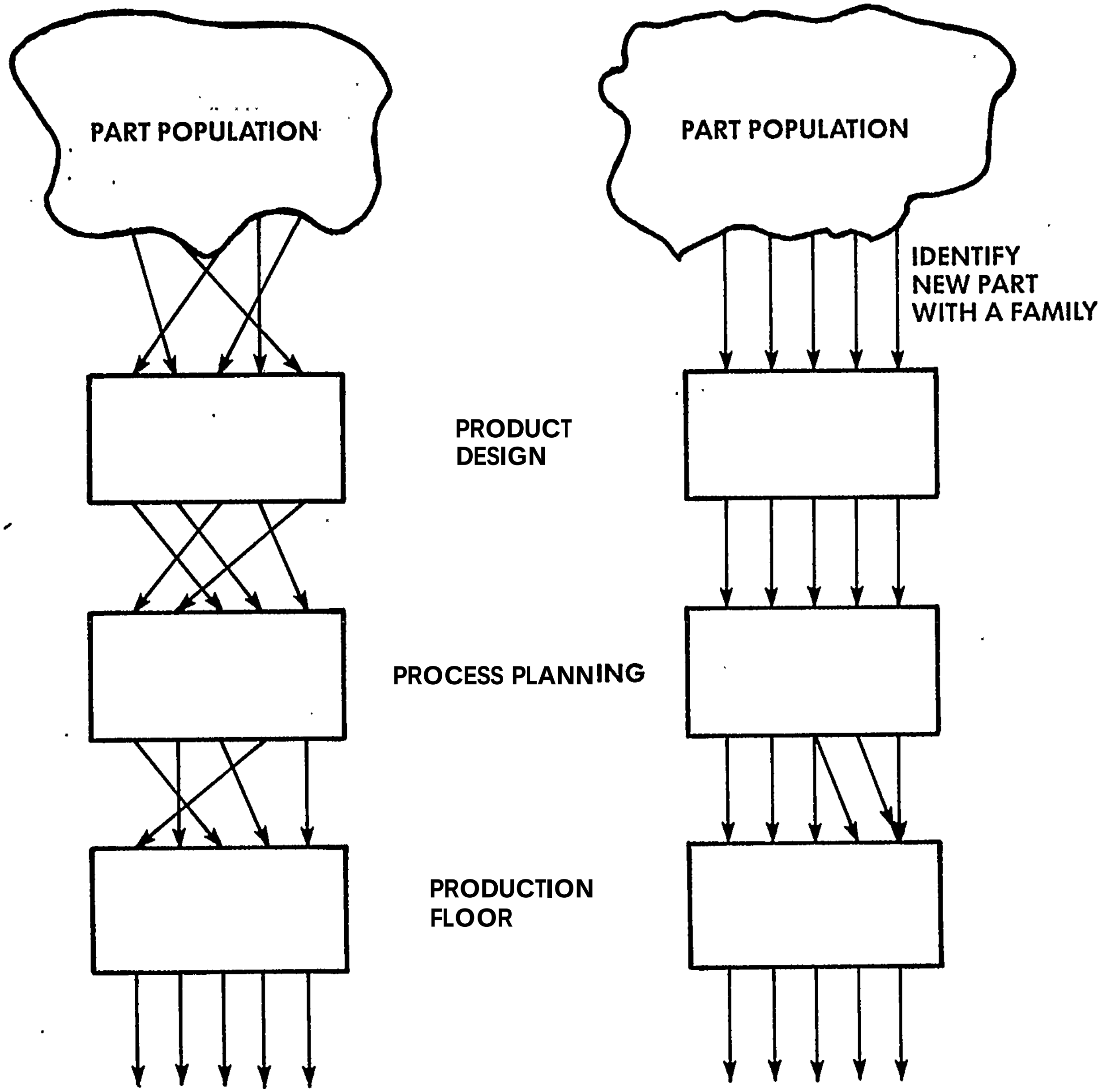


FIG. 2 STRUCTURED MANUFACTURING DATA

jigs and fixtures and/or new or improved technologies. Statistical analysis can also be applied to determine the trends in quality and productivity as well as monitoring the effect of jigs and fixtures and/or new technologies that may have been implemented.

Product/Process Matrix Logic

The National Shipbuilding Research Program publication, "Product Work Breakdown Structure", June 1986, has provided a useful organizational tool for analyzing the shipbuilding process. It subdivides a ship into manageable subsets of interim products.

These interim products can be grouped into families that require similar manufacturing processes. These families of products can further be grouped by the shop or trade that has responsibility for their manufacture. This product/process information for the fabricating trades/shops is presented in a matrix format in Figure 3:

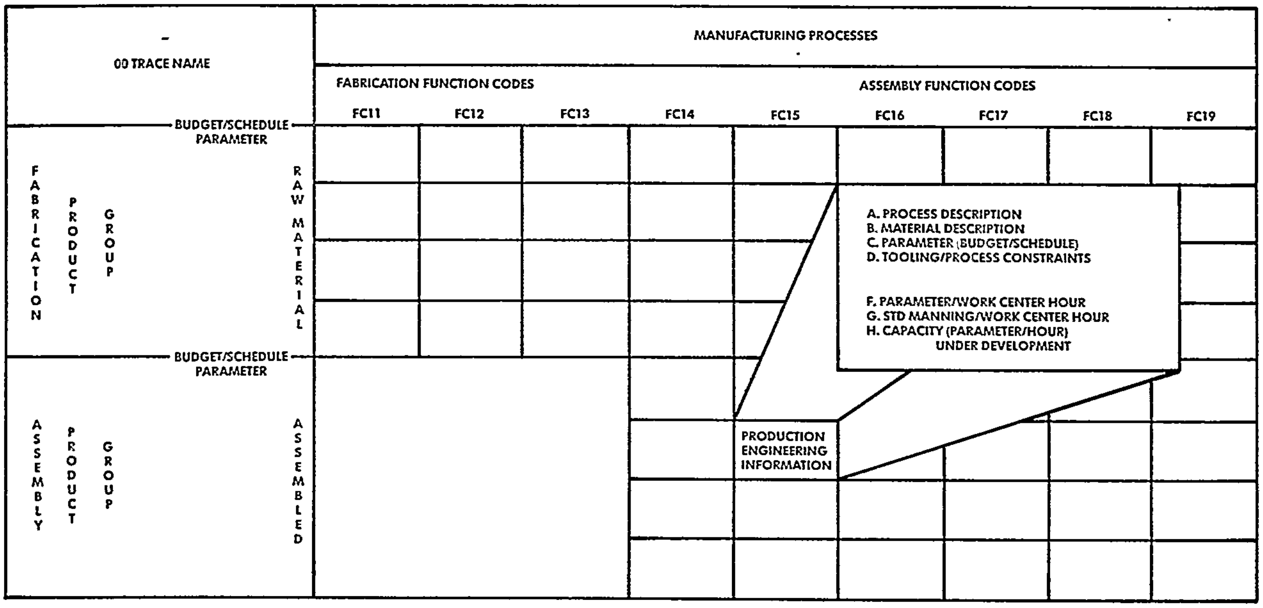


FIG. 3 INTERIM PRODUCT/CONSTRUCTION PROCESS MATRIX

The products are subdivided into two categories: raw materials (including purchased components) and assemblies. The manufacturing processes were found to be similar for all trades and are also divided into two categories: fabrication and assembly.

Raw material is staged for the fabrication processes of cutting and bending. Fabricated components and purchased components are inspected and kitted for the assembly processes of assembly, joining, finishing, quality assurance, and kitting for a later stage in the construction process. These manufacturing processes are further defined by the following function codes:

FC 11 QUEUE - Raw material sorting, moving, kitting, etc.

FC 12 CUTTING - Burning, shearing, sawing, etc.

FC 13 BENDING - Bending, forming, flanging, etc.

FC 14 Q & QC - Fabricated material queue, kitting and quality control

FC 15 ASSEMBLY - Assembly of parts

FC 16 JOINING - Welding, brazing, bolting, etc.

FC 17 FINISHING- Grinding, pickling, coating, etc.

FC 18 QA - Quality Assurance

FC 19 KITTING - Kitting for installation pallet by Product Work Breakdown Structure

The Product/Process Matrix is the tool for systematically identifying the Production Engineering Information required to support effective implementation of a CAPP System. The following Production Engineering Information will complete the matrix for each fabrication shop or assembly area:

- <u>Detailed Process Descriptions</u> - Complete description of each of the different manufacturing process methods available for a given product, including the decision logic followed in determining which method is used.
- <u>Detailed Material Descriptions</u> - Complete descriptions of the raw materials that are typically processed by the shop such as material type and maximum and minimum sizes.
- <u>Tooling and Process Constraints</u> - The capacity constraints for each method described in the Detailed Process Descriptions as well as the handling constraints (size and weight).
- <u>Work Content Parameters</u> - Work content parameters (hereafter referred to as parameters), a work measurement tool, to determine the amount of labor required to complete a task for each interim product. (Examples include the number of pieces to be fitted, the linear feet of weld joint to be fitted, the weld pass length (number of passes X linear feet of weld joint) to be welded, number of pipe pieces to be installed, etc.)
- <u>Efficiency Rates</u> - Efficiency rates calculated by dividing the work content parameter value by the hours required to complete the task.
- <u>Standard Manning Levels</u> - The number of persons that can efficiently be assigned to a interim product, for each specific work site.
- <u>Capacity</u> - Stated as Parameter/Hour, capacity for a work station is calculated by multiplying the Efficiency Rate by the Standard Manning level for each station.

<u>Interim Product/Construction Process Matrices</u>

Product/Construction Process matrices have been developed for each of the BIW fabrication shops. Included in the matrices are examples of the Production Engineering Information covering the detailed process descriptions and the materials used by each shop. Figures 4 and 5 are examples of such matrices. The balance of the BIW manufacturing data is considered proprietary, however, typical examples are provided in Figure 6 to enable the reader to gain a clear understanding of the concepts involved.

Figure 6

Weld Length Efficiency Rates for Structural Shops and Ways

Area	Efficiency Rate (Ft/Hr)
Panel Shop	14.07
Curved Panel Shop	9.73
Assembly Shop	1.51
Ways	0.60

<u>INTERIM PRODUCT FLOW</u>

The material in a fabrication shop spends more of its time in queue or moving from one work site to another than it does in "value added" activities. The flow of material, as well as the queue time, must be known for each interim product family in order to assign schedule durations for each of the products. In a shop where Group Technology (GT) has not been applied to identify interim product similarities, such products are generally handled as unique items and, hence, any data that may have been accumulated to record work site efficiencies or cycle time will vary widely. Once the flow path for "value added" work sites for a particular interim product family is established, the processes can be analyzed, production engineering data gathered and changes with known impacts can be accomplished to improve the productivity.

In developing data for a shipyard CAPP system it is apparent in all shops that the flow path options for material between actual work sites in a shop are nearly infinite. However, when viewed from a GT perspective, the problem becomes manageable. Once again, it is the application of an old technology to form the manufacturing data base for the CAPP triangle.

PRODUCT	QUEUE	CUTTING	BENDING	Q&QC	ASSEMBLY	JOINING	WELDING	QA	KITTING
PLATE	SQ FT								
PARALLEL EDGE PLATE PARTS NON-PARALLEL PLATE PARTS INTERNAL PLATE PARTS	SEQUENCE SORT BLAST/PRIME CONVEY INSIDE STACK	MACH BURN MANUAL BURN SHEAR SAW PUNCH SHEAR	BEND ROLL LINE HEAT FLANGE PUNCH	TO BATH TO WEB LINE TO BULKHEADS TO FOUNDATION TO MISC SMALL PARTS TO COMPLEX 3-D				INSPECT STATUS REPORT	SORT TRESSEL STORE SHIP
SHAPES	LIN FT	—	—	—	—	—	—	—	—
PREFABBED SHAPE INTERNAL PARTS	SEQUENCE SORT BLAST/PRIME CONVEY INSIDE STACK	LAYOUT MANUAL BURN SHEAR	FRAME BEND LINE HEAT TWIST PUNCH DRILL STRAIGHTEN	TO BATH TO WEB LINE TO BULKHEADS TO FOUNDATION TO MISC SMALL PARTS TO COMPLEX 3-D				INSPECT STATUS REPORT	SORT TRESSEL STORE SHIP
WEBS & GIRDERS	—	—	—	—	WELD LENGTH	—	—	—	—
WEBS & GIRDERS FROM SHAPES WEBS & GIRDERS FROM PLATES WEBS & GIRDERS FROM BOTH				FROM SHAPES FROM PLATES FROM MISC SMALL PARTS	LAYOUT POSITION TACK	JOIN TO BULKHEADS TO FOUNDATION TO COMPLEX 3-D	WELD INSPECT PICK-UP	INSPECT STATUS REPORT	SORT RACK STORE SHIP
BULKHEADS, DECKS, & PLATFORMS	—	—	—	—	WELD LENGTH	—	—	—	—
SINGLE PLATE BULKHEAD SINGLE PLATE BULKHEAD W/WEBS MULTIPLE PLATE BULKHEAD MULTIPLE PLATE BULKHEAD W/WEBS				FROM PLATES FROM SHAPES FROM MISC SMALL PARTS FROM WEBS & GIRDERS	JOIN PLATES LAYOUT FRAMING TACK	WEBS & GIRDERS TACK TO COMPLEX 3-D	WELD INSPECT PICK-UP	INSPECT STATUS REPORT	SORT TRESSEL STORE SHIP
FOUNDATIONS	—	—	—	—	—	—	—	—	—
SIMPLE FOUNDATION FROM SHAPE SIMPLE FOUNDATION FROM PLATE SIMPLE FOUNDATION FROM BOTH COMPLEX FOUNDATION FROM SHAPE COMPLEX FOUNDATION FROM PLATE COMPLEX FOUNDATION FROM BOTH		LAYOUT MANUAL BURN PORT PLASMA	ROLL FLANGE SHEAR BEND DRILL	FROM PLATES FROM SHAPES FROM MISC SMALL PARTS FROM WEBS & GIRDERS	WELD LENGTH POSITION TACK	TO BULKHEADS TO COMPLEX 3-D	POSITION WELD INSPECT PICK-UP	INSPECT STATUS REPORT	STORE PICK TRAILER SHIP
MISC SMALL PARTS	—	—	—	—	WELD LENGTH	—	—	—	—
MISC SMALL PARTS FROM PLATE MISC SMALL PARTS FROM SHAPE MISC SMALL PARTS FROM BOTH				FROM PLATES FROM SHAPES	LAYOUT FIT TACK	TO WEB LINE TO BULKHEADS TO FOUNDATION TO COMPLEX 3-D	POSITION WELD INSPECT PICK-UP	INSPECT STATUS REPORT	BOX OR PALLET STORE PICK TRUCK SHIP
DOORS, HATCHES, SCUTTLES	—	—	—	—	QUANTITY	—	—	—	—
(ANY DOOR, HATCH, OR SCUTTL THAT IS)100 LBS SHOULD BE BUILT ON A TABLE IN FOUNDATION AREA)				FROM PLATES FROM SHAPES FROM MISC SMALL PARTS		LAYOUT POSITION TACK TURN BACKFIT	POSITION WELD POSITION WELD INSPECT PICK-UP	INSPECT STATUS REPORT	STORE PICK TRAILER SHIP
COMPLEX 3-D ASSEMBLIES	—	—	—	—	WELD LENGTH	—	—	—	—
COMPLEX 3-D FROM PLATES COMPLEX 3-D FROM SHAPES COMPLEX 3-D FROM BOTH COMPLEX 3-D FROM BOTH (INCLUDING WEBS, GIRDERS, BULKHEADS, MISC SMALL PARTS, FOUNDATIONS, OR ANY COMBINATION OF THESE				FROM PLATES FROM SHAPES FROM MISC SMALL PARTS FROM WEBS & GIRDERS FROM BULKHEADS		LAYOUT POSITION TACK TURN BACKFIT	POSITION WELD POSITION WELD INSPECT PICK-UP	INSPECT STATUS REPORT	STORE PICK TRAILER SHIP

FIG. 4 STRUCTURAL FABRICATION INTERIM PRODUCT/CONSTRUCTION MATRIX

PRODUCT	QUEUE	CUTTING	BENDING	Q&QC	ASSEMBLY	JOINING	FINISHING	QA	KITTING
PIPE FERROUS NON-FERROUS ALUMINUM	LIN FT DRAW	SAW	LAYOUT BEND	TO KITTING TO PIPE ASSEMBLY TO OUTFIT PACKAGE				INSPECT STATUS REPORT	KIT TRANSPORT
HOSE	LIN FIT DRAW	SAW		TO KITTING TO HOSE ASSEMBLY TO OUTFIT PACKAGE				INSPECT STATUS REPORT	KIT TRANSPORT
HANGER MATERIAL	LIN OR SQ FT DRAW	CUT	BEND	TO KITTING TO HANGER ASSEMBLY TO OUTFIT PACKAGE				INSPECT STATUS REPORT	KIT TRANSPORT
WAVE GUIDE	LIN FT DRAW	SAW	BEND	TO KITTING TO WAVE GUIDE ASSEMBLY				INSPECT STATUS REPORT	KIT TRANSPORT
PURCHASED FOR ASSEMI	*QUANTITY*			TO PIPE ASSEMBLY TO HOSE ASSEMBLY TO WAVE GUIDE ASSEMBLY TO OUTFIT PACKAGE				INSPECT STATUS REPORT	KIT TRANSPORT
ASSEMBLED PIPE PIPE WITH 0-1 FITTINGS PIPE WITH 2-5 FITTINGS PIPE WITH 5 OR MORE FITTINGS				LIN FT FROM PIPE FROM PURCHASED FROM HARDINGS FROM MACHINE SHOP	LAYOUT FIT PREP BRAZE OR WELD		TEST INSPECT CLEAN COATINGS	INSPECT STATUS REPORT	KIT TRANSPORT
HOSE ASSEMBLY				LIN FT FROM HOSE MATERIAL FROM PURCHASED	LAYOUT ATTACH FITTINGS		CLEAN TEST	INSPECT STATUS REPORT	KIT TRANSPORT
WAVE GUIDE ASSEMBLY				LIN FT FROM WAVE GUIDE MATERIAL FROM PURCHASED	LAYOUT ATTACH FITTINGS	ASSEMBLE	TEST CLEAN PROTECT	INSPECT STATUS REPORT	KIT TRANSPORT
HANGER ASSEMBLY				QUANTITY	LAYOUT ASSEMBLE	WELD	CLEAN PRIME	INSPECT STATUS REPORT	KIT TRANSPORT
OUTFIT PACKAGE				LIN FT FROM PIPE FROM PURCHASED FORM HARDINGS FROM MACHINE SHOP FROM ASSEMBLED PIPE FROM HANGER ASSEMBLY FROM HOSE ASSEMBLY	LAYOUT ASSEMBLE WELD OR BRAZE	BOLT ASSEMBLIES	TEST CLEAN PAINT	INSPECT STATUS REPORT	KIT TRANSPORT

FIG. 5 PIPE AB INTERIM MATRIX

Interim Product Flow Logic

As in any Industrial Engineering analysis of a material flow problem, the present flow must be determined. Using the fabrication plant layouts, the interim product flow paths are determined. Figure 7 is an example of the material flow in a structural fabrication shop. A natural result of this effort is the identification of "bottlenecks" and "multiple travel paths". The rearrangement of the facility and/or improved organization of material can frequently result in improved interim product flow. As a result of identifying the present material flow, a future material flow layout is prepared. This is simply a plant layout with an improved hopefully "optimum" material flow indicated on the layout. Figure 8 is an example of a proposed material flow aluminum bulkheads. The process of drawing such layouts results in the identification of "value added" work sites, travel distances, travel times, handling frequencies and queue times. All of this information is essential for the development of an effective CAPP system.

In parallel with the material flow layout development. interim product flow diagrams are produced as an expansion of the interim product/ construction process matrices. Separate flow diagrams are developed for each interim product family with all potential "value added" process paths displayed. The flow diagrams are used to analyze the "value added" activities that occur for each product. The term "value added" refers to those processes which add to the worth of the interim product such as cutting a bar or plate to size, shaping a bar or plate, and/or joining two or more pieces together to form an assembly. This effort also identifies "bottle-necks" in the process flow. This is determined by applying the most probable manning and efficiency rates for a specific work site against the work to be completed at that site. The "bottleneck" is the work site with the longest cycle time.

Sample Interim Product Flow Diagrams

Completed material flow diagrams provide the information necessary to identify the "value added" points in the material flow. These points or work sites are identified on the flow diagram. An example diagram is presented for the structural fabrication shop in Figure 9.

It is readily apparent that learning curve efficiencies can be achieved over a short period of time by maintaining a consistent flow within a shop. It also is apparent that the supervisors of shop floor flow control frequently make changes in a sincere effort to improve productivity without being able to analyze the impact of such changes.

The implementation of a CAPP system provides the tools to analyze such changes prior to their implementation.

BUDGET AND SCHEDULE PARAMETERS

One of the key elements of manufacturing data in CAPP is the work measurement tool - "parameter". A parameter is a measurable attribute that will reflect the work content in an interim product. Work content is a measure of the amount of work to be accomplished at a work station. An interim product is any of the products defined as a part of a family of products in the interim product/ construction process matrices defined in the preceding paragraphs. The foreward of the Department of Defense MIL-STD-1567A "Work Measurement" states:

> "Experience has shown that excess manpower and lost time can be identified, reduced and continued method improvements can be made regularly, where work measurements programs have been implemented and conscientiously pursued.
>
> "Active support of the program by all affected levels of management, based on an appreciation of work measurement and its objectives. is vitally important. Work Measurement and the reporting of labor performance is not considered an end in itself but a means to more effective management. Under- standing the implication inherent in the objectives of the work measurement program will promote realization of its full value. It is important that objectives be presented and clearly demonstrated to all personnel who will be closely associated with the program.
>
> "The following are benefits which can accrue as a result of the employment of a work measurement program:
>
> (a) Achieving greater output from a given amount of resources

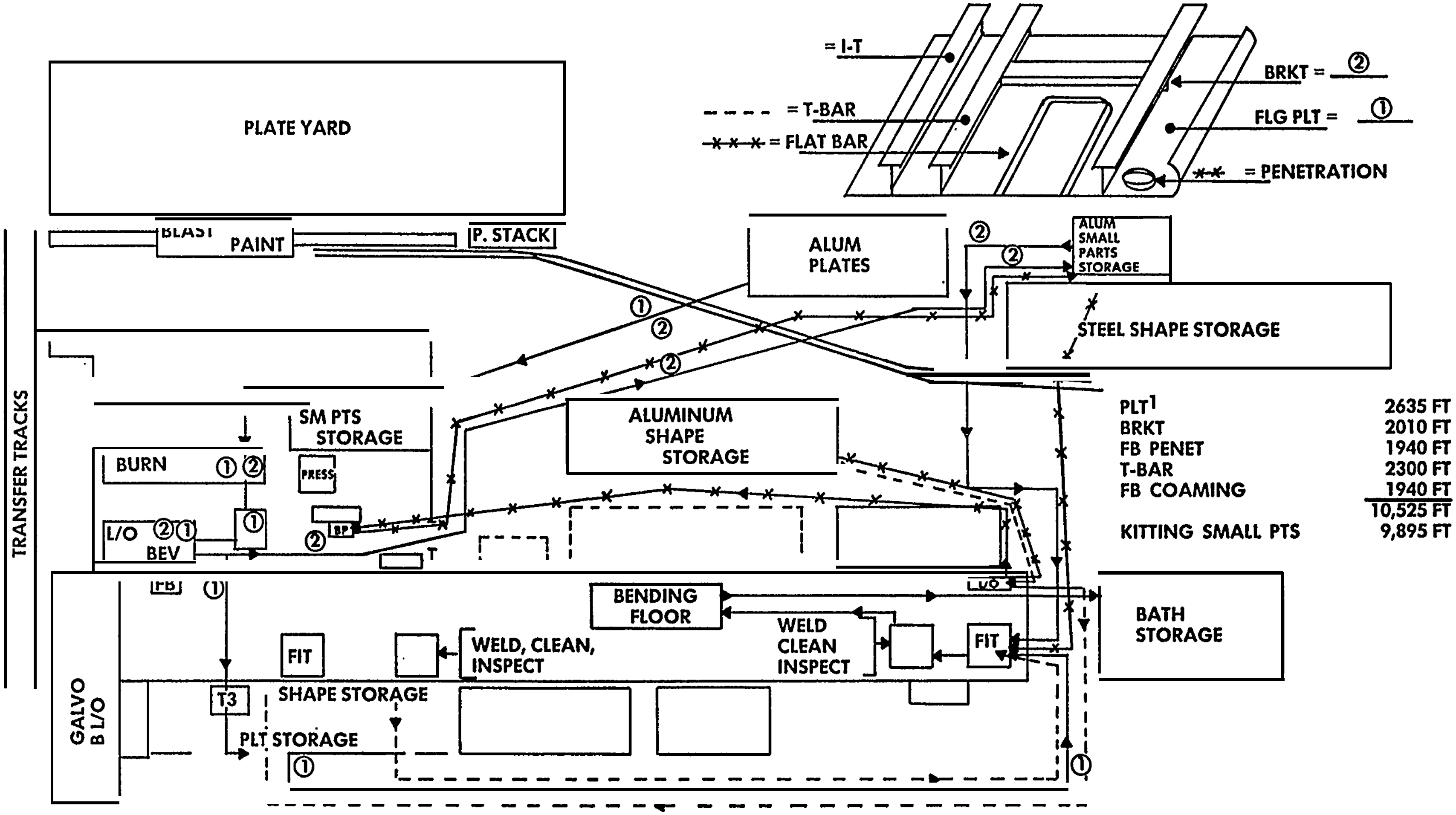


FIG. 7 ALUMINUM BULKHEAD MATERIAL FLOW RE

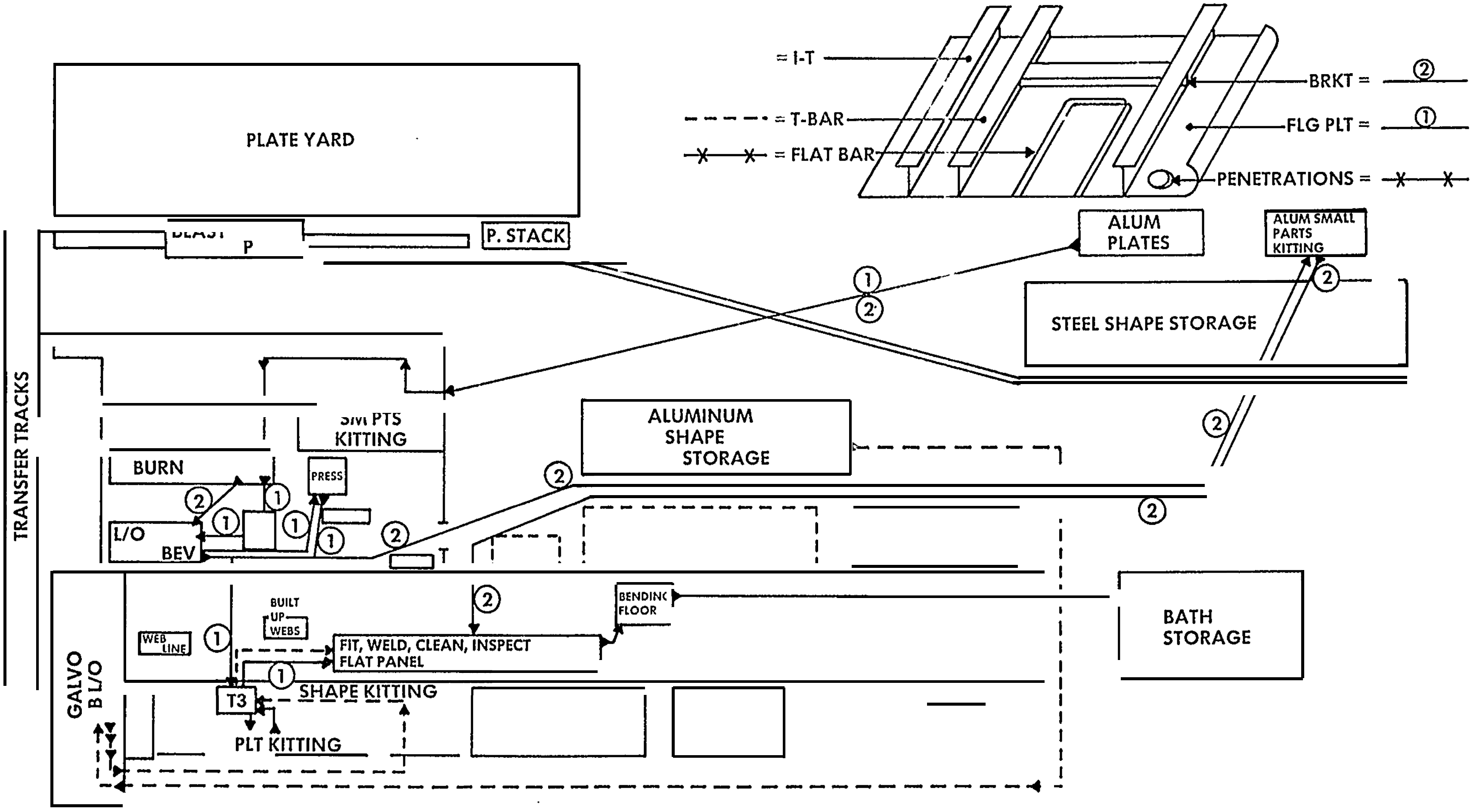


FIG. 8 ALUMINUM BULKHEAD MATERIAL FLOW (FUTURE)

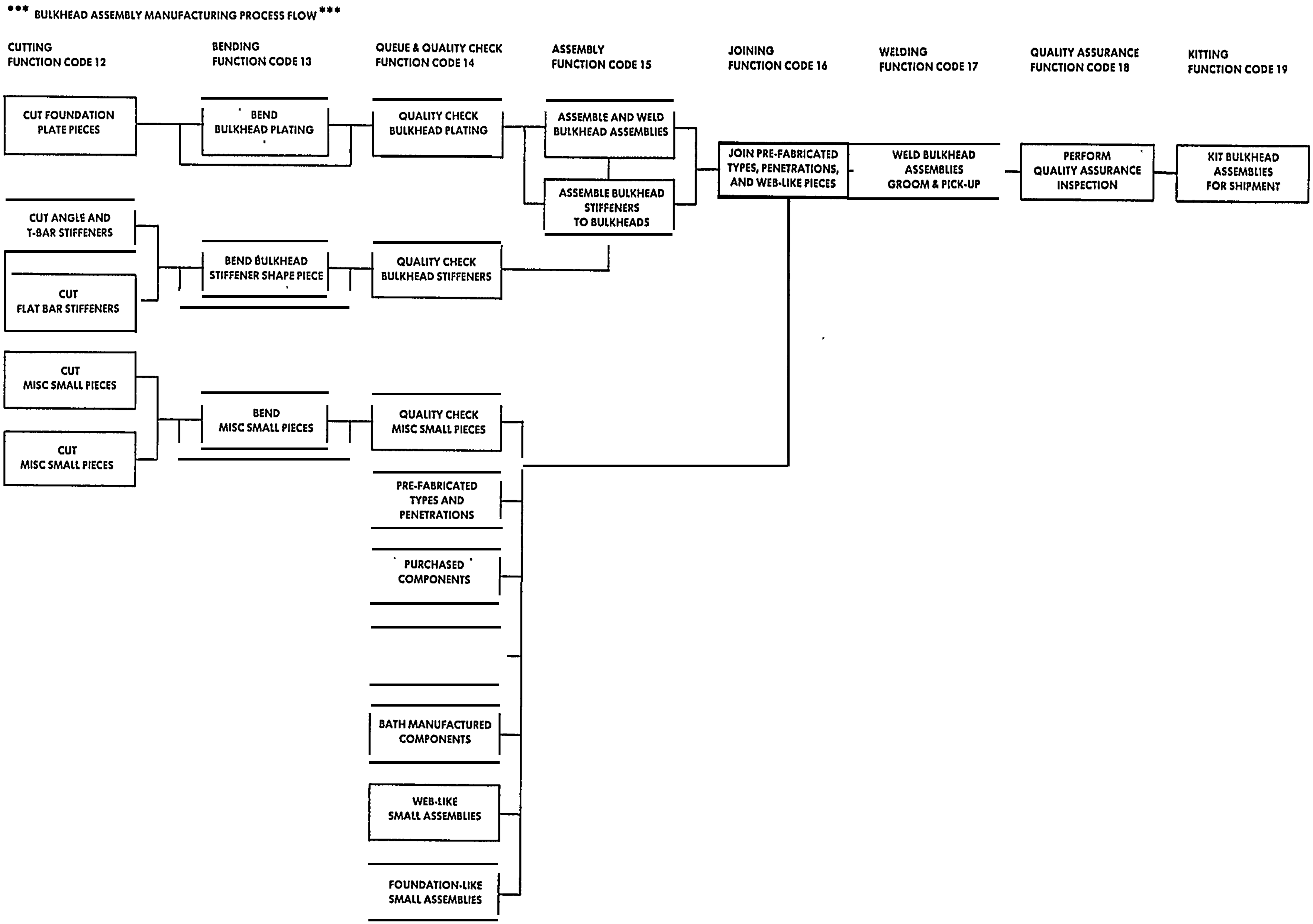


FIG. 9 BULKHEAD ASSEMBLY PROCESS FLOW

(b) Obtaining lower unit cost at all levels of production because production is more efficient

(c) Reducing the amount of wasted time in performing operations

(d) Reducing extra operations and extra equipment needed to perform these operations

(e) Encouraging continued attention to methods and process analysis because of the necessity for achieving improved performance

(f) Improving the budgeting process and providing a basis for price estimating, including the development of Government Cost Estimates and should-cost analyses

(g) Acting as a basis for the planning of long-term manpower equipment, and capital requirements

(h) Improving production control activities and delivery time estimation

(i) Focusing continual attention on cost reduction and cost control

(j) Helping in the solution of layout and materials handling problems by providing accurate figures for planning and usage of such equipment

(k) Providing an objective and measured base from which management and labor can project piecework requirements, earnings and performance incentives.

Without work content measurement tools, the accuracy of a Computer Aided Process Planning (CAPP) system will be reduced considerably and the plan would soon be abandoned due to shop floor congestion or under use as a result of inaccurate cycle times.

Many elements can be used for work content measurement. Example parameters are provided as follow:

EXAMPLE PARAMETERS

Structural Fabrication

	Parameter
Marking/Burning	
Numerical control marking and burning	PL
Flame Planner	PL
Telerex	PL
CM-56 Parts Cutter	PL
Manual marking	PL
Manual burning	PL
Profile cutting	P
Bending	
Profile bending	P
Plate bending	PL
Small piece bending	P
Subassembly	
Fitting	FT
Welding	FT
Finishing	FT
Others	
Material handling	Tons
Shot blasting	PL P
Painting	PL
Flat Assembly	
Plate joining	FT
Fitting	FT
Welding	FT
Finishing	FT
Curved Assembly	
Preparation	Tons
Plate joining	FT
Fitting	FT
Welding	FT
Finishing	FT
Pipe Fabrication	
Pipe	Lin Ft
Hose	Lin Ft
Hanger material	Lin Ft
Wave Guide	Lin Ft
Material handling	Qty
Fittings. flanges, etc.	Qty
Assembled pipe	Qty
Ferrous	Qty
Non-ferrous	Qty
Hose assembly	Lin Ft
Wave Guide assembly	Lin Ft
Hanger assembly	Qty

Sheet Metal Fabrication

	Parameter
sheet Goods	
Grating	Sq Ft
Honeycomb panels	Sq Ft
Plate 1/2”	Sq Ft
Sheet metal	Sq Ft
Shapes	
Angle	Lin Ft
Channel (Deck Shoes)	Lin Ft
Extrusions	Lin Ft
Flat bar	Lin Ft
Pipe or tubing	Lin Ft
Purchased for Assembly	
Comm. equipment	Qty
Cooling coils	Qty
Dampers	Qty
Filter housings	Qty
Gauges	Qty
Heaters & reheaters	Qty
Terminal ends	Qty
Thermostats	Qty
Vent valves	Qty
Rectangular vent	Lin Ft
Round vent	Lin Ft
Foundations	
Simple foundations	Qty
Complex foundations	Qty
2D & Simple 3D	
Access covers	Qty
Cable protectors	Qty
Control panels	Qty
Deck coaming	Qty
Draft marks	Qty
Fire extinguishing fdns	Qty
File stations	Qty
Flange shields	Qty
Floor plates	Qty
Fume tight collars	Qty
Gooseneck	Qty
Grab rods	Qty
Guage boards	Qty
Hangers	Qty
Joiner curtain frames	Qty
Joiner curtain plates	Lin Ft
Ladders	Qty
Light traps	Qty
orifice plates	Qty
Pans	Qty
Penetrations	Qty
Pipe battens	Qty
Protective covers	Qty
Sheathing	Sq Ft
Shelves	Qty
Stowages	Qty
Vent air lifts	Qty
Vent dampers	Qty
Vent flanges	Qty
Vent screens	Qty
Vent terminals	Qty

Exhaust Ducting Intakes/Uptakes

Corten	Lin Ft
Expansion joints	Qty
Sheathing	Sq Ft
Complex 3-D Assembly	
Benches	Qty
Berths	Qty
Bins	Qty
Boxes	Qty
Bulk stowages	Qty
Cabinets	Qty
Commissary equipment	Qty
Counters	Qty
Coupling covers	Qty
Drawers	Qty
Dressers	Qty
Hinged shelves	Qty
Hoods	Qty
Installation fixtures	Qty
Ladders	Qty
Lockers	Qty
Louvers	Qty
Priming chambers	Qty
Power & lighting panels	Qty
Racks	Qty
Service stands	Qty
Sinks	Qty
Stowages	Qty
Tanks	Qty
Reefer Construction	
Reefer boxes	Cu Ft

Electrical Fabrication

	Parameter
Electrical Equip Foundations	Qty
Cable trays	Qty
Light legs	Qty
Terminal boxes	Qty
Distribution boxes	Qty
Complex Manufactured Equipment	Qty
Power Panels	Qty
Switchboards	Qty
Controllers	Qty
Miscellaneous	
Pre-Plug Special Cable	Qty
Purchased or GF Equipment	Qty

Miscellaneous Fabrications

	Parameter
Grating	Sq Ft
Steel	Sq Ft
Aluminum	Sq Ft
Diamond plate	Sq Ft
Operating gear material	Lin Ft

Miscellaneous Fabrications Cont'd)

	Parameter
Shapes	Lin Ft
I-Beam	Lin Ft
Angle bar	Lin Ft
Flat bar	Lin Ft
Round bar	Lin Ft
Wire rope	Lin Ft
Purchased for assembly	Qty
Grating assembly	Sq Ft
Operating gear assembly	Lin Ft
C0₂ pull assembly	Lin Ft
Outfit package	Spc Est
Label plates	Qty

Abbreviations

H = Hour
PL = Plate
Ton = Long Ton (2,240 lbs.)
Sq = Square
P = Piece
FT = Foot
Lin = Linear
Qty = Quantity

Budget and Schedule Parameters Logic

A parameter is simply a measurement of the work content in a task that needs to be completed. It may be the square footage of surface to be blasted or painted, the number of bolts to be installed, or the footage of weld to be deposited. Once the task can be determined by dividing the work content by the time required to complete the task.

$$\text{Efficiency rate} = \frac{\text{Work Content}}{\text{Time}}$$

The efficiency rate is highly dependent on the method used and stage of construction involved, however, for individual work stations it has proven to be very constant. Process changes at a work station or the addition of jigs and fixtures will change the efficiency rate. However, the change should be known in advance because a cost benefit analysis should be completed prior to incorporation of the change.

There are two types of efficiency rates as defined by MIL-STD-1567A. They are defined as follows:

> "Type I Engineered Labor Standards. These are standards established using a recognized technique such as time study, standard data, a recognized predetermined time system or a combination thereof to derive at least 90% of the normal time associated with the labor effort covered by the standard and meeting requirements of paragraph 5.1. Work sampling may be used to supplement or as a check on other more definitive techniques.
>
> **"Type I Engineered Labor Standards. All Type I standards must reflect an accuracy of ±10% with a 90% or greater confidence at the operation level. For short operations, the accuracy requirement may be better met by accumulating small operations into super operations whose times are approximately one-half hour. Type I standards must include:**
>
> a. Documentation of an operations analysis
>
> b. A record of "standard practice or method followed when the standard was developed
>
> c. A record of rating or leveling
>
> d. A record of the standard time computation including allowances
>
> e. A record of observed or predetermined time system time values used in determining the final standard time.
>
> " Type II Labor Standard. All labor standards not meeting the criteria established in paragraph 5.1."

Type I standards are similar to the Maynard Operating system Technique (MOST) data compiled between 1979 and 1985 for the National Shipbuilding Research Program. Figure 10 is an example of such data. Some of these standards can be utilized in implementing a CAPP system. Another example of Type I data is the numerically controlled cutting data available from the AUTOKON data base in the BIW mold loft. Figure 11 is an example of such data. It is noted that the parameter for both types of efficiency rates could be the same. The parameters selected for use at an individual shipyard will most likely be unique for that shipyard.

7.0 STANDARD TIME CALCULATIONS

7.1 Fitting Operations (Level Time) Factors for Hyde Assembly Shop

C. Shell Sub-Assemblies on 90° Diaphragm Mocks

Fitting Operation	Hour/Factor	"MOST" No.
Set, Regulate & Secure (flat assemblies):		
Plates on Mock (mild steel plate)	1.574/ea.	12,30,40
(HY-80)	2.249/ea.	12,30.41
Stringers	.232/ea.	23,30
Webs	.214/ea.	13.30
Set, Regulate & Secure (radius shell assemblies):		
Plates on Mock (mild steel plate)	2.814/ea.	11,12,16.30
(HY-80)	3.097/ea.	11,12,17,30
Stringers	.350/ea.	30,42
Webs	.214/ea.	13,30
Make-up fit & Tack (flat assys): *Shell Seams & Butts		
(mild steel plate)	.048/ft.	14,18
(HY-80)	.099/ft.	15,19
Stringers to Shell (to mild steel)	.023/ft.	24
(to HY-80)	.045/ft.	25
Webs to shell (to mild steel)	.063/ft.	26
(to HY-80)	.098/ft.	27
Make-up fit & Tack (flat assys): *Shell Seams & Butts		
(mild steel plate)	.048/ft.	14,18
(HY-80)	.099/ft.	15,19
Stringers to Shell (to mild steel)	.028/ft.	43
(to HY-80)	.052/ft.	44
Webs to Shell (to mild steel)	.063/ft.	26
(to HY-80)	.098/ft.	27

* Make-up of shell seams also includes installation of strong backs.

FIG. 10 TYPE I PRODUCTION STANDARD EXAMPLE

```
                              NESTED FORMAT = 4010 / 34
CUTTING INFORMATION
  CONTOUR                TIME               LENGTH              SPEED
    PART               MIN : SEC           FT-IN-16             IN/MIN

CUTTING              = 198=10             455-01-11             27.559
RAPID TRANVERSE      = 11= 6              182-01-11            196.850
MARKING              =    1= 9              2-07-15             27.559
REMAINING            =    0=10              0-04-13             27.559
71   PREHEATING   =   7=   6
TOTAL                = 217=41             640-04-02

USED PLATE
     AREA        WEIGHT        %/TOTAL

  217.323      8149.612         62.092
```

FIG. 11 AUTOKON PRODUCTION DATA

structural Fabrication Scheduling

In reviewing scheduling and material flow the most significant factor observed was that "in-process" material remains in queue a much longer time when compared to the "value-added" time at the work site. (Value-added time is that period of time when work is performed on the interim product to increase its value.) The shop schedule, from the master schedule point of view, is a "window" of time for each unit. To control material and manage the process, both the material and the interim products are presently managed by unit in most U.S. shipyards. In identifying interim products for the present unit construction philosophy it is evident that the flow is as shown in Figure 12. The interim products remaining in queue result in shop floor congestion that hampers the productivity of the shop. Multiple flow paths and different construction approaches for similar products negate any learning curve benefits that can be realized based on interim product similarities.

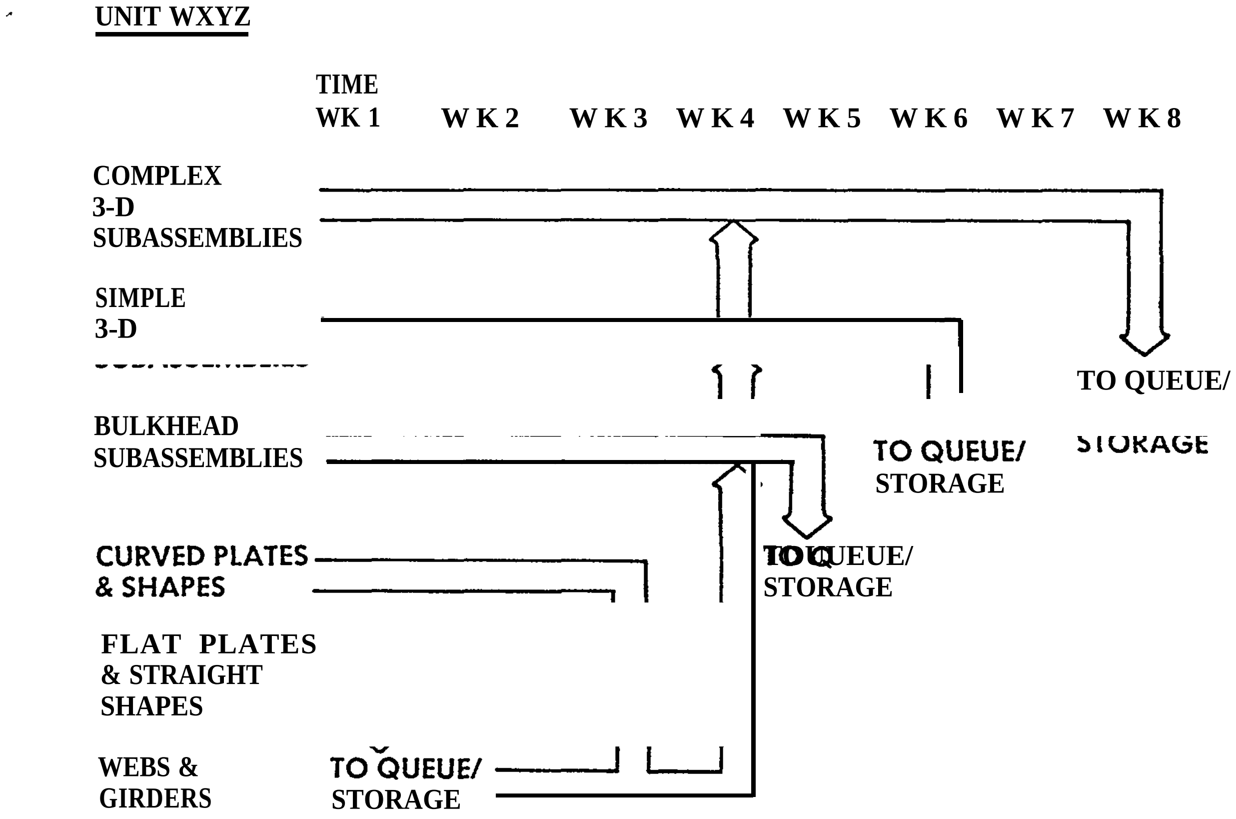


FIG. 12 UNIT FABRICATION SCHEDULE

If a problem with material availability arises. the entire unit is delayed even though its total "value added" time in the cycle is short. When material problems arose during construction, the entire unit construction is halted for several weeks while waiting for a replacement from a raw material supplier.

With the recognition of the interim product/construction process relationship it is possible to further subdivide the unit into similar products and schedule the "value added" time in the shop. Figure 12 is then revised as shown in figure 13.

Integrating interim products across several units demonstrates that a process lane can be level-loaded based on relatively constant efficiency rate returns from each of the work centers.

The manning level at an individual work site is the major factor responsible for meeting schedule needs. With the refinements in the work content measurement approach and efficiency rate returns not only are the schedules more accurate but the projected manning requirements accuracy is increased, thus allowing shop management to more effectively manage the effort.

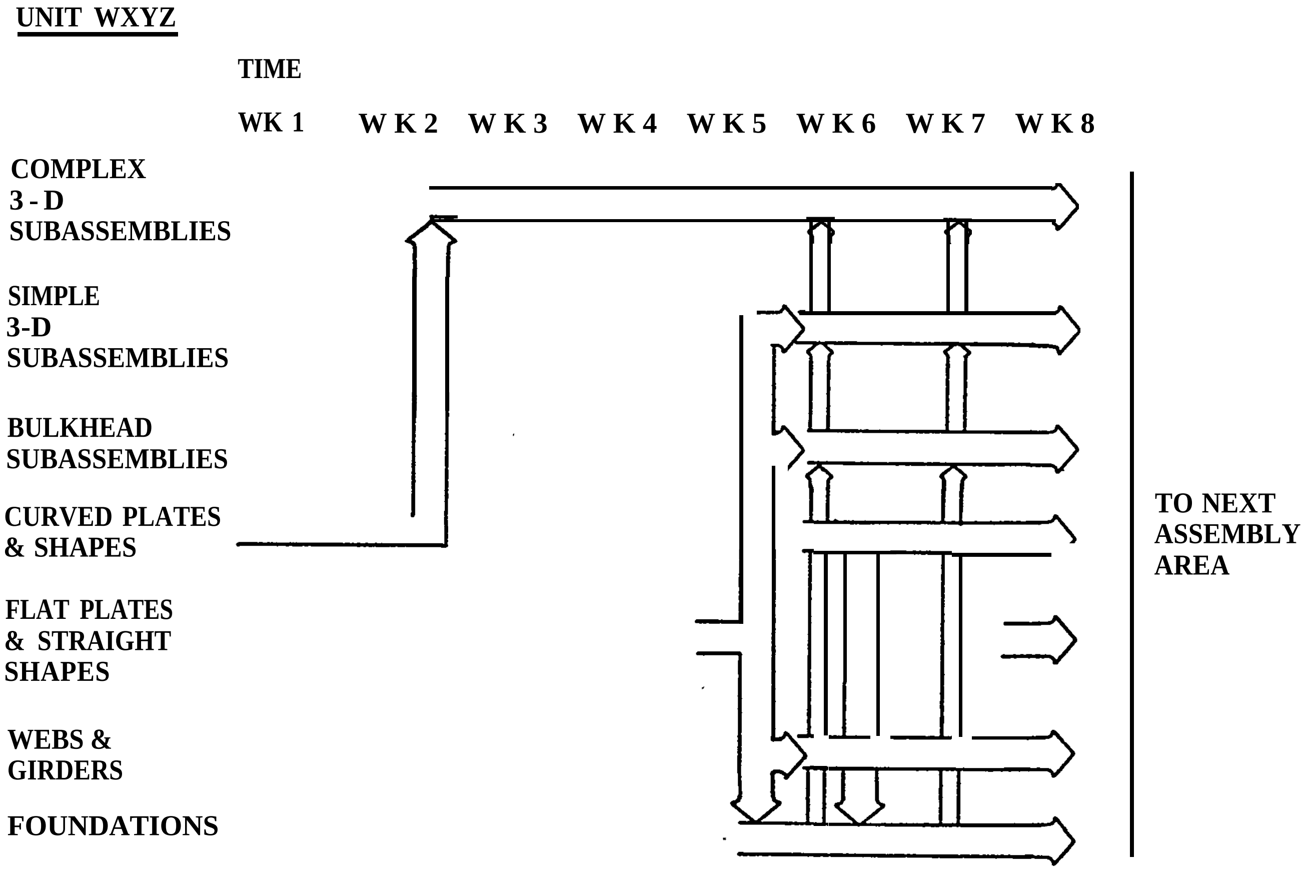


FIG. 13 INTERIM PRODUCT FABRICATION SCHEDULE

To meet the dynamics of shop floor control it is necessary to provide weekly updated schedules that cover a relatively short period. Examples of such schedules are shown in Figures 15-17. These provided a realistic schedule to each station in the shop.

To meet the management needs for shop manning, a three month schedule is provided. Again, each work station is scheduled with a total shop integration to achieve the best possible level-loading of personnel.

CAPP SYSTEMS EVALUATION

The factors required in the manufacturing environment for a Computer Aided Processing Planning (CAPP) system are:

- o A clear identification of product families
- o A clear identification of related processes
- o A consistent vocabulary
- o A simple coding scheme
- o A simple work content measurement tool
- o A measurable definition of shop/process lane capacity
- o An accurate schedule based on shop capacity
- o A clear identification-of required material flow control documentation
- o An identification of data base requirements.

The interim product/process model described in the preceding paragraphs requires that the output from a CAPP system include the following:

- o A process plan for the item to be manufactured based on "product family" characteristics. The process plan should group products with similar manufacturing process requirements in support of process flow lane concepts. There may be several process plans that exist in the individual planner's memory or personal data. These process plans should be accumulated and then combined for optimium effectiveness or

1.25' x 50' FLAT PANEL AREA
2.25' x 50' FLAT PANEL AREA
3.25' x 5O' FLAT PANEL AREA
4.25' x 50' FLAT PANEL AREA
5.10' x 31'TABLE
6, I5'X 30' TABLE
7. B/U WEBB TABLES
8. RUDDER MOCK AREA
9.25' x 50' MI$.C LARGE AREA
10.25' x 50' MISC LARGE AREA
11. 25' x 50' MISC ALUM, MISC LARGE, SPY
12. MISC SMALL STL FIT AREA
13. MISC SMALL STL WELD AREA
14. MISC SMALL STL FIT & WELD AREA
15. MISC SMALL ALUM WELD & CLEAN AREA
16. MISC SMALL ALUM FIT AREA
17. MISC SMALL STL FIT & WELD AREA
18. INDUSTRIL/MISC AREA, TABLES

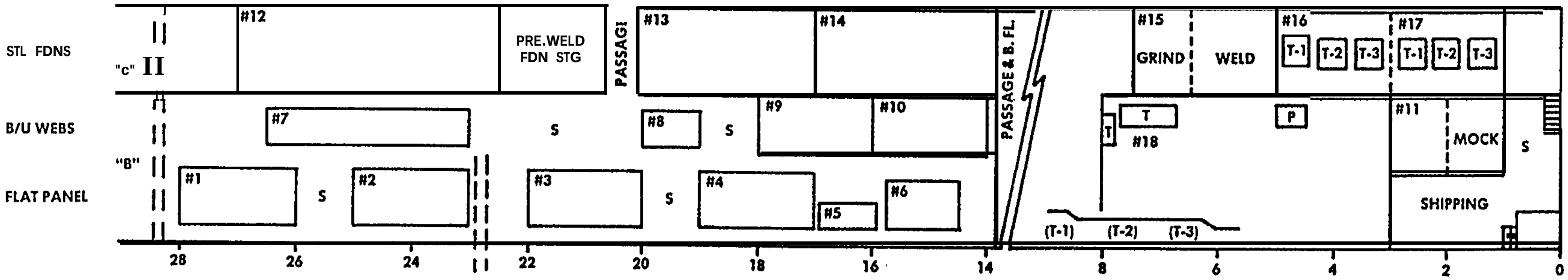


FIG . 14 ASSEMBLY AREAS - STRUCTURAL FABRICATION SHOP

(4) WEEK KIT PLAN BAY "B"

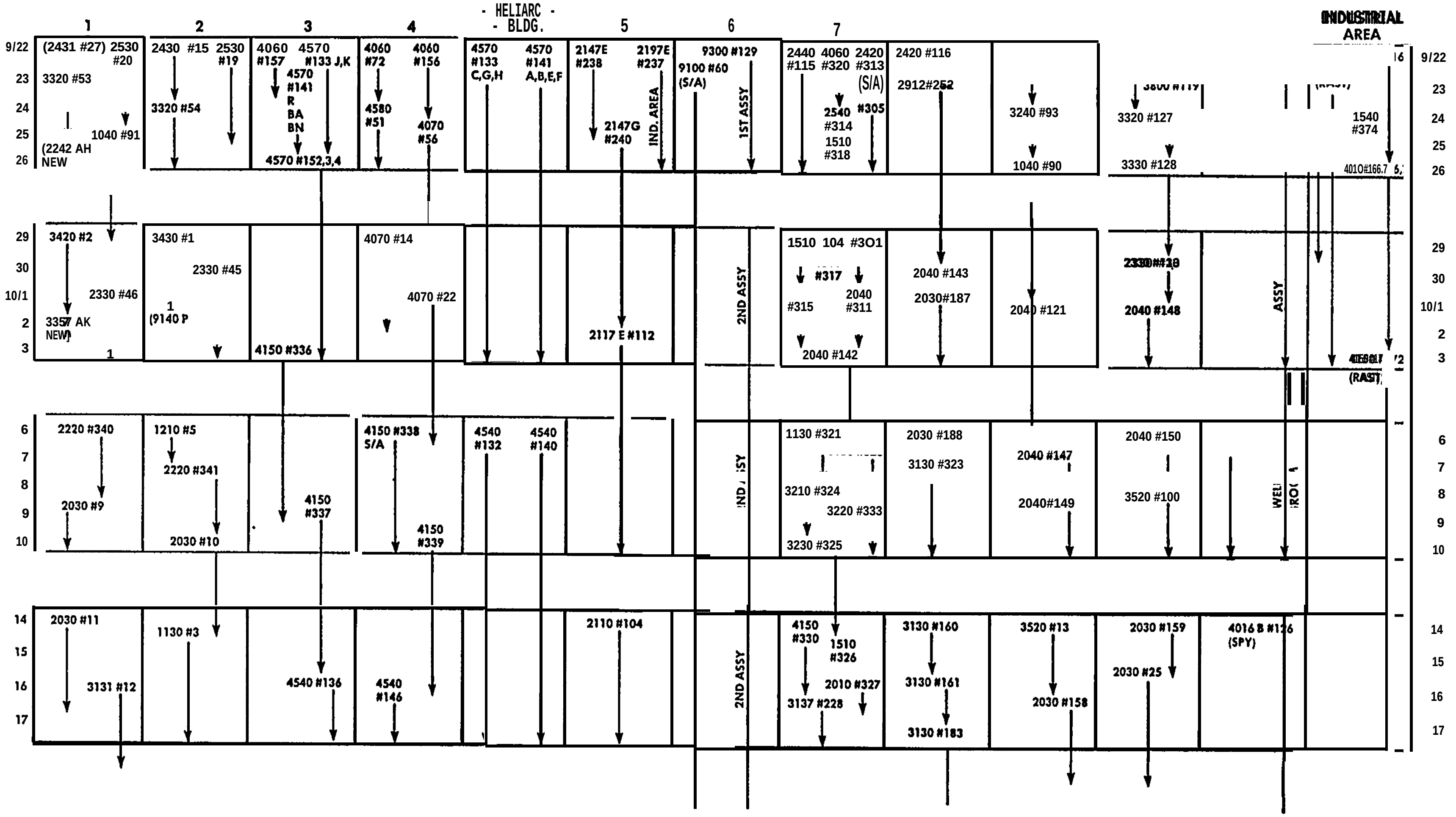


FIG. 15 ASSEMBLY AREA SHORT TERM SCHEDULE

MLJ 9-22-86

HULL / UNIT	KIT #	9-22	9-23	9-24	9-25	9-26		9-29	9-30	10-1	10-2	10-3
1-4050	28 Z	REMAKES										
1-9533	131	↓										
1-4020	253A	☒										
2-2140	239A	☒										
2-2140	241	☒	☒	☒	☒	☒		☒				
2-2241.2	266	☒	☒	☒	☒	☒		☒				
2-2120	261 A	☒										
2-3122,6,7,8	229	☒	☒	☒	☒	☒		A'D KIT				
↓	230	☒	☒	☒	☒	☒						
2-9506	103	☒	☒	☒								
1-4410	280	☒	☒	☒	☒	☒						
WO HPO-068		☒	☒	☒								
1-3800 SZ	276	☒	☒	☒								
2-2933 OP	231	☒	☒	☒	☒	☒		☒				
1-4010	352	☒	☒	☒	☒	☒		JOBS -IT, U 2 H,J,K,L,M,N,R,T,U,V,AC			AD KIT	
2-2546,7,8	285	☒	☒	☒	☒							
2-9511	248	☒	☒	☒	☒	☒						
1-4580	109	☒	☒	☒								
1-2526 F	REV	☒										
1-2236,7,8	282	☒	☒									
↓	282 A	☒	☒									
1-2765 B	REV	☒	☒									
420-9523 D	SS 801 B	☒										
WO# 07-2276	2912 P	☒										
2-9516	291	☒	☒									
2-9521 E	363	☒	☒	☒								
1-9251 BF	NEW			☒	☒							
1-1546	374			☒	☒	☒		☒	☒	☒	☒	
1-3358 W	NEW				☒							
2-3310	221 A							☒				
1-9546	196							☒	☒	☒	☒	☒ +
2-2127,8	262							☒	☒	☒	☒	☒ +
↓	263							☒	☒	☒	☒	☒ +
2-3122,6,7,8	229 A									☒	☒	☒
1-1536,7,8	272 A									☒	☒	☒
1-1700 SZ	277									☒	☒	☒
1-4510	274									☒	☒	☒ +
2-1131,2,6	297 A							☒	☒	☒	☒	☒
1-4010	352 A							☒	☒	☒	☒	☒
	351							☒	☒	☒	☒	☒ +
	353							☒	☒	☒	☒	☒ +
↓	354							☒	☒	☒	☒	☒ +
2-2246,7,8	278							☒	☒	☒	☒	☒ +
2-9511	247							☒	☒			
2-9514	286				☒	☒		☒	☒	☒	☒	☒ +
420-9523 D	SS 718 718 A							☒				☒
1-1511,2,3,4	299											☒ +
1-1600 SZ	287							☒	☒	☒	☒	☒
2-1040	201							☒				
2-2110	288							☒	☒	☒	☒	☒ +
								☒	☒	☒	☒	☒ +
								☒	☒	☒	☒	☒

FIG. 16 SMALL 3-D ASSEMBLY SCHEDULE

combined and segregated to give the best combinations for the various possible scenarios. This task will enhance the completeness of the plans by expanding them to include step by step sequences. manning requirements, tool requirements. equipment control settings, standard time information. technical data sources and charging instructions.

- <u>Assembly or construction drawings or sketches for each stage of the process</u>. This requires that the design process be integrated with the process plan to maximize the effectiveness of the designer's output.
- <u>Raw material sorting and kitting instructions to direct the right pieces and parts to the right place at the right</u> time. Raw material pick lists and the daily sequencing of raw materials into the shop are examples of raw material requirements output.
- <u>Piece, part, subassembly and assembly kitting instructions for each stage of the process</u>. These instructions should include kitting information for the shop's products in support of the major assembly shops.
- <u>Work content for each stage of the assembly process</u>. The work content parameters used should only be at the level necessary to provide information to level-load the process lanes and provide feedback for shop management for productivity monitoring. The work content information can be utilized with the current efficiency rates to determine accurate budget values and schedule durations. Budgets and schedules will then reflect current methods and shop capabilities and can be generated from a computer program that is a part of the CAPP software.
- <u>A level loaded schedule for each of the stages in the process</u>. This should be prepared on a short term basis only (e.g. two week schedule updated weekly) to support the major milestone schedule.
- <u>Weekly product status and work station performance reports providing clear data to shop management</u>. The data should enable shop management to make short term adjustments to the process plans to respond to problems and changes occurring on the shop floor.

The manually prepared documents currently used to control the flow of material at the structural fabrication shop at BIW are as follows:

- Freight Packing Slip - The packing slip received with the raw material from the shipping company.
- Sorting Instruction Sheet - Provides instructions to the material handlers in the plate yard as to the sequence of plates in each plate stack.
- Daily Sequence Sheet - Provides instructions to the material handlers in the plate yard for the sequencing of plates into the shop.
- Material Issue Requisition - Provides information to the material control system as to what material has been issued against a specific unit or charge.
- Material Transfer Document - Provides information to the material control system to identify material that had been allocated to one unit or charge but had been used on another unit or charge.
- Interdepartment Work Order - A request by one department to provide fabricated material for another department that does not have the capability to fabricate the required material within its own shop.
- Interdepartment Shipping Order - Document used to ship the material on an Interdepartment Work Order.
- Fabrication Shop Internal Shipping Order - Document used to ship loose pieces from the layout areas to the next work station.
- Material Storage Location Form - Document used by layout to ship loose pieces to a storage area.

- Retraction Document - Document used to control material from a storage area to a work station.
- Assembly Ordering Form - Document used to request all the pieces and subassemblies to complete an assembly.
- Left Off List - List of items that were not installed into an assembly because of some production constraint.
- Delivery Sheet - Document used to control movement of raw material between storage areas.
- Plate/Shape Loading Sequence Sheets - Document used to load a plate rack and shape rack for shipment of completed material to an assembly site.
- Short Range Order Form - Document used to control shipment of material to an assembly site.
- Long Range Order Form - Document used by the assembly shops to notify the fabrication shop of the future material requirements.
- Bill of Material - A list of all the material required for the assembly of a complete unit.

The required data bases identified for a CAPP system to automatically supply the above lists in the structural fabrication shop include:

- Material Receiving Data Base
- Shapes Location Data Base
- Consolidated Shapes List Data Base
- Plate Stack Data Base
- Shop Schedule Data Base
- Daily Sequence Data Base
- Loft Summary (Piece and Part) Data Base.
- Parameter Data Base
- Efficiency Rate Data Base
- Nest Data Base.

The proposed Consolidated Shapes List, Data Base and Shop Schedule Data Base allow for computer selection of the “shape process lane” items from the Loft Summary Data Base which can be sorted by shape fabrication and/or layout area. Hard copy printouts of the data for the weekly or daily requirements can be provided directly to the structural fabrication shop. Coupling this information with the structural shape location data base provides a pick list for the raw material handlers. This allows the raw material to be provided to the "shape process lane" area on a "just in time" basis. This information can also be integrated across contracts to allow similar materials to be processed concurrently.

The Plate Stack Data Base, based on a preplanned plate storage area, coupled with the Loft Summary Data Base and the Shop Schedule Data Base can provide a pick list (Daily Sequence Data Base) for the raw plate material handlers. Again. this information can be integrated across all contracts to allow similar grade and thickness material to be processed in batches. The nesting of parts, based on schedule requirements, just prior to shop fabrication can increase the usage of standard sized plates and reduce scrap costs. The Nest Data Base would need to be closely coupled with the material charging system to support cost charging against the proper contracts.

The Material Receiving Data Base provides a real time information source to determine the availability of material for the weekly update of the level loaded work station schedules.

The development and maintenance of these data bases provides consistent data control which facilitates the utilization of bar codes for gathering and entering data. Bar codes for recording charging data, material and interim product identification, kit inventorying, raw material control and material control input information can all be provided on the process plan and kitting documentation to allow for bar code data recording. This can increase data input efficiency by a factor of ten and decrease input error to nearly zero.

Group Technology (GT), as described in the National Shipbuilding Research Program report "Product Work Classification and Coding". is an essential element for product family identifications and for the development of a coding system that rationalizes and simplifies the data base information. Organizing the information by common attributes that are required by the users limits the size of the data bases. This organization occurs at various stages of design and construction. In addition, structuring the information in a hierarchical fashion limits the amount of data that must be scanned by the computer to integrate the information for each stage of construction.

INPACT ANALYSES OF COMPUTER AIDED PROCESS PLANNING

As shown in Figure 2, Computer Aided Process Planning (CAPP) has an impact on all phases of the shipbuilding process. Some work areas, such as detailed planning. will experience an increased workload due to the additional information that must be developed to operate a CAPP system. However, the total benefits a shipyard can derive from implementing CAPP far outweighs the workload increase in most areas.

Impact on Preproduction Activities

The greatest impact CAPP has on preproduction activities is that the discipline required to support information retrieval during the planning process results in a more structured approach to the development of that information. General standards relating to classification and coding of parts, subassemblies, assemblies and units are developed to provide a common language for all disciplines. This results in overall improved communications and reduced costs. Specific benefits for each area follow:

1. Estimating. Estimating departments primarily derive a benefit because using parameter values allows the estimate to be based on measurable work content. Current Efficiency Rate Returns from the various shops involved reflect current work practices thus providing up-to-date information for the estimating process. The work content data that is developed during the estimating process can be used to measure the design development against the estimated bid, and for the development of baseline budgets after contract award.

   In fact, data throughout the estimating, design and planning process becomes related. Thus, each step in the estimating, program planning. design, and detail planning process is a refinement of the data developed during the previous stage. The tiered development of data supports the application of design budgets during the design phase and enhances the capability of a shipyard to develop an auditable trail of the effect of both engineering changes in design and methods and process changes in production.

2. Program Planning. Computer Aided Program Planning can be applied in much the same manner as Computer Aided Process Planning. Each can use the same work content and efficiency rate data to develop program planning information such as facility loading, standard program plan language, unit sequencing, and preoutfit levels. Manual or variant Computer Aided Program Planning would most economically serve the needs of a shipyard program planning office due to the text type nature of program plans.

3. Program Scheduling. Program scheduling has potentially the most to gain from the use of a CAPP system. The accuracy of the top level schedules can be significantly enhanced by using the work content developed by estimating and the efficiency rate returns and projected manning for the various yard areas.

4. Budgeting. The development of budgets for the tasks to be completed in the various shipyard areas can become a computer exercise when the work content is broken down into the various stages of construction and the applicable efficiency rates are applied. of course, as the design matures and detailed drawings become available the work content values must be refined to reflect work content on the detailed drawings. Changes in work content are then auditable as far back as the estimating process.

5. Material Lift. Material lift will see little impact from a CAPP system unless "Just-in-time" material nesting on standard plates and shapes is

implemented to suit process lane requirements and capabilities. The primary benefit of such implementation is the elimination of uniquely sized plates and multiple length shapes for each unit. BIW has progressed a considerable distance in this area although "Just-in-time" nesting is not in place. on the CG 51 contract over 3500 plate sizes were required to build the structural hull. For one thickness and grade there were over 250 individual sizes. Through cross-nesting between units within given "schedule windows" this number was reduced to about 2500 on CG 58. On DDG 51 there are 36 plate sizes. Although higher scrap rates will occur until "just in time" nesting is implemented the savings in bulk-buys, lower inventory requirements and elimination of delays due to bad plates is sure to pay for the higher scrap costs by tenfold.

6. Production Drawings. Drawings for the fabrication floor could be grouped by interim product type or process. This could lead to an increase in the number of shop drawings that would be needed if unit relationships are maintained or to a decrease in drawings if the unit relationship was only maintained through an interim product identification code and interim products for each family, are grouped on a single drawing. The workload of the designer could increase if the responsibility for work content measurement was placed on the designer. This could have the additional benefit of making the designer aware of the production work content that may be added to the drawing because of the approach taken in the development of the design. The benefit of being able to retrieve similar past designs reduces the design time required because frequently an existing design or one with minor changes will satisfy requirements. This results in fewer designs and a higher level of productivity in the production shop as a result of learning curve benefits.

7. shop Planning. The greatest benefit will be realized in shop planning. The planning process will be automated through the use of variant or generative process planning systems and the accuracy and consistency of the plan produced will improve. In addition, the completeness and accuracy of information provided as raw material pick lists, interim product kit lists and interim product work content will significantly improve.

8. shop Scheduling. The accuracy of the shop schedules will significantly improve due to "real time" information feedback on efficiency rates, problem areas, and identified bottlenecks.

Impact on Production Activities

1. Material Handling. Material Handling will significantly improve due to several factors:

   o Due to the grouping of products by families, raw material pick lists will be more accurate and timely to support the process lanes. In addition. similar interim products are generally constructed of the same material thus reducing the complexity of the pick list and the picking process.

   o The development of material flow layouts will identify inefficiencies and bottlenecks, and will enhance the material flow.

2. Shop Level-loading. The availability of work content information, and current returns of efficiency rates, coupled with manning projections will enable the planner to level-load the shop to a high degree of accuracy. In addition. shop production management can be made aware of varying manning requirements and respond accordingly.

3. Productivity. The increased accuracy of the schedules, raw material pick lists and kitting lists will improve productivity by having the right material available at the right time. In addition, the construction of similar

interim products in consistent manner will lead to increased productivity through learning curve efficiencies. Also, each step in each process can be analyzed for productivity improvements with changes being incorporated only after the improvements have been verified through simulation techniques.

COMPUTER AIDED PROCESS PLANNING SYSTEM IMPLEMENTATION APPROACH

The implementation of a Computer Aided Process Planning (CAPP) System requires the development of a manufacturing data base which provides interim product/construction process relationships. The prerequisites of such an effort are the identification of similar interim product families and related processes. Once the interim product/process relationships are defined, a consistent approach in applying the processes for producing the interim product must be achieved. When such consistency is achieved, the identification of work content parameters, process constraints and capacity standards can be achieved and the accumulation of data to operate a CAPP system can proceed. A Group Technology (GT) code to facilitate retrieval of the data is, of course, an essential element. As with any project, the procedural steps must be well planned in order for it to be properly managed. Of the utmost importance is ensuring the project has a limited, manageable scope. Encompassing too many processes or too large a production area is a sure step towards failure.

Interim Product/Process Matrix Development

The interim Product/Process matrices presented in the preceding paragraphs are generic in nature and can be used as a first step. It is recommended that the grouping of interim products into families should be reviewed with both production and engineering departments to ensure full acceptance of the matrices. The systematic gathering of the Production Engineering Information proceeds as follows:

- Detailed Process Descriptions: Methods to accomplish each of the processes should be described including any parameter data that is pertinent to the operation. This data is equivalent to the "feeds and speeds" data in a machine shop. A shipyard’s maintenance shop is frequently a valuable source of data, as is the welding engineer's office. The operator is an excellent source in obtaining opinions on the shop equipments' true capabilities.

- Detailed Material Descriptions: The primary source for this information is the shop’s material clerk and the shop planner.

  Engineering personnel are also reliable source; however, the list of materials should be reviewed with the shop personnel to delete any unique materials not familiar to the shop. This provides an automatic flag during the planning process to ensure appropriate procedures are invoked to control the fabrication processes.

- Tooling and Process Constraints: The predominate constraint is often material handling capacity. Capacity information is generally available from a shipyard's industrial engineering office the maintenance office. Work station operators are also an excellent source, especially for safety constraints.

- Work Content Parameters: Yard budgeters are the primary source for useful parameters. Frequently budgeters will have historical data that they use in formulas for estimating the work content of a task. These formulas and the supporting data can frequently be introduced into the software for the selected CAPP system. The identified parameters should be reviewed with the shop floor supervision because they frequently have easy-to-use methods for determining work content and manning requirements. Being the ultimate user of work content parameter data, the shop floor supervisor should have a major input in its selection.

- Efficiency Rates: The initial collection of data for developing efficiency rates may be broad based depending on the method of labor return collection used in the shop. The start-up efficiency rates will generally be Type II labor standards. (the start-up parameter used for the BIW Structural Fabrication shop was linear foot of weld for all assembly processes. The efficiency rate covered all trades, for all processes, from start of assembly to completion of assembly. As the process lanes were developed, the parameter for welders became weld pass length, and for fitters it became fit length or number of pieces.) Once the process lanes become established, Type I labor standards can be determined. Data gathering can then be accomplished for independent steps in the total process. This is probably the first area in which computer assistance is mandatory in order to manage the resulting data base.

o Standard Manning Levels: The establishment of standard manning levels can initially be established based on assembly size. This effort should be coordinated with the shop floor supervisors. The data should be updated after process lane operations have become stabilized.

o Process Lane Capacity: Using efficiency rates and standard manning levels, the throughput capacity for each work station can be determined. This will generally result in one process being a bottleneck for each process lane. These bottlenecks can be analyzed and modifications to each lane implemented to maximize capacity, if production output warrants the changes. If the bottleneck cannot be eliminated, manning for the balance of the process lane must have some flexibility to shift personnel because the bottleneck capacity limits the process lane capacity. In addition, queue storage space for the input and the output of the bottleneck process will generally be required in order to effectively man the balance of the process lane.

Process Lane Development

The start-up of a process lane requires that a number of pre-production activities be established. The following is a list of the essential elements:

o The interim product/construction process matrix to determine which process lanes are required.

o The determination of the parameters to be used to control the manning and scheduling of the process lanes

o The determination of the work content in the interim products to be produced for a period of six to 12 weeks and related Type II efficiency rates to determine which lanes will require some flexibility to construct more than one type of interim product

0 Interim product flow networks to determine cycle times and sample manning

0 Process lane layout to determine work and storage area requirements. equipment locations and material flow.

The remainder of the tasks are described as follows:

o Work Content Measurement
Having determined suitable parameters for each of the interim products. the measurement of the work content can be accomplished. For systems such as AUTOKON, numerical control data burn lengths and burn time can be supplied directly from the system. For other interim products, manual determination of the parameter quantity is generally required. This can best be accomplished by a shop planner who is familiar with the general processes that occur in a shop.

o Interim Product Flow Network

The structural fabrication interim product f1ow networks for Bath Iron Works were presented earlier in this paper. As is evident, the matrices are an expansion of the interim product/process matrix for each interim product family identified. The interim product flow networks can be developed once the basic interim product/construction processes relationships have been established. Using the work content parameter quantities and preliminary efficiency rates. flow networks can be used to simulate production runs of typical interim products. This process can identify potential bottlenecks and indicate the areas in the plant layout where buffer storage sites are required. It is helpful to include the preferred manning and the efficiency rates applicable for each process on the network.

- <u>Process Lane Layout</u>

  The material flow. as it presently exists. will provide a valuable tool for determining the layout of actual process flow lanes. Current flow paths that are established due to handling capabilities and space constraints can be identified. The process lane layout can then be developed based on the current flow and the interim product flow networks. It may be necessary to first develop an ideal layout and then develop the best compromise based on a cost/benefit analysis of each suggested rearrangement of equipment and modification of the flow paths.

  It must be recognized that there may be some flexibility required because of interim product quantities as well as changes necessary due to process refinements or improvements. Once the process lane has been put in place, changes should be controlled and implemented only when analysis substantiates that improvement in <u>total</u> productivity will result.

Scheduling Implementation

The shop floor is a dynamic environment susceptible to equipment failures, material problems and manning variations. The schedule must be capable of adequately responding to such conditions. Therefore it is recommended that the shop floor schedule cover only a two week period and that it be updated on a weekly basis. This allows the shop floor supervisor to manage the work at hand and plan for the coming week. This also enables the scheduler to respond to shop floor problems by rescheduling problem jobs downstream and/or developing appropriate work-arounds.

As presented earlier, the actual scheduling process is relatively simple once the work content is known, efficiency rates have been established and station manning levels stabilize.

CONCLUSIONS

The introduction of Computer Aided Process Planning (CAPP) to shipyards brings with it a structured discipline that can result in a significant productivity increase (10-40%) and cost/time savings. The following summarizes the areas where these savings can be realized.

- The recognition of interim product similarities results in a learning curve savings throughout a single ship program.
- The establishment of process lanes to capitalize on interim product similarities results in repeating processes that can be analyzed for process improvement through the use of jigs and fixtures and/or improved technologies.
- The manufacturing data from the "value added" work sites can be monitored using statistical control methods to determine trends in quality, productivity, manning requirements, and the effect of new technologies.
- The raw material and interim product flow paths. which become somewhat fixed because of process consistency, can be determined and analyzed to reduce redundant moves and improve safety.
- The location of equipment relative to raw material and interim product flow can be analyzed to improve productivity and safety.
- The manufacturing processes and sequencing stored in the individual planner’s memories can be captured and stored on hard copy or in a data bank and the best combination of the individual approaches can be utilized in planning work. In addition, the process plans become consistent for similar tasks because the individual preferences are removed from the process plans.

- The process plans contain improved and more complete information. The process plan information can become similar to that provided in machine shops, such as step by step sequence, manning requirements. tool requirements, equipment control parameters, time requirements, kitting informatior, technical data sources, and charging and shipping instructions.

- Consistent data control enhances the application of bar code technology in providing and gathering data. Bar codes for recording charging data. material and interim product identification, kit inventorying, raw material control and material control system input information can be provided on the process plan and kitting documentation to allow for bar code data recording. This can increase data input efficiency by a factor of ten and decrease input error to nearly zero.

- The manufacturing process planner is freed from routine clerical duties and is able to concentrate on methods improvement and cost reduction changes to the process plans.

- The accuracy and consistency of process plans for new projects is improved, which results in a higher confidence level on the part of shop floor supervision and laborers. Budgets and scheduling information are no longer based on "inspired guesstimates", but are based on work content measurement and "real time efficiency rate returns that reflect current methods and capabilities.

- Budgets and schedules can be computer based using work content information and efficiency rates. Thus the budgeter can spend additional effort to determine actual work content and the scheduler can spend his valuable time resolving scheduling problems.

- Data throughout the estimating, design and planning processes become related. Thus, each step in the estimating, program planning, design and detail planning process is a refinement of the data developed during the previous stage. The tiered development of data supports the application of design budgets during the design phase and enhances the capability of a shipyard to develop an auditable trail of the effect of both engineering changes in design and methods and process changes in production.

- Process planning information remains current due to the feedback loops which result from the structured approach required for a CAPP system.

Investigation of CAPP systems revealed a common thread in all systems in that a GT code is necessary to efficiently manage the manufacturing data base. The National Shipbuilding Research Program report "Product Work Classification and Coding", June 1986, presents a useful approach to developing such a code. The investigation also revealed that the code may include many related attributes that may be required for only specific stages in the design/ planning/manufacturing process. For instance, the functional attributes necessary for design development and customer approval are not necessary for fabrication and installation but may be necessary for system activation and testing. Thus the identifier carried by a product need only include elements to provide traceability through the manufacturing process. Portions of the code may be added or deleted at each stage. It also became apparent that process related attributes should be added as far downstream in time as data processing/scheduling will allow. Thus, it will be possible to react to the dynamics of shop floor problems and changing production requirements.

The code string expands based on the "first-touch” concept. This means that the first person in the process to logically require or identify a data string adds the related data to the interim product identifier. The computer software then operates only on that portion of the data string required for the process or stage for which the document is being provided.

Review of the commercially available CAPP systems revealed that the systems advertised had a wide range of sophistication from simple word processing manipulation of existing process plans to those that provide all of the recognized outputs in some form. The more sophisticated systems, such as General Electric Company's CASA/CAMA, tended to rely on other related programs to provide the necessary output, such as a Material Resource Planning System. Whereas others, such as LOCAM had the option of being a unique, stand alone system.

It can be concluded there are commercially available CAPP system that can be applied to the shipbuilding industry without having to develop a unique set of specifications and software. This is due in large part to the generic approach used in the basic, commerical CAPP software. Section 4.7 of the National Shipbuilding Research Program's "Product Work Classification and Coding", June 1986, presents the D-Class approach to a shipyard CAPP system. Appendix E of "computer Aided Process Planning for Shipyards" August 1986 presents the LOCAM approach. Both approaches capture, in a data base, the manufacturing logic presently contained in the minds and "little black books" of planners and manufacturing engineers. Use of the computer and this decision logic, can now develop consistent, complete, process plans.

The CAPP system is best illustrated in Figure 17.

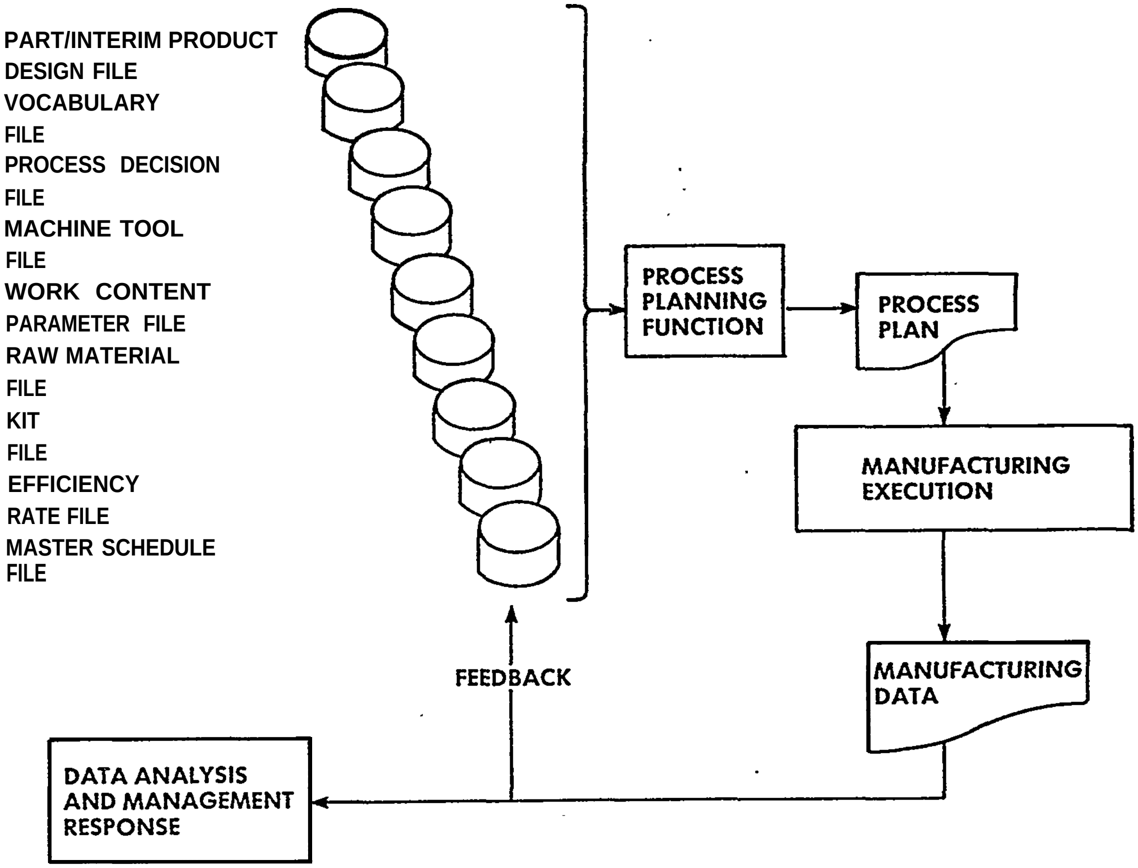


FIG. 17 CAPP SYSTEM OPERATIONS

Design/schedule/manufacturing data **is integrated through the use of** CAPP **system software to develop a** process-plan for each interim product. The results of the process plan are gathered and used to update the data base and to provide information for management action controlling the processes and providing additional feedback to the data base. The approach for each shop is identical with only the data base information changing, based on the parameters required by the interim products.

Recommendations

The development of the structured data base information required for a CAPP system can be very beneficial to a shipyard. Although the actual approach taken by a shipyard for developing such a data base may vary, the basic framework presented earlier should be followed.

It is recommended that the SP-4 panel of the Society of Naval Architects and Marine Engineers fund a limited implementation project to demonstrate the usefulness of a currently operating CAPP system in the shipyard environment.

The project should include:

- o The automated development of Type I time standards for a structural fabrication shop. The "MOST" data developed during the various National Shipbuilding Research Program reports on "Work management" should be used where applicable.
- o The generation of GT Codes for a structural fabrication shop.
- 0 The generation of process plans using a variant process planning system.
- o The generation of process planning documents to support process lanes in a structural fabrication shop.
- o The publishing of a report documenting the results of the implementation project and a projection of expected savings for the implementation of a CAPP system throughout a shipyard.

Acknowledgements

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Soviet Technique for Estimating Post-Welded Deflection: Case of Butt Welding

No. 15

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ABSTRACT

The hulls of modern ships are almost entirely welded. This makes the prediction of postwelded deformations very important. The number of parameters involved in the process of welding are large so the exact mathematical theory for prediction of deformations is unavailable. Some researchers have estimated the postwelded deflections based on empirical and semi-empirical equations. The growing literature on the study of postwelded deflections of hull plates enables the estimation of these deflections based on the plate geometry and the plate material. The limited number of critical parameters covered by these experiments makes it difficult to systematically organize the data. This has delayed the introduction of a framework for estimating the influence on the plate deflection from welding speed, current, number of passes, welding rod size and material, etc.

The approach adopted in the Soviet Union was to develop an integrated framework to include the critical welding parameters. The main Results from this approach were published in several books, with the main reference being a book by Kuzminov published in 1974.

From the standpoint of Ship Production it is useful to understand this Russian approach as well as to give examples of its use. Therefore this paper:

1. Introduces the Russian procedure for calculation of deflection due to butt welding;
2. Presents the graphical aids used in this procedure;
3. Presents a worked example using this procedure for a butt welded plate.

INTRODUCTION

With the introduction of welding to shipbuilding it became necessary to control the out of plane distortions resulting after the welded plates cooled. This postwelded behavior can have a critical influence on the strength of the steel structure. This concern has led to several approaches to dealing with this problem.

1. Postwelded plate deflection measurements of laboratory tests [1], [2].
2. Postwelded plate deflection measurements actual shipbuilding plates [2], [3], [4].
3. Development of semi-empirical formulas to estimate the postwelded plate deflection for a given welding situation [5].
4. Development of numerical codes for estimating the postwelded plate deflection [6].

Due to the large number of critical parameters such as the speed of the welding element, the plate dimensions, the plate thickness, the amount of heat transferred and the cooling process, it has been difficult to perform an analysis of the welding process which often involves large postwelded plate deflections.

This has made it difficult to introduce a methodology to account for all the critical weld parameters. Thus in the work of Antoniou et al. [3], [4] a large number of welded ship plates were studied to relate the postwelded out of plane deflection patterns to the plate geometry and thickness under the assumption that the welding process is repeatable. The interested reader can also find an extensive number of results for different weldments in the book of Professor K. Masubuchi [2].

While these works provide guidance, they are unable to completely account for the welding parameters. In contrast, the welding research in the Soviet Union has attempted to account for the welding parameters through a specially developed methodology which treats the welding process contributing to the postwelded deflection. This Soviet methodology is presented in a semi-empirical format described in the book of S. A. Kuzminov [5]. This book incorporates the results of numerous experiments and is based on the principles of heat transfer and strength of materials. In developing this method, Kuzminov made use of 109 Russian works on the subject of welding and post-weld deformations in fillet and butt welded steel structures. The comprehensiveness of this method can be understood from Table 1 which summarizes the input parameters used to estimate the post-welded plate deflections resulting from butt welding of two plates.

Using the input data in Table I a number of graphs and semi-empirical formulas are employed to calculate the following:

a) Longitudinal shortening of the welded structure. If it exceeds a critical value, the structure becomes unstable and this results in additional out-of-plane deflections.
b) Heat energy of weld per unit length. This energy depends on the number of passes, flux presence, etc. This heat energy and additional parameters are used to find the angular deformation of the butt welded structure after each weld pass.
c) The total angular deformation and normal deflection. These are obtained as the sum of angular deformation resulting from each pass. If the welded plates are found to be unstable the corresponding deformations are also added.

In this paper we present the outline of Kuzminov's method applied to postwelded deformations of butt welded plates. A numerical example is given to illustrate the application of his methodology.

The utilityof this paper is that it enables the reader to come to an understanding of the relationship of the welding process with the final deflections, as well as to provide the reader with a framework for conducting future research on the determination of postwelded deflections.

ANALYSIS

Figure 1 shows the cross section of a plate of thickness t_p made up by butt welding flat sections of width b. The postwelded deformation is due to the angular deformation denoted as β taken at plate butt welded edges. Fig. 1 shows typical section which is not influenced by the presence of side structure.

The maximum out-of-plane deflection of the plate mid-span is given by:

$$f_\beta = \frac{\beta b}{8} \tag{1}$$

In some cases the plate edges are restrained as shown in Fig. 2. In such a situation the maximum plate deflection is given by:

$$\cdot_\beta = 0.037\ \beta a \tag{2}$$

where a is the distance between the restricted edges.

The plate can become unstable from the longitudinal shortening at the welds occurring after the edge restrictions are removed. The condition of instability is given by

$$\frac{v}{b\,t_p} > \varepsilon_{cr} \tag{3}$$

Table 1. Summary of Input Data Used in Estimating Post Welded Plate Deflection Caused by Butt Welding [5]

Input Data

a) Geometry of Plates (length, width, and thickness)

b) Material Data:

- Coefficient of linear expansion
- Density
- Specific heat capacity
- Strain at yield point
- Modulus of elasticity
- Poisson's ratio
- Thermal conductivity
- Melting point
- Yield temperature
- Strain corresponding to the yield limit

c) Welding Data:

- Electrode diameter
- Weld velocity
- Current and voltage

---

where

v = the volume of longitudinal shortening of the butt weld per unit length (cm^3/cm)

b = width of the butt welded plate sections (cm)

E_{cr} critical value of deformation.

The critical value of deformation E_{cr} can be approximately determined using:

$$E_{cr} — 0.9\ \frac{p}{}\ \left(1+0.448\ \frac{f_\beta^{L}}{{}^{\prime}P}\right) \tag{4}$$

ℓ being the length of the plate.

The volume of longitudinal shortening per unit length is given by

$$v = K_m V_m \tag{5}$$

where Km is a coefficient given by

$$K_m = I + \frac{\varepsilon_s m}{8\ y}\ \frac{o}{c\gamma}\ \theta \tag{6}$$

where m is the number of passes,

ε_s is the strain corresponding to the yield limit of the material,

γ is the density of the material, g/cm^3

c is the specific heat capacity of plate, cal/g x °C

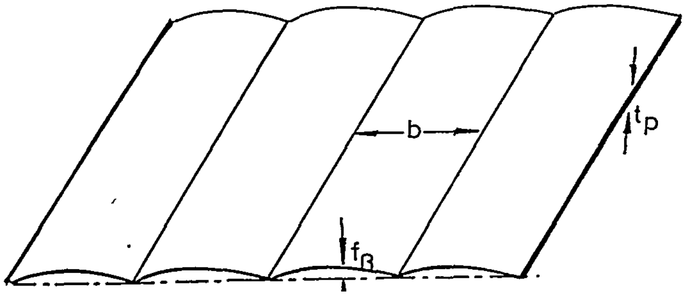


Fig. 1. Geometry of Butt Welded Plates without Constrained Edges [5]

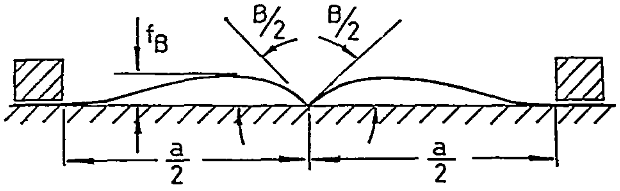


Fig. 2. Geometry of Butt Welded Plates with Constrained Edges [5]

a_o $\frac{\lambda}{Cy}$ is the rate of heat transfer in the plate, cm²/sec.

A is the thermal conductivity, cal/cm x sec x °C

θ is the coefficient of proportionality between the heat energy per unit length and the cross sectional area of the weld, cal/cm³

V_m is the volume of shortening due to one pass

If the number of passes are equal to 3 or less $K_m \approx 1$ and

$$v = V_m \sim 0.29 \frac{\alpha}{c\gamma} q_P$$

For mild steel plates

$$v \simeq V_m \simeq 3.6 \times 10^{-6} q_p \tag{8}$$

If the inequality (3) is satisfied, i.e., the plate becomes unstable the deformation f can be calculated as:

$$f = 0.6\, \ell \sqrt{\frac{\text{[illegible]}}{h\, t_p}} - \varepsilon_{cr} \tag{9}$$

The heat energy per unit length of butt welded plate is estimated from:

$$q_p = 0.24 \frac{IU}{V} \eta \quad \text{(cal/cm)} \qquad \text{(lo)}$$

where 1 = welding current (amps)
U = voltage of arc (volts)
V = speed of welding (cm/sec)
η = effective efficiency based on welding material.

Typically $0.65 \leq \eta < 0.80$.

If welding is performed under flux a part of the heat energy is absorbed by the heating and melting of the flux. This lost heat energy q_{nf} can be estimated based on the heat energy given by (10):

$$q_{nf} = \eta_f q_p \tag{11}$$

The coefficient K_f is given in Fig. 3 as a function of electrode diameter d_e. Measurements have indicated that K_f falls between curves 1, 2 in Fig. 3. The dashed line in Fig. 3 can be used to give representative K_f values when performing calculations.

The angular deformation β due to multi-pass butt welding can be found as

$$\beta = \sum_{i=1} (\pm \beta_i) \tag{12}$$

where m is the number of passes and β_i can be determined using Fig. 4.

The sign "+" in (12) corresponds to the case when the angle between the welded plates measured from the upper surface decreases when the weld pass is completed. The sign "-" corresponds to the case when the angle increases.

The parameter S in Fig. 4 is calculated by

$$S = s\psi_n \eta_n \frac{q^1_p}{t^2_{i=1}} \quad \text{(cal/cm}^2\text{)} \tag{13}$$

where q^1_p = effective heat energy per unit length, cal/cm.
ψ_n = relative heating coefficient
η_o = heat transfer efficiency
t_i = height of the cross section of the-butt weld after the i-th pass (cm) as shown in Fig. 5.

It is necessary to determine the value of S from the welding processes. For arc welding the welding electrode diameter d_e, the separation gap between the plate and the electrode, and the current I are critical parameters. Fig. 6A shows the zones affected by the welding. To characterize the extent of influence the width b. and depth ho are introduced to define the relative heating coefficient ψ_n.

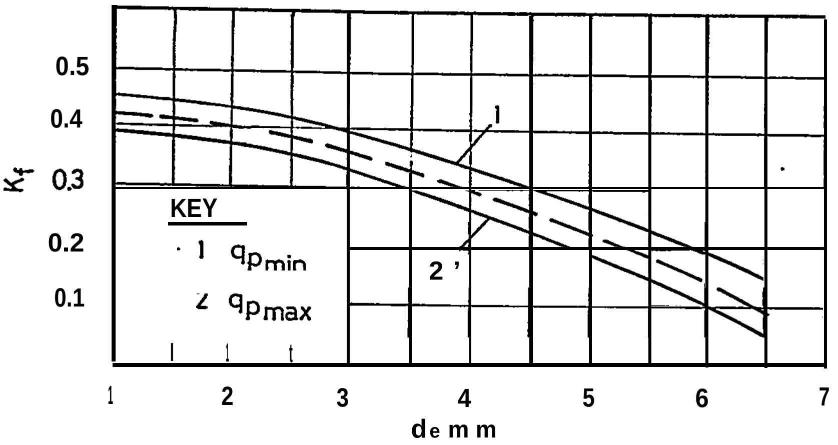


Fig. 3. Coefficient of Flux Heat Energy K_f versus Welding Electrode Diameter d_{-} [5].

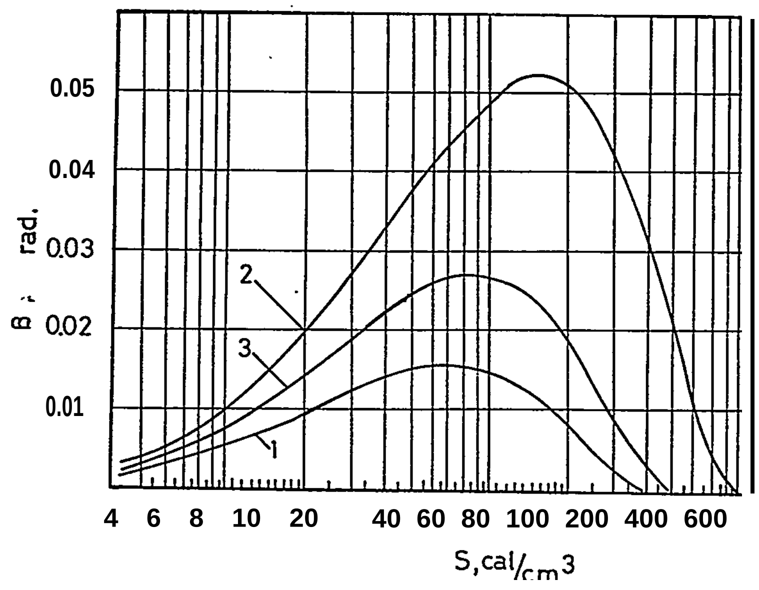


Fig. 4. Post Welded Plate Deflection Angle ß versus Heating Intensity Parameter S [5].
1: Welding with restrained edges; 2: welding with unrestrained edges, 3: multipass welding

$$\psi_{-} = h_o/b_0 \tag{14}$$

A number of tests with hull plates showed that the ratio of ho/ho is within the following limits

$$1.1\ h/b < h_{-}/b_{-} < 1.2\ h/b \tag{15}$$

Fig. 6 B presents the results from a number of tests where the current and electrode diameter were varied and the value of ψ_{-} was measured.

Further studies showed that the heat transmission during welding could be characterized by the parameter ε.

$$E = \frac{q'_{-}V^2}{c\gamma T_{-}a_{-}^{2}} = \frac{q'_{-}V^2}{\lambda T_{-}a_{-}} \tag{16}$$

where V is the velocity of welding electrode, cm/se

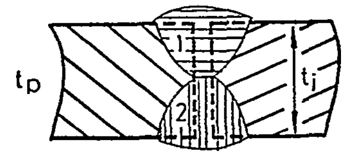
T_o is the yield temperature of plate, °C

The value of q'_p has a complex relationship with the welding regime and geometry of the welded plate. To express this relationship the following formulas were introduced to cover typical welding practice:

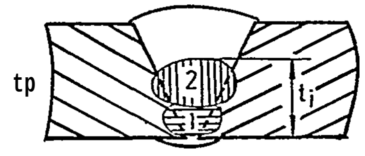
a) One or two passes; manual welding

$$q\ ^{2}{}_{P}\ ^{q}P \tag{17}$$

a) Vertical Edges



b) 'V' Notched Edges



c) X or K Edges

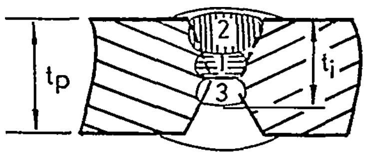


Fig. 5. Illustration of Butt Weld Cross Section Height t_i for Various Plate Edge Geometries [5].

b) One or two passes; welding under flux

$$q'_p = (1 - K_t K_f)\, q_p \tag{18}$$

c) Multipass welding; manual

$$q'_p = K_{pi}\, q_p \tag{19}$$

d) Multipass welding under flux

$$q'_p = K_{pi}\,(1 - K_t K_f)\, q_p \tag{20}$$

In equations (18), (20) the contraction coefficient K_t appears.

To estimate the contraction coefficient K_t, representing the effect of the plate thickness the heat intensity P is introduced.

The heat intensity P in Fig. 7 is calculated using:

$$P = p\eta_o\psi_o \frac{q'_p}{t_i^2} \quad (\mathrm{cal/cm^3}) \tag{21}$$

where P is a coefficient given by

$$P = \frac{1450}{c\gamma T_m} \tag{22}$$

η_o is given in Fig. 8 as a function of e (eq. 16). ψ_o is given in Fig. 6B. The coefficient K_{pi} has to be found from Fig. 9 being a function of the weld pass number, N. Curve 1 corresponds to the values of the coefficient K_{pi}. for X and K shaped plate edges.

Curve 2 gives the coefficient for the V shaped plate edges, while curve 3 corresponds to the side opposite the weld pass for X and K shaped edges.

The values of the coefficient η_o can be found by performing several iterations since P depends on q'_p which is a function of K_t given by Fig. 7.

The coefficient s in Eq. (13) is determined from

$$s = 100 \frac{\alpha}{c\gamma\varepsilon_s} \tag{23}$$

where a = coefficient of linear expansion.

In this manner the angular deformation of the post butt welded plate can be estimated and the maximum out-of-plane deflection can be found using the corresponding Eqs. (1) or (2).

NUMERICAL EXAMPLE

In the representative example-we consider the angular deformation of a butt welded plate whose whickness is t_p = 14 mm (1 pass). The welding regine was:

d_e = 5 mm, 1 = 990 amp, U = 40 volts,

V = 35 m/hour

Automatic welding under flux.

The data based on the plate material is as follows:

a = 12.7×10^{-6} 1/°C

c = 0.13 cal/g °C

γ = 7.85 g/cm^3

E_s = 12×10^{-4}

$_0$ = 750 °C

a_o = 0.068 cm^2/sec

p = 1 η = 0.85

Solution

From (1o)we obtain q_p = 8300 cal/cam

From Fig. 3 K_f = 0.25

$q'_p = (1 - K_f)\, q_p$ = 6230 cal/cm

$\frac{q'_p}{t^2}$ = 3180 cal cm^3

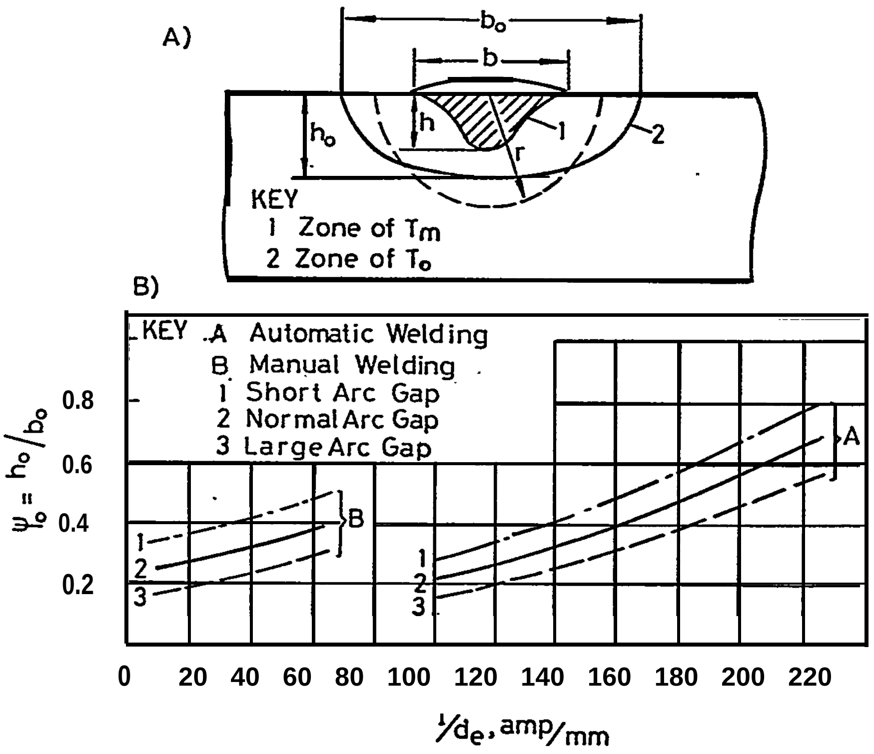


Fig. 6. Illustration of Zones Influenced by Welding [s].
A. Equivalent zone at yield temperature T_o T_m = melting temperature
B. Relative heating coefficient ψ_o versus current to electrode diameter ratio I/d.

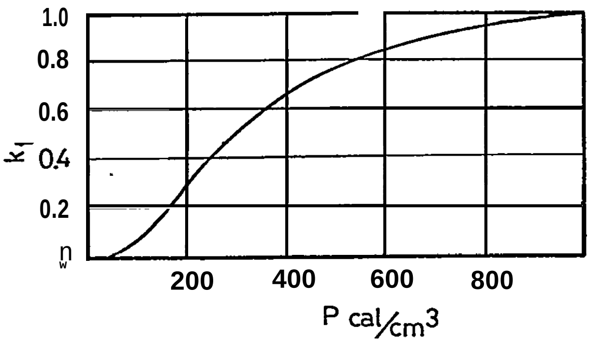


Fig. 7. Heated Plate Contraction Coefficient K_t versus Heat Intensity Parameter p [5].

Fom Fig. 6B for I/d_e = 198 amp/mm ψ_o = 0.56

From Fig. 8 for $\varepsilon = \frac{q'_p V^-}{c\gamma T_m a_m} = 1270$ $\eta_c = 0.23$

From Fig. 7 for P = 410 cal/cm^3 K_t=0.72

From (18) q'_m = (1-0.25x0.72)8300=6800 cal/cm

Note that now a corrected value of η_c can be found.

From (23) s = 1

From (13) $S = s\psi_o\eta_c \frac{p}{2} = 450$ cal/cm^3

From Fig. 4 ß= O if the plate restrained against bending B = 0.025 rad. the plate is not restrained.

Note that in the case when the plate is restrained against bending we have to check its stability after the edge restrictions are removed.

DISCUSSION AND CONCLUSION

This paper has illustrated the methodology adopted by the Soviet researchers in treating the estimation of post welded deformation of butt welded plates. The welding process was treated as an initial heat input which was modified by the process speed, weld pass, the presence of flux, etc. A numerical example has been presented to illustrate how this information is used.

While this is useful for practical work the framework illustrated in this paper can easily be extended to handle U. S. or European standard equipment such as welding

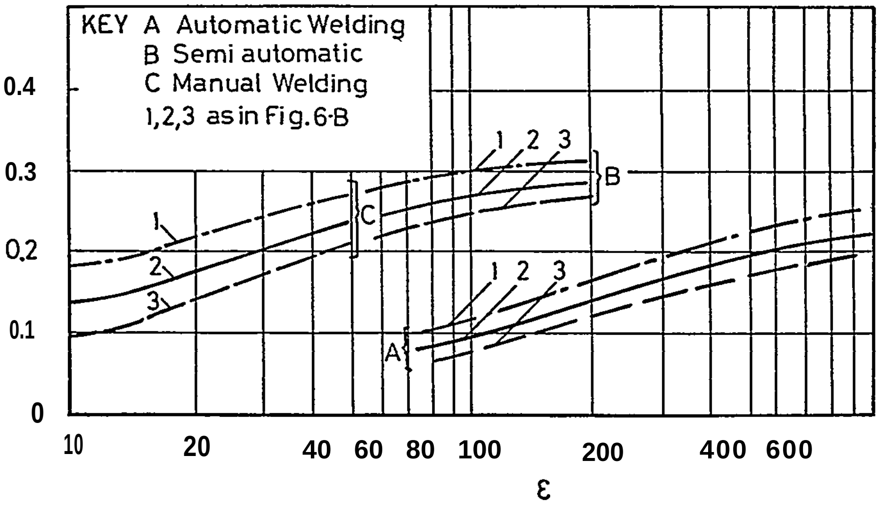


Fig. 8. Heat Transfer Efficiency η_ versus Heat Transmission Parameter ε [5].

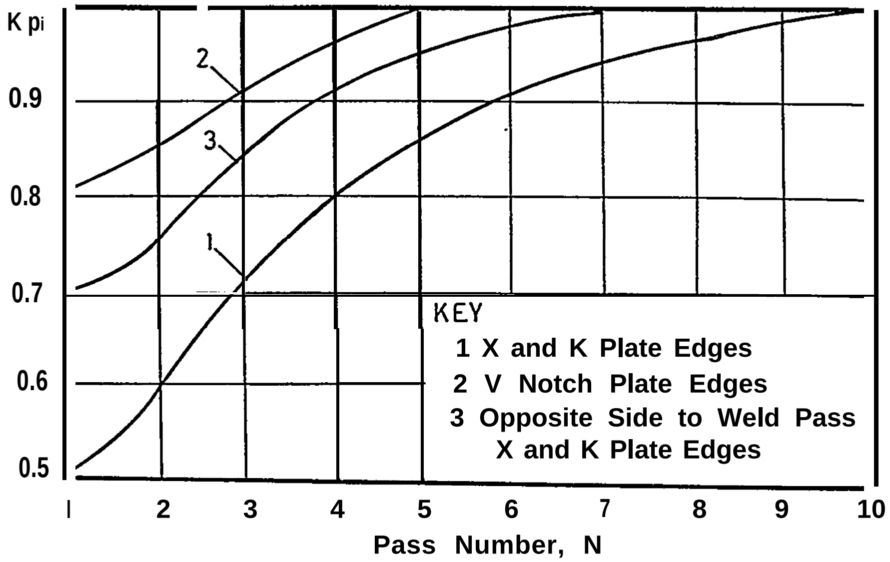


Fig. 9. Weld Pass Parameter $K_p$versus Weld Pass Number m [5].

rods and automated equipment speeds, welding current, etc. In this manner this work can be adopted in future automation and control schemes to obtain high quality welds with small defections.

ACKNOWLEDGEMENTS

The authors are grateful to Dr. E. Suhir who was kind enough to supply them with a copy of S. A. Kuzminov's monograph. The authors are also grateful to Mrs. M. Latapie for typing this paper.

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A Planning Guide-New Technologies in Pipe Joint Fabrication

NO.16

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ABSTRACT

In the past few years. methods of joining pipe together have been introduced to supplement and. in some cases replace, both the traditional welded and the brazed pipe fitting. It is necessary to examine what is available. and to justify its place and application in the marine market.

This paper intends to examine the Swage Marine Fitting (SMF) and the Heat Recoverable Coupling (HRC) and, briefly. the Compression and the bite type fittings. We will look at them from economic, performance, and environment al standpoints. In the case of the SMF and HRC fittings, technical papers on the usage of each fitting and its constraints have been presented. The purpose of this paper is to evaluate them together and incorporate them into an overall piping system.

In addition. the two primary guides for piping on military ships will be examined. These will be used to place the SMF and HRC into correct perspective, and to make recommendations for further applications. Comments will also be offered on the testing method and the results gained. Graphs are provided to illustrate the economic advantage of the SMF application.

INTRODUCTION

A plaque seen at a major shipbuilder best expresses the two main concerns within the shipbuilding community: cost and quality. The plaque reads as follows:

> "we shall build good ships.
> At a profit if we can,
> At a loss if we must,
> But always good ships."

Another point of view is that of the owner, who must balance the money available against the function of the vessel. From this, he must generate specifications and a contract package. An ancient teXt best states his dilemma:

> "Suppose one of you wants to build a tower. Will he not first sit down and estimate the cost and see if he has enough money to complete it? For if he lays the foundation and is not able to finish it, everyone who sees it will ridicule him, saying, This fellow began to build and was not able to finish."
> LUKE 14:28 (NIV)

The primary cost factor in the ship is not the material, but the manpower involved. Labor costs have driven shipbuilding into automation, modular construction, and zone outfitting. Labor costs have driven shipbuilding, first to Japan, then to Korea, and in the future, possibly to the People's Republic of China. Furthermore, the volume of ship construction has decreased markedly, to some degree caused by the downswing in the Petro-Chem industry. It is apparent that in order for yards to be more cost competitive, gains in productivity will have to be achieved.

It appears that one of two approaches are currently taken with regard to new technologies. Some technologies are moving so fast that to test them prior to specifying them would have them obsolete prior to implementation. Additionally, they greatly affect the ability of the ship to perform the job for which it was built. Failure to implement these technologies would possibly place the owner behind the competition. The owner's response, and logically so, is to order the technologies off the drawing board. Other technologies are not advancing as fast, and do not affect the mission or purpose of the ship, other than the cost. These are thoroughly tested prior to implementation.

It is in this second area that we are going to develop comments and conclusions, specifically in the area of pipe joining technology. Two technologies have been introduced in the past several years that offer advantages that hould be considered by yards and owners. The Swage Marine Fitting (SMF) offered by the Deutsch Company under the trade name Pyplok(R), and the Heat Recoverable Coupling (HRC) offered by the Raychem Corporation under the name *of* Cryofit(R) or Cryoweld(R), are both available to the marine industry, both have aerospace fitting counterparts. and both are approved by NAVSEA for use on nuclear and non-nuclear surface ships in non-nuclear applications. Neither has been approved, however. for use within the reactor compartment or on a nuclear submarine. *A* one-time SMF application has been made with NAVSEA approval on a U.S. nuclear submarine: it is interesting to note, in contrast, that both SMF and HRC have been applied on the British Trafalgar Class and on French nuclear submarines.

Two questions must be answered to the satisfaction of the owners or Navy for yard application: these are: Do SMF and HRC perform the job for which they are designed? Do they offer significant economic advantages?

To answer these questions. Navy standards and SAE guidelines will be used. These include. but are not limited to:

Mil-Std 777 Schedule *of* Piping, Fittings, and Associated Piping Components for Naval Surface Ships

Mil-Std 438 Schedule of Piping. Valves, Fittings and ASSociated Piping Components for Submarine Service

Mil-Std 278 Fabrication Welding and Inspection: and Casting Inspection and Repair for Machinery, Piping and Pressure Vessels in Ships of the United States Navy

Mil-Std 1629 Procedures for Performing Failure Mode, Effects and Criticality Analysis

SAE-HIR 1694 Materials for Fluid Systems for Marine Vehicles

SAE-HIR 1063 General Environmental Considerations for Marine Vehicles

The traditional methods of assembling shipboard piping have been either welding or brazing. Both methods have associated problems. including system contamination, hot work restrictions. non-destructive testing requirements, and a high degree of labor skill required. The public sector yards have documented the amount of time required to accomplish each of these two methods of pipe joining (see Table 2). The labor intensity. particularly for the walding process. is high. Note that the decrease in time for subsequent joints is not significant. These, however, are the estimating standards. It is to these standards that we will make performance and economic comparisons.

-TABLE 2-

OPERATION .1.6 SHOP 56 W/C 5612
FITUP AND INSTALL PI PIPING
SURFACE CRAFT

	1/4	1/2	3/4	1	1.1/4	1.1/2	2	2-1/2
Butt Weld	2.6	2.9	3.0	3.5	4.0	4.3	*5.0*	*5.8*
Each Additional joint in area	2.2	2.5	2.6	3.0	3.4	3.7	4.3	4.8
Socket Weld	2.0	2.2	2.3	2.6	2.7	2.9	3.2	3.4
Each Additional joint in area	1.2	1.4	1.5	1.7	1.8	1.9	2.2	2.5
Flanged Joint	0.5	0.6	0.6	0.6	0.7	0.7	0.8	0.8

OPERATION .1.6 SHOP 66 W/C 5612
FITUP AND INSTALL P3A PIPE*
SURFACE CRAFT

	1/4	1/2	3/4	1	1-1/4	1.1/2	2	2-1/2
Braled	1.2	1.6	2.0	2.3	2.6	2.9	3.4	3.7
Each Additional joint in area	0.6	0.8	1.0	1.4	1.8	2.0	2.4	2.8
Flanged joint**	1.3	1.5	2.0	2.1	2.2	2.4	2.7	2.9
Threaded	0.3	0.3	0.4	0.4	0.4	0.4	0.5	0.5

☛ NOTE An additional 25% man-hour allowance should be added for coverage of special P-3A submarine field joints that require documentation and hub cleaning for ultrasonic inspection.

**NOTE Tbe time values to make up a flanged joint include time to clean flange faces, install gaskets, and bolt-up only. Attachment of flange to pipe or fitting in included in the time for the fit-up and brazing of the connecting joint.

Rather than do elaborate re-introductions of the SMF and HRC fittings, technical considerations can be reviewed by referring to papers presented by LCDR Baskerville to ASNE in September 1981 (on the HRC) and by LCDR Mahoney, also to ASNE in September 1981 (on the SMF). The differences between the two fittings center on the method of attachment to the pipe, residual stresses. configurations available. and on current approval status.

The choice for method *of* attachment is between a “passive” crimp and an “active” crimp. The “passive” crimp Of the SMF is characterized by a plastic deformation of both the PiPe and the fitting in which little residual force exists (less than 20,000 psi). The “active” crimp of the HRC is characterized by plastic deformation of the pipe only. This results in a balance of forces between the swaging force of the fitting and the “spring back” of the pipe (70,000 to 100.000 psi in residual stress).

The SMF is currently manufactured in 6, 000 pound pressure class in 70-30 Copper-Nickel for use on 70-30 and 90-10 Copper-Nickel, and on al1 grades of Copper pipe to 3/4" NPS (I" O.D.). Additionally, a Stainless Steel fitting is approved for 3,750 psi service on ferrous pipe to 1-1/2" NPS. Both pressure classes are approved for use from -60 - 400 degrees F. The SMF is installed by the USE of a hydraulic tool which mechanically reduces (swages the fitting around the pipe. The SMF is a one piece fitting, available in numerous configurations and end standards, with low residual stress at the joint.

The HRC is available in two versions *for 6,000* psi service: a monolithic (Nitnol) and a composite (Nitnol with a Cuprous liner). Due to the "active" crimp, a limitation on pipe wall thickness exists. Additionally, for seawater service, ths composite coupling is required. The temperature limits are generally from -65 to 575 degrees F, except when environmental protection is used. This requires a protective heat shrink sleeve that drops the upper temperature limit to 194 degrees F. *A* low pressure HRC fitting (400 psi) has been NAVSEA approved for use on Cuprous piping with wall thicknesses, dependent on pipe size, to 2-1/2" NPS. HRCS have been approved For use on non-nuclear submarines, in addition to surface ships.

The HRC is available as a coupling only, requiring machine shapes to make up configurations and adapters. Moderate to high residual stress is associated with the HRC.

APPLICATION

A review of Mil-std 438 provides the best indication where the SMF and HRC might find application. Both documents name systems, define the system parameters,and define materials for assembly of *that* system. The documents suggest that for some systems. alternate material selection is acceptable. In Mil-Std 777, more than 110 system/material combinations are available. Of these, twenty fall outside of the temperature range of the SMF. and fifteen outside of the temperature range of the HRC. Another ten system/material combinations must be discounted due to material compatibility (brass, aluminum, GRP, and PVC).

The largest number of systems are found under 400 psi, and are usually assembled with Mil-F-1183 (brazed) fittings.

In Mil-Std 438. we find fewer of the high temperature systems. However, we find systems that were not critical on a surface ship. that are critical in nature due to exposure to seawater pressure. The quality control standard imposed on the submarine is a great deal more stringent.

The use *of* both the SMF and the HRC has been evaluated by General Dynamics, Electric Boat Division. initially to determine suitability for gage and instrumentation piping. A recommendation has' been made that, SNF and HRC be considered for service tkroughout the submarine. Currently, both the "Bite Type", Mil-F-10866, and the "compression style", find usage in the gage instrumentation systems. as wall as other systems within the submarine. NAVSEA has been working to provide alternate fittings for the "compression" type. Since many manufacturers exist, the control/interchangeability of components associated with this type of fitting is a Problem.

We also find three levels of application under consideration. In new construction, pipe and fittings are new. and cleanliness can be enforced more easily. There is more shop fabrication of subassemblies. and modular outfitting is commonplace. In an overhaul mode. there are modifications and/or additions to existing piping, some subassembly work, and routing around existing installations. Hot work and gas freeing are added job complications. The third possibility is a repair situation where only a handful of fittings will be involved. In this option, cleanliness. gas freeing, and proximity of weapons or other combustibles become major Considerations. In all three cases, nondestructive testing and final system hydrostatic test are required. It is apparent that as you escalate from one situation to the next. the installed cost on a per fitting basis is increased.

PERFORMANCE

Performance tasting of both SMF and HRC was done in line with test criteria developed by David Taylor Naval Ship Research and Development Center. These tests address some of the criteria required by SAE-HIR 1694: Table 1 reflacts the test data. It is interacting to note that two the tests (burst and tensile) are test-to-fail in nature. while the balance are test-to-pass. It is not unusual, therefore, that we pay the most attention to the burst and tensile data. We find that we know little about the extreme limits *of SMF* or HRC performance. other than that they exceed the requirements as set down by the Navy. With the comparison to traditional methods. we know more about the outer limits of performance. Traditional fittings failed in the critical tests

-TABLE 1-

PERFORMANCE TEST BANKING
CONVENTIONAL vs. NON-CONVENTIONAL PIPE JOINTS

Measure of performance	Butt Weld	Socket Weld	SMF	*HRC*	rase	Bite	Compression
Fatigue	Pass	Fail(1)	Pass	Pass	Fail(2)	Pass	Untested
Burst	Pass	Pass	Pass	Pass	Pass	Pass	
Tensile	Pass	Pass	Pass	Pass	Pass	Pass	
Impulse	Pass	Fail(3)	Pass	Pass	Fail(4)	Pass	
Torsion	Pass	Pass	Pass	Unk.	Pass	Pass	
shock	Pass	Pass	Pass	Pass	Pass	Untested	
Vibration	Pass	Pass	Pass	Pass	Pass	Untested	
Fire	Pass	Pass	Pass(5)	Pass(5)	Fail(6)	Untested	
Environment	Pass	Pass	Pass	Pass(7)			

Note(1) Catastrophic joint failure occurred between 20% and 40% of test cycle.

(2) Catastrophic joint failure occurred between 20% and 40% of teat cycle.

(3) Catastrophic failure occurred below 5O% of test cycle.

(4) Catastrophic failure occurred below 60% of test cycle.

(6) During 20 min. ffre test at 2000 with GN^2 at 100 psi..

(6) Catastropbic joint separation occurrcd within three minutes of start fire test.

(7) Potential stress cracking during salt spray tests requires that environmental protection measures be taken in area - where exposurres may occur.

Fatigue -	80,000 cycles hydraulic impulse at operating pressure Plus bending stress dependent on pipe material (60 KSI for steel, 44 KSI for 70/30 CUNI, 30 KSI for copper).
Burst -	four times operating pressure
Tensile -	greater than minimum pipe yield
Impulse -	one, and one half times operatiig pressure
Torsion -	varied
Shock -	Per Mil-901C
Vibration -	Per Mil-167
Fire-	Thirty minutes at 2000 degrees F. at 100 psi dry nitrogen with proof and burst to follow.
Environmental -	168 hours of salt spray test.

(fatigue and impulse). SMF and HRC have been tested to extremes without failure.

Several comments can be made With regard to the information presented in Table 1. These are tests in a laboratory environment, and do not fully duplicate "real world" conditions. Factors that are currently unknown may be significant considerations in future applications. This does not mean that the testing was incomplete, but that factors may exist that were not taken into account. As new areas are considered, such as nuclear power. new problems and considerations may develop.

Within the temperature band (-60 to 400 degrees F for the SMF and -65 to 575 degrees F for the HRC). both fittings offer significant benefits over the socket weld and the braze fitting. The important aspects of the SMF. HRC, or any fitting are performance limits and boundaries. If the engineer or planner recognizes that limits exist, and respects them, problems will be few, if any. NAVSEA technical approval letters explicitly define the operating limits for both technologies.

Some testing presents a problem because of incomplete data. The engineer will make an effort to determine the value of the data generated from the fire testing. In this case, a pipe with a low (100 psi) pressure in it, without a heat-sink, is characteristic of few systems. The addition of fluid to the pipe changes the whole nature of the test. Additionally. consideration of the test results by the engineer or planner is essential. The engineer must be concerned with "Maximum Economic Safety". *A* perfect system can be built, if one is willing to pay for it: the engineer must determine what is necessary for the job. If the fire test is reviewed from these standpoints, we come to the following conclusion: The most unacceptable joint is the braze joint, which catastrophically fails in a short time.

Within service limits, the following conclusion can be reached from the summary of tests: The SMF and HRC can provide comparable performance to the butt weld and better performance than the socket weld. If fire is a major consideration, braze joints should not be used in any system. Careful examination of the specification for the Mil-F-18866 fitting, in particular the 3,000 psi limit to 1" O.D. and *2,000* psi above that, quickly disqualify it from applications covered by NAVSEA Std. Dwg. 810-1385850. The use of compression fittings is severely limited by NAVSEA.

The testing is demanding. The "standard" joints fare the worst, failing catastrophically in fatigue and impulse tests. If a system failure occurs, obviously strains greater than those of testing were seen. When does the average pipe joint see temperatures like those in the fire tests? The answer is, rarely. In this case, the question of heat sinks has not been addressed. If considered, the fire around a fluid filled pipe would have to be out of control for more than 30 minutes to reach the internal temperatures required to validate the 2,000 degree F test requirement.

The environmental tests, however, do bring up some concerns about the HRC. Although seawater was used as the attacking media, it is not alone. Consider the chlorides that are present in insulating materials, or the generation of gaseous acids in a closed environment. These are valid concerns to the engineer and the planner.

Both the SMF and the HRC have each put thousands of fittings to sea in service on various vessels in varied applications. Both have enviable records from the standpoint of reliability and rework. The question about which *offers* the economic advantage remains. Let us examine the standard fittings and draw a comparison.

ECONOMICS

The economic considerations are developed around the time required to apply a conventional fitting and associated materials costs. We will use the data provided by a public yard, the way they use it (labor hours, times 1-1/3 to cover labor and material). We will take standard work day and divide it in half, because of the disruptions for a midday break (break-down and set-up of equipment, cool-down periods, etc.), to determine the maximum number *of* joints completed. This will give us an average joint cost. Average joint cost times 2 is the installed cost *of* a coupling or elbow: a multiple of 3 is the cost of a tee joint.

We will develop our method around a P-1 welded joint (shipboard). Graphs will cover alternative situations (shop, submarine, P-3A, F-3B, P-2, etc.). For the sake of simplicity. three data points are used; 1/4", 3/4". and 1-1/2" NPS.

From the table for P-1 welded joints. the following information is given (figures are in manhours):

	1/4 "	3/4"	1-1/2"
Socket weld	2.0	2.3	2.9
Each additional joint in area	1.2	1.5	1.9

With material cost:

	1/4 "	3/4 "	1- 1/2"
Socket weld	2.6	3.0	3.8
Each additional joint in area	1.6	2.0	2.5

Average joint requirement with material:

	1/4 "	3/4 "	1-1/2 "
Socket weld	1.2	2.5	3.1

To make this data useful. everything must be converted to either manhours or dollars. We will use dollars. Manhour rates vary from $25 to as high as $50. depending on the area (manhour rates may include labor, overhead. support labor. consumable materials. and other costs, including profits). We will use a value *of* $30, realizing that it is close to some labor rates but lower than others. It offers the advantage of a simple multiplication to make it useful to the reader.

The cost per joint becomes:

	1/4 "	3/4 "	1-1/2"
Socket weld	$66	$75	$93

A coupling or elbow would cost $132 at 1/4". $150 at 3/4"'. and $186 at 1-1/2" NPS.

We have plotted *the* joint costs, the coupling/elbow costs, and the tee costs on graphs (see Figures 1 through 7) which represent the possibilities.

To compare the alternate fittings, the acquisition cost must be altered by a factor to cover labor, storage, receipt-inspection, and/or tooling depreciation. Using 25% for the sake of discussion, if an SMF coupling cost:

	1/4"	3/4"	1-1/2"
SMF	$23.20	$35.00	$67.50
SMF (corrected)	$29.15	$43.75	$84.38

Navy contracts should reflect the current pricing. Additionally, quantity purchasing may or may not be a consideration in the prices reflected. For the P-1 welding comparison, above, a 3,750 psi CRES SMF was used. Keep in mind that at this point, many applications will be a fitting "overkill", in that the fitting far exceeds the system requirement. Additionally, remember that this will probably be true in other categories. These charts, even without cost data on the SMF or HRC, will give the user a point of evaluation for other new fitting concepts or procedures as they become available.

In each chart, the traditional method of assembly is the baseline. The installed cost for the SMF developed above has been included in Figures 1 and 2 for comparison. Below the baseline will be referred to as "Economically Acceptable", and above the baseline is "Conditionally Unacceptable"; conditional, because of the possibility of mitigating circumstances.

No one fitting method accomplishes all aspects of the piping problem without imposing some drawbacks. What is required is a method of evaluation that will allow the planner or the designer to establish that method or group of methods that will give him the desired system, having made acceptable trade-offs between performance, economics, schedules, environment, and conditions imposed by the work location.

In evaluating the joining methods, the following considerations are necessary, in the order given:

Temperature
Pressure/ Material Compatibility
Shapes and Adapters required
Protection Requirements
Working Space
Economic Considerations

The easiest assessments to make are the categorizations by temperature. They are:

Temperature	Weld	Braze	SMF	HRC(P)	HRC
575&above	Y	N	N	N	N
400 to 575	Y	N	N	N	Y
194 t0 400	Y	Y	Y	N	Y
-65 to 194	Y	Y			Y
-65 & below	Y	Y	N	N	N

Legend Y=Yes N=No

Note-The limits on the Mil-F-ll83 Fitting has a upper temp limit of 425 degrees.

Note-HRC(P)with environmental protection.

Note-For the ease of charting the lower temperature limits of tbe HRC and the SMF were assumed to be the same

PRESSURE/MATERIAL CONSIDERATIONS

The SMF is currently approved for 6.000 psi for any of the Cuprous pipes. and 3,750 psi for any of the Ferrous pipes. The HRC is approved for 6,000 psi for either the Cuprous or Ferrous pipes (thin wall copper requires the composite version. as do seawater applications). Additionally, the HRC has a 400 psi version, provided pipe wall thickness boundaries are observed. Weld or braze fittings can be procured by pressure class and material compatibility.

OTHER CONSIDERATIONS

There are certain intangible items that must be evaluated by the planner or engineer. These include such items as fittings requirements (shapes, adapters, etc.). space restrictions. and weight, fire hazard, and environmental considerations.

In review, the weld or braze joints offer a variety of configurations and material/pressure compatibility. They also bring with them the problems associated with hot work, labor skill and intensity, and cleanliness. If these problems can be overcome at reasonable cost, then both are viable options. In some cases, this will be true: in many others, the SMF or HRC would be better choices.

The bite type fitting has to be examined carefully due to the limitations imposed by the Mil-Spec. The fitting has been available for so long that its limits have been forgotten or overrated. This fitting q must be reviewed to ensure that its application remains in line with its design limits.

The compression fitting offers its own set of problems. A variety of vendors exist. and though the parts needed to assemble a fitting look similar, theY are not. The fitting offers limited inspectability. and is confined to O.D. sizes.

The SMF is offered in both pipe and tube sizes, and is available in numerous configurations and adapters. Considerations for the planner include sufficient access to the pipe to get the tooling over the fitting. Normally, to get one's hand around the fitting is sufficient. It is possible to complete a system with no hot work involvement with the variety of fittings available, thereby minimizing or eliminating systems flush.

The HRC offers an advantage in the area of tooling requirements and working envelope. Its drawbacks are the storage requirement (liquid nitrogen bath required until installed). the hazard of handling liquid nitrogen. the need to position the fitting right the first time, and the lack of one piece fitting configurate other other than couplings. The time limit to install the fitting is dependent on the ambient temperature, and configurations are achieved through the use of machine shapes and multiple couplings.

It would not be unreasonable to use more than one fitting concept to accomplish assembly of a system. A system would consist of all aspects of the piping requirement. It would be Possible that sections would be best accomplished in a shop environment. then joined to other sections onboard ship. Depending on the capabilities available, two or even three joining methods could be used,

By using this information, the planner or engineer may have two or more methods of assembly. His decision should be to select the best choice, yet giving the trades the option of other methods if conditions or considerations differ from those originally planned.

It seems apparent that neither the system classification (P-1, P-2. P-3a. etc.) or the system being discussed gives valid grounds for joining method selection. System classification is a method of assigning "Maximum Economic Safety" through testing and inspection. The cost differential between P-1 and P-2 can be determined, as can the differential between P-3a and P-3b. The installed cost of either the SMF or HRC does not change, regardless of system designation (P-1 versus P-2 or P-3a versus P-3b). The ship system is also a variable, due to its changing requirements (pressure, temperature. environment, and location). The engineer must be aware of all aspects affecting the system being developed, and all factors that affect it.

Having settled on those fitting types that will accomplish the assembly of the system, consult the graphs {Figures 1 through 7) to determine how the greatest economic advantage is obtained. Depending on the application, both the SMF and HRC should provide cost advantages required by the current economic climate. Proper consideration and application of new technologies is essential to protect the future *of* the U.S. shipbuilder.

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FIGURE 1

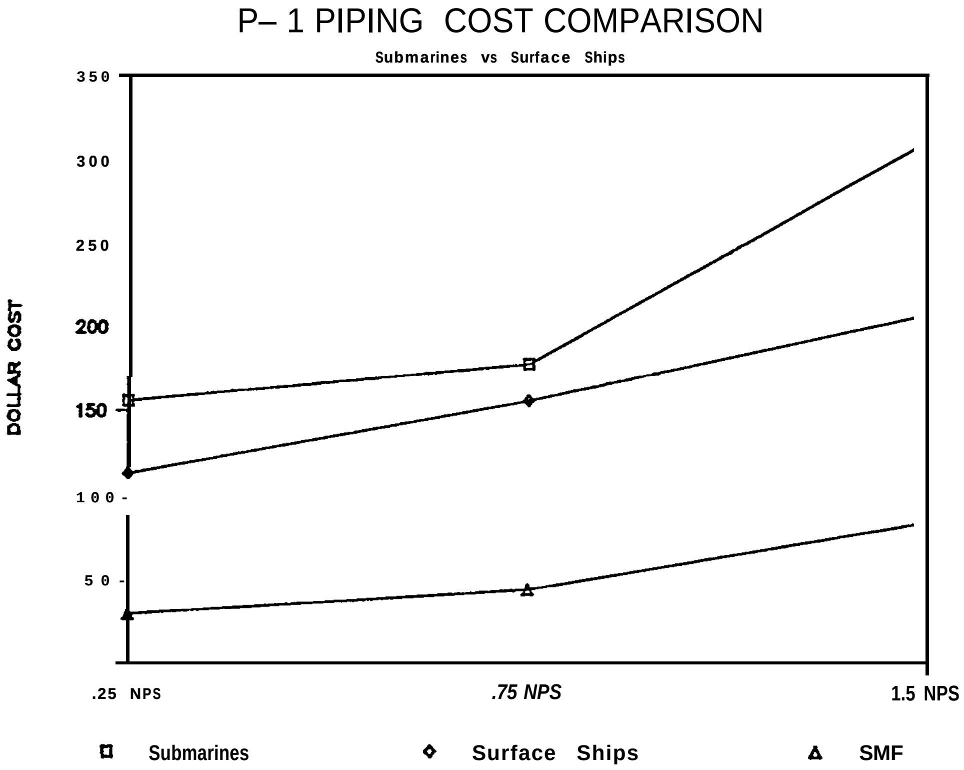

P– 1 PIPING COST COMPARISON
Submarines vs Surface Ships
DOLLAR COST
350
300
250
200
150
100
50
.25 NPS
.75 NPS
1.5 NPS
□ Submarines
◇ Surface Ships
△ SMF

FIGURE 2

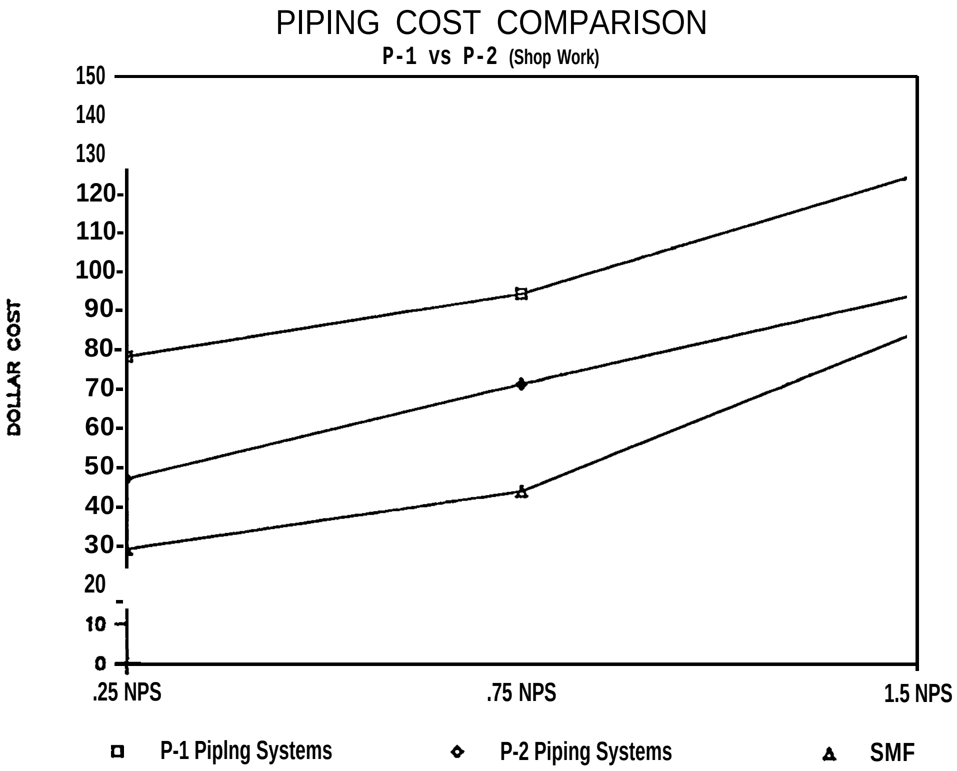


FIGURE 3

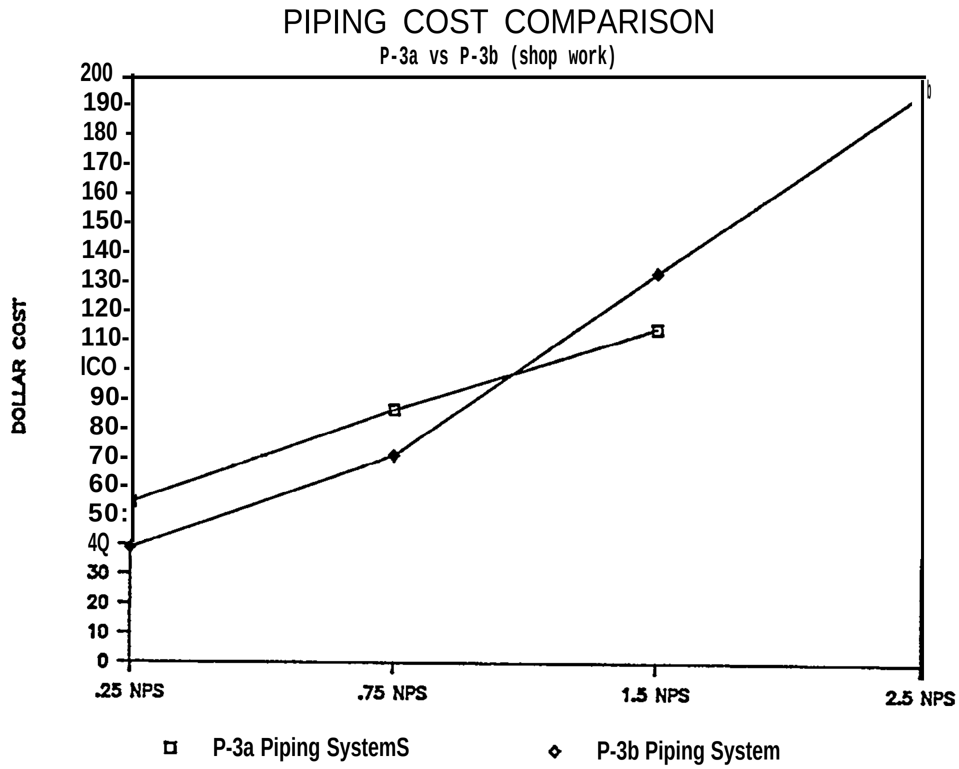


FIGURE 4

PIPING COST COMPARISON

P-3a Surface Ships

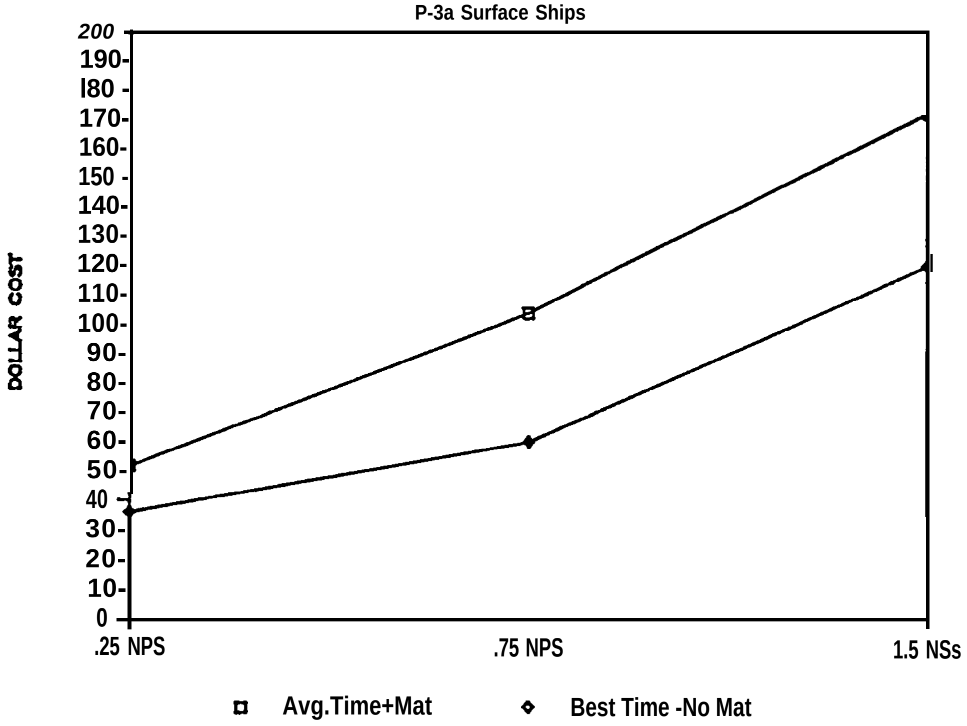


FIGURE 5

PIPING COST COMPARISON

P-3b Submarines

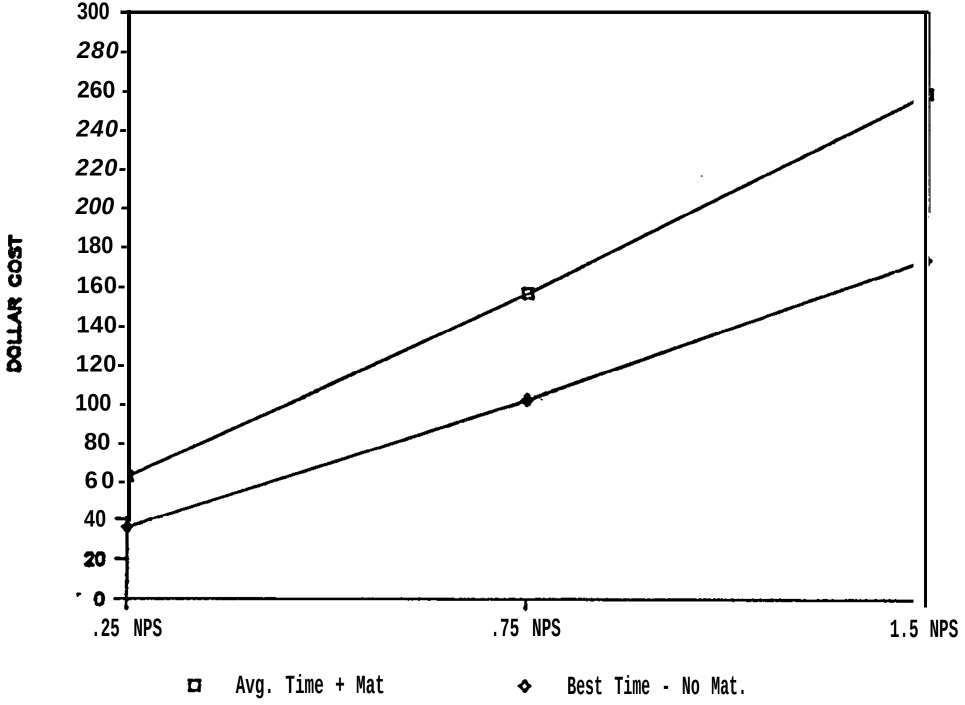


FIGURE 6

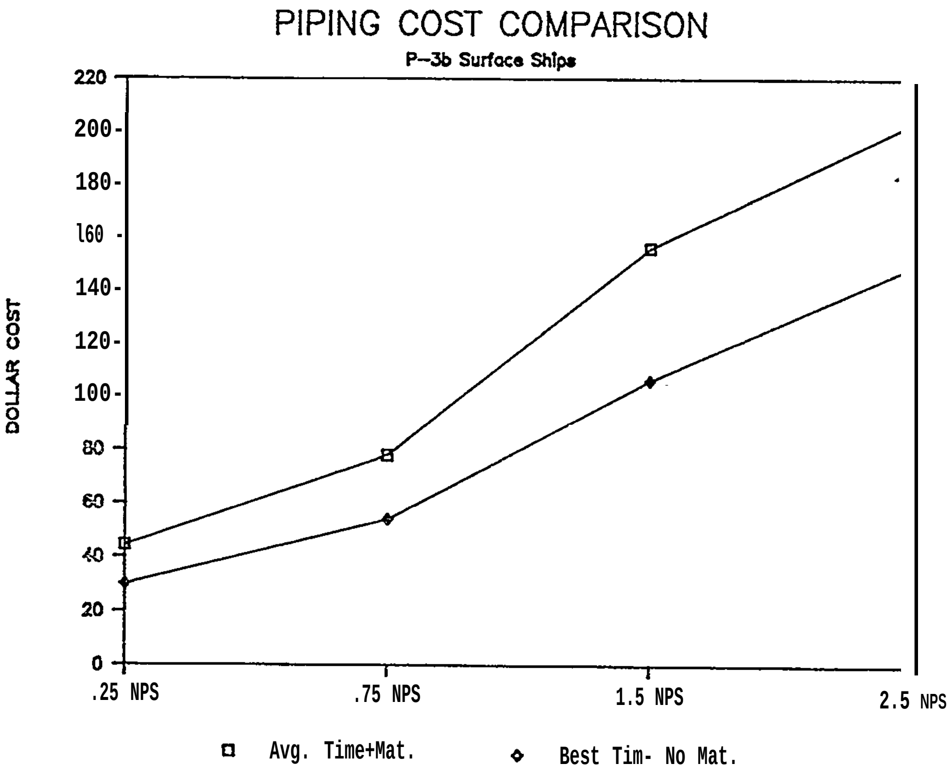


FIGURE 7

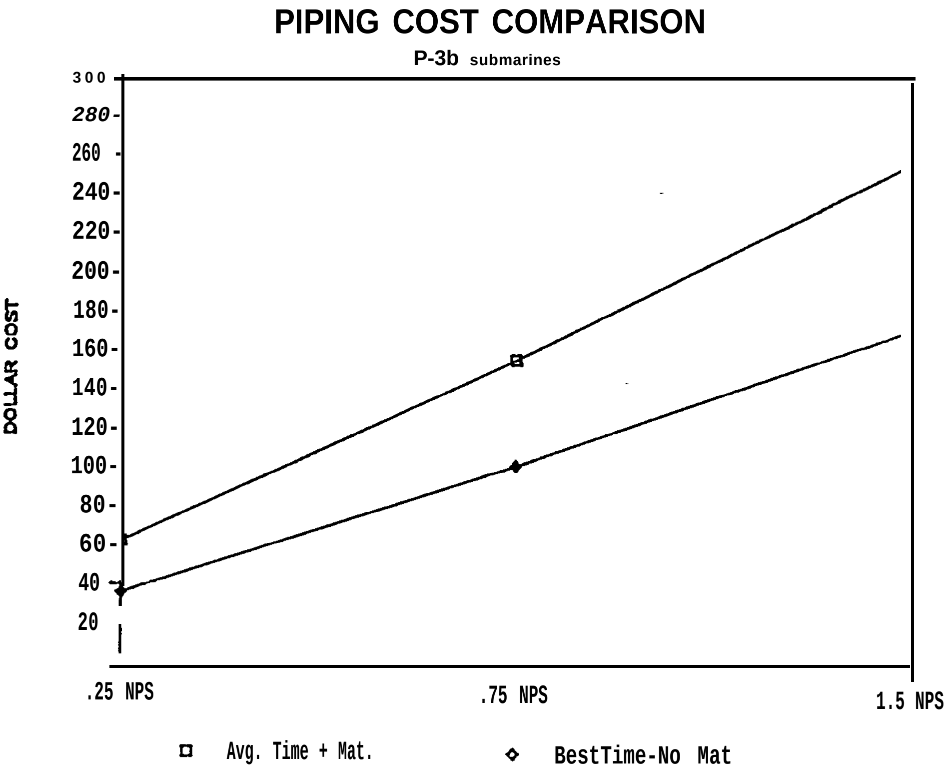


FIGURE 6

PIPING COST COMPARISON

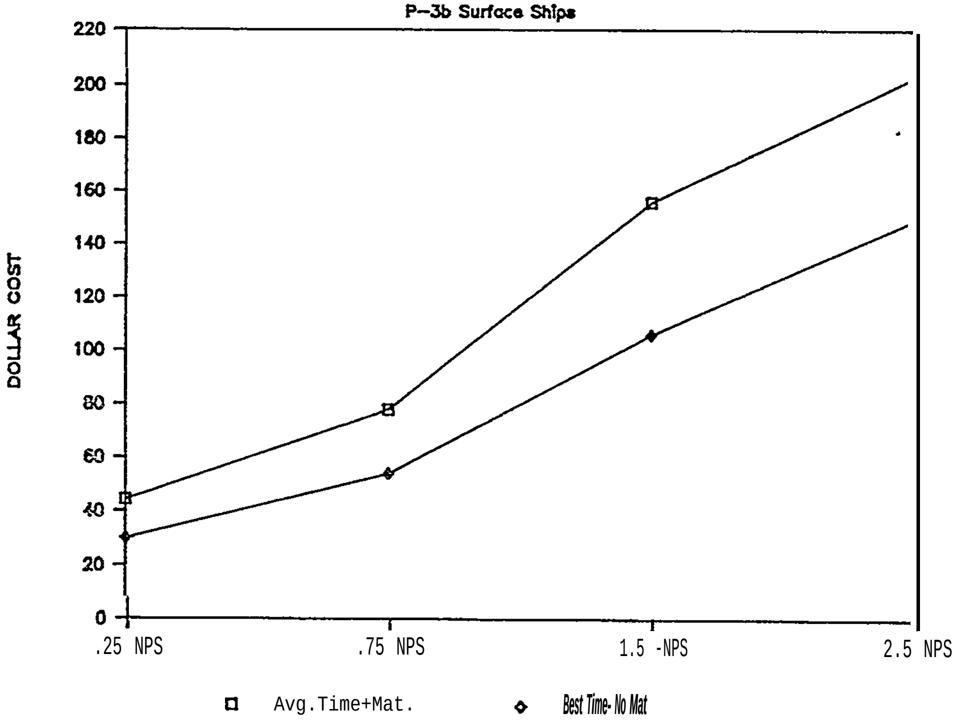
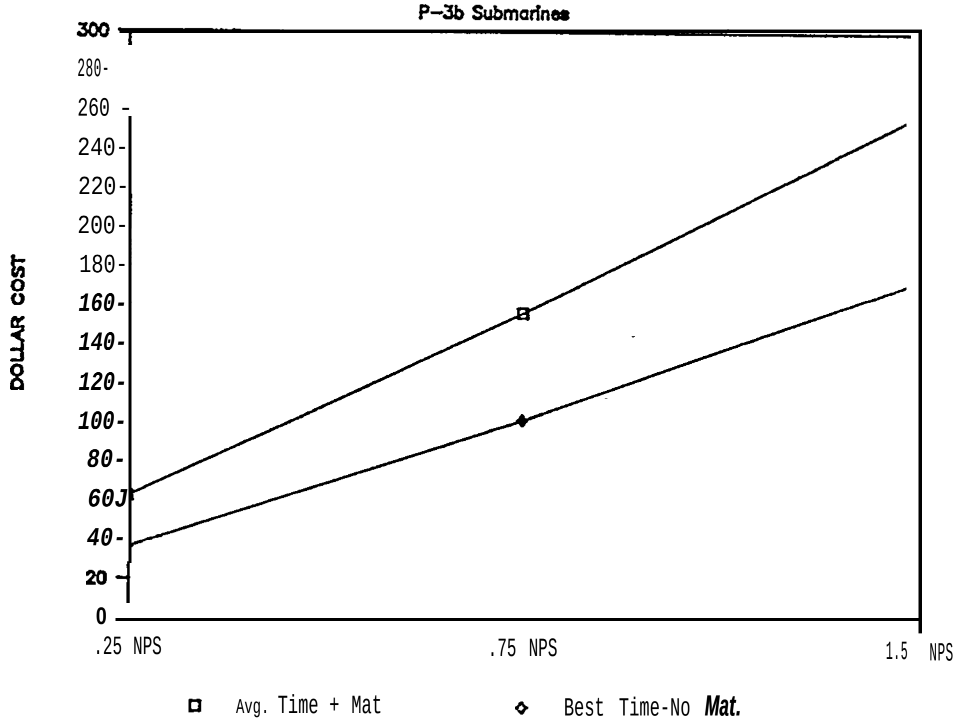


FIGURE 7

PIPING COST COMPARISON



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Novel Techniques and Their Applications for Measuring Out-of-Plane Distortion of Welded Structures

No. 17

Koichi Masubuchi, Member, William H. Luebke, Member, and Hiroshi Itoh, Visitor, Massachusetts Institute of Technology, Cambridge, MA

ABSTRACT

Whether or not a certain amount of planar distortion is critical, a point of consistency in the ship fabrication process is the need to accurately assess an existing degree of distortion in both local and global domains. At the Massachusetts Institute of Technology, three novel measurement devices have been developed as an adjunct to ongoing research. Distortion can now be evaluated either through laser interferometry, low-power laser beam triangulation, or direct surface contact. In addition to describing the operation and construction of the devices, their particular applications from a ship production/plate forming perspective are detailed.

NOVEL TECHNIQUES AND THEIR APPLICATIONS FOR MEASURING OUT-OF-PLANE DISTORTION OF WELDED STRUCTURES

Introduction

How bent is bent? The answer to this question has been important to shipbuilders and designers for centuries. And today, as newer materials and fabrication techniques are introduced, possibly with more stringent fit-up tolerances, it may be of even greater significance. The objective of this discussion is to introduce several new measurement techniques which may ultimately assist those in the shipbuilding industry who are dealing with such a question.

"Distortion," from the perspective of this paper, is considered to be the degree a shape may vary from its intended form. In the extreme case, this can range from a complex-contoured section of hull plating to the planar characteristics of a main deck or bulkhead. With the former, a precise amount of bending is required; with the latter, complete absence of bending becomes the ideal. clearly, "distortion" in shipbuilder parlance may be a welcomed or damned phenomenon.

Whether or not a certain amount of distortion is critical at a particular location onboard ship, a point of consistency in the fabrication process is the need to accurately assess the state of bending in both local and global domains. Such assessment could be performed for individual plates prior to join-up, in situ for checking overall section contours, for post-weld distortion removal activities, or conceivably as part of an effort to quantify post-collision hull damage.

Over the past few years, a significant amount of research at the Massachusetts Institute of Technology (MIT), under the tutelage of Professor Koichi Masubuchi, has been devoted to studying weld distortion phenomena as well as thermo-mechanical plate bending techniques using laser line heating(1,2). Although the end objectives of each project differed markedly, they all shared a common need for rapid, reliable, and accurate distortion assessment (measurement) in the laboratory. Complementing the main thrust of each study was the concomitant development of devices which could satisfy such measurement requirements. Based on this work, distortion may now be evaluated either through laser interferometry, low-power laser beam triangulation, or direct surface contact.

Scope

This paper presents alternate applications for three MIT distortion measurement methods from the standpoint of ship production and repair. Since the measurement technique involving laser interferometry was previously reported at the Spring Meeting of the Society of Naval Architects and Marine Engineers (SNAME) in 1985 (3), only a summary is provided here for completeness. Regarding the remaining devices, the discussion will concentrate on design considerations, principles of operation, brief hardware/software descriptions, attendant measurement results, and their current state of development

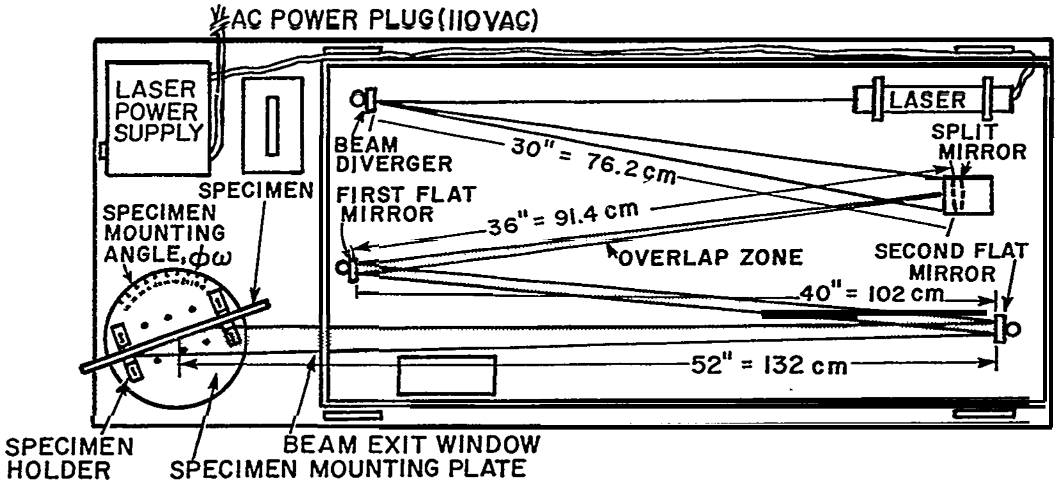


Fig. 1 Laser Interferometer developed at MIT (top view)

Measurement Method #1: Laser Interferometer (Summary)

Interferometry measurement involves the use of constructive and destructive interference among waves of light emitted from a single source. With the present arrangement, and as depicted in Figure 1, a 10 milliwatt, helium-neon laser serves to provide an intense, monochromatic beam of light which is expanded, columnated, and split into two phase-locked overlapping beams. Beam geometry is shown in Figure 2. Because of the overlap, a system of parallel interference fringes composed of alternating bright and dark vertical lines will appear on a diffused surface placed anywhere in the overlap zone.

Measurement of out-of-plane distortion is accomplished by interpretation of an illuminated specimen's fringe patterns. When the specimen is not flat, the interference fringe pattern is distorted; the nature and the amount of such fringe distortion thus details specimen distortion.

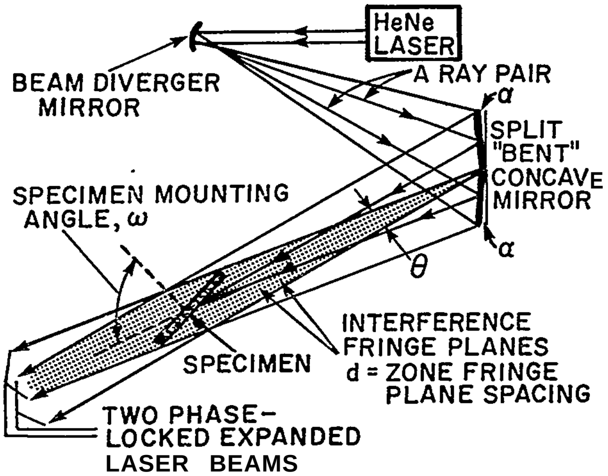


Fig. 2 Laser Interferometer optics

A sample fringe pattern on a fillet weld specimen appears in Figure 3. Although not detailed here, equations have been developed which enable the operator to quantify local specimen distortion based on corresponding fringe distortion.

Depending on the orientation of the phase-locked light and the specimen, a change in the fringe pattern may show longitudinal bending, lateral bending, or contour deformation which may exist, for example, along a typical fillet weld. Changes in specimen surface elevation within 5 ten thousandths of an inch (0.0005″) can be detected with the laser interferometer developed at MIT.

Although laser interferometry may be considered a non-contact measurement method, specimens with metallic surfaces should first be optically diffused with a thin layer of spray paint to reduce glare and enhance fringe definition. Ideally, no surface obstructions should be present, since their shadows could mask important contour changes. Specimens must also be fairly smooth, and free from deep pits or corrugations.

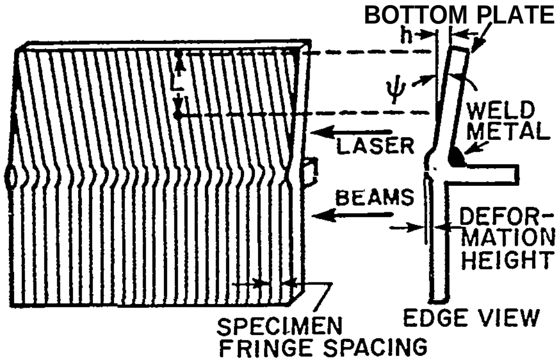


Fig. 3 Fringe pattern observed on the back surface of a fillet weld having both contour and lateral bending distortion

Based on the intensity of the laser light source, the ambient light level must be low enough to observe specimen fringes. Additionally, fringe pattern stability will also depend on minimal air convection currents at the specimen surface as well as a vibration-free environment for both the specimen and interferometer.

Reference (1) provides the background, theory, and sample calculations required for distortion analysis using the MIT laser interferometer. Also discussed are photographic and video camera recording procedures used to examine fringe patterns changes both during and subsequent to welding sequences.

The following two methods were developed to support present research concerning automated thermo-mechanical bending of steel plates using laser line heating. Consequently, the devices were conceptualized from a need to assess plate-wide specimen distortion which would be difficult using interferometry. As will become obvious, their use may be easily extended to measurements in three dimensions over large surface areas if required by an industrial facility.

Measurement Method #2: Non-Contact Distortion Measurement Using Low-Power Laser Beam Triangulation

Motivation. Because of the complexity involved in thermo-mechanical plate bending, especially in lieu of human expertise in the process, dependency on computer-assisted monitoring and control is presently considered essential. A natural progression toward evaluating the feasibility of fully automated plate forming was the development of a measuring subsystem which could be computer integrated with distortion prediction algorithms, laser pass sequencing logic, plate speed and laser power controls, etc. To achieve technological harmony among all critical components and interfaces, elimination of the human element in distortion measurement and feedback was adjudged fundamental. Further, from the standpoint of mechanical simplicity and to minimize interference with the optical laser path, etc., a non-contact type of measurement seemed most viable.

Design Considerations. Because of its anticipated role in an “automated” environment, the non-contact distortion measurement device (NCMD) to be described was envisioned to operate in at least a semi-permanent location as a plate forming system component. Implicit in this respect was an assumed specimen orientation. Given this scenario, seven additional requirements were specified.

1. Accurate Local Distortion Measurement. Plate distortions can range from a few thousandths of an inch to several inches depending on the desired contour and point of measurement. Consequently, the NCMD must be able to discern small changes in surface elevations as well as accept a broad range of possible elevations.
2. Rapid Measurement Process. Accurate measurement at the expense of delaying the process is not acceptable. This criterion included both set-up and actual measurement times, both of which would be critical in an automated environment.
3. Real-Time Availability of Results. As a corollary to the proceeding item, once a measurement procedure was performed, access to its outcome was desired on a near-instantaneous basis. Data conversion and subsequent availability within a few seconds were considered especially essential for in-process plate bending feedback.
4. “Negative or Positive” Distortion Measurement Capability. Considering general plate curvature, both concave terrains may coexist. Such conditions should be anticipated and accommodated without operator intervention.
5. Ease of operability. While analysis and use of measurement data may comprise a sophisticated portion of a bending prediction algorithm, design philosophy considered that obtaining the data should be a straight-forward procedure not requiring special expertise or training for the end user. From this perspective, acceptance of the NCMD would be enhanced at the worker level and training expenditures minimized.
6. Durability. The device was expected to find use in an industrial environment. Susceptibility to temperature fluctuations, dust, electromagnetic and infrared radiation, rough handling, etc., was probable.
7. Economy in Design. One of the most fundamental of all design decisions, this factor was assumed to apply not only to initial development of the new device but also to future industrial facility procurement and follow-on repair/ maintenance requirements.

Principles of Construction and Operation. The triangulation method adopted in the NCMD design has the capability of measuring a vertical change in plate elevation above a horizontal reference plane by sensing a change in an established angular relationship among system components. To develop the prescribed geometry, the device is positioned directly above a plate specimen. Although vertical separation between the prototype and a typical plate is approximately seven feet in the laboratory, this distance is not critical for proper operation. Presumably such a device could be mounted near or on the ceiling of the building where measurements are to be performed.

Referring to Figure 4, the essential geometry is detailed. Angle θ is formed by the reflection of a low-power laser beam between two mirrors and the plate specimen. The system's height above a horizontal reference plane, L, and the horizontal separation between mirrors, d, are fixed. Elevation above the plane, "delta Z", is determined from the following equation:

$$\Delta Z = L - (d)(\mathrm{Tan}\ \theta).$$

The value of angle θ in the equation is known based on mirror motor position when the laser spot on the plate has been centered in the camera's optical image area. Of course plate thickness must be taken into account to determine actual plate distortion.

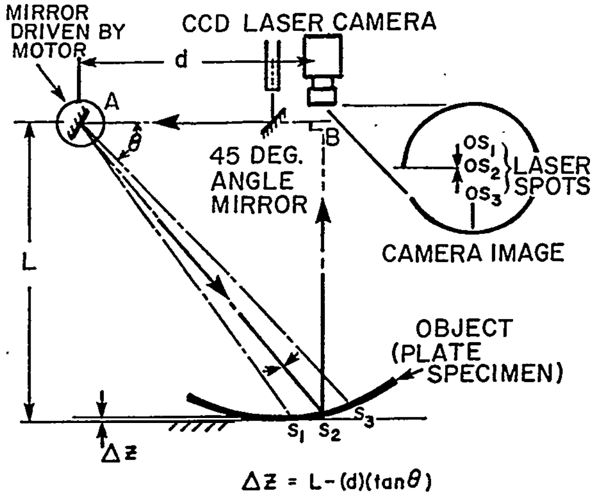


Fig. 4 Geometric principle of operation for the non-contact distortion measurement device

External to an IBM-compatible AT&T PC 6300 personal computer and the required component power supplies, the complete NCMD as designed consists of six pieces of hardware rigidly mounted to an aluminum frame. A perspective of their arrangement is provided in Figure 5. Figures 6-9 offer more detail. Individually, they include:

1. Low-power Helium-Neon Laser Assembly. Beam power is approximately 2 milliwatts; beam width is approximately 0.03 inches.

2. Precision Mirror Drive Motor and Mirror. The angular position of this motor's drive shaft determines the value of θ used in the above equation. Angular resolution is 0.000251 radians (25,000 equal angular increments per revolution). The mirror is attached directly to the drive motor as shown in Figures 6 and 9.

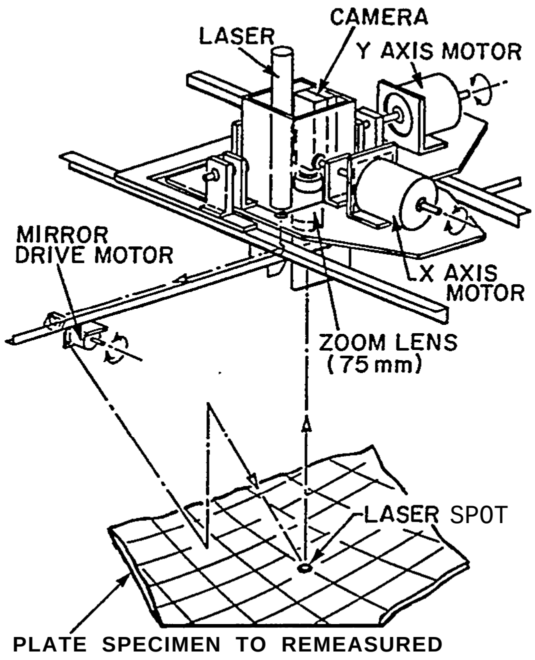


Fig. 5 Perspective of non-contact distortion measurement device hardware arrangement

3. Charge Coupled Device (CCD) Camera. Fitted with an adjustable zoom lens and a software-controllable aperture, the camera is used to detect reflection of the low-power laser spot from a specimen's surface. Laser spot position within the image area is determined by electronic measurement of intensity. The distance between the optical axis of the CCD camera and the mirror drive motor shaft determines the value of "d" in the distortion measurement equation above.

4. X-Axis Scanning Motor. For reference, a horizontal (x,y) Cartesian coordinate plane is assumed to be centered on each plate measured. The x-axis scanning motor repositions the rigid component frame so that elevations along the entire specimen axis can be determined. Figures 8 and 9 offer two views of this motor.

5. Y-Axis Scanning Motor. Although not installed in the present configuration, this component is an identical counterpart to the x-axis

motor except that it allows y-axis measurements. Correct sequencing of both motors affords plate-wide measurements and thus three dimensional representation of the specimen contours.

6. 45° Angle Mirror. Rigidly mounted directly below the low-power laser tube, this mirror simply redirects the beam toward the mirror/mirror drive assembly. Front and side views of this mirror are available in Figures 6 and 7.

Figure 10 is a "system view" of the NCMD at MIT. A laser formed dish-shaped steel plate is shown positioned for measurement.

Fig. 6 Frame assembly of non-contact distortion measurement device (Illustrates housing for helium-neon laser & CCD camera; mirror motor is visible in right foreground.)

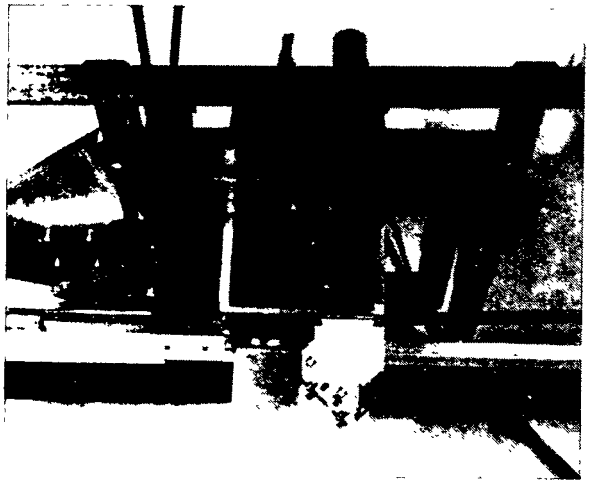


Fig. 7 Helium-neon tube and CCD camera mountings in frame assembly of non-contact distortion measurement device.

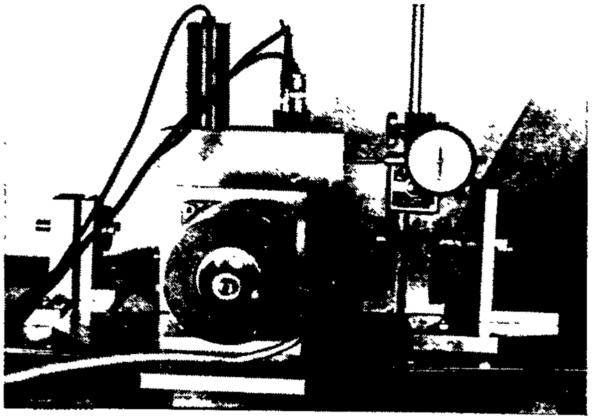


Fig. 8 End view of X-axis scanning motor attached to frame assembly of non-contact distortion measurement device.

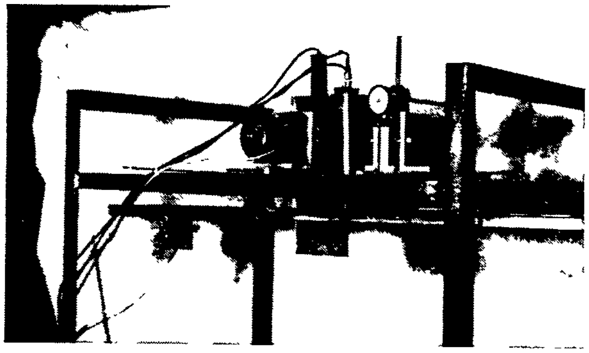


Fig. 9 View of frame assembly hardware for non-contact distortion measurement device. (Note mirror motor in left background and mounting bracket for Y-axis scanning motor in right foreground.)

Fig. 10 Plate specimen measurement with the non-contact distortion measurement device.

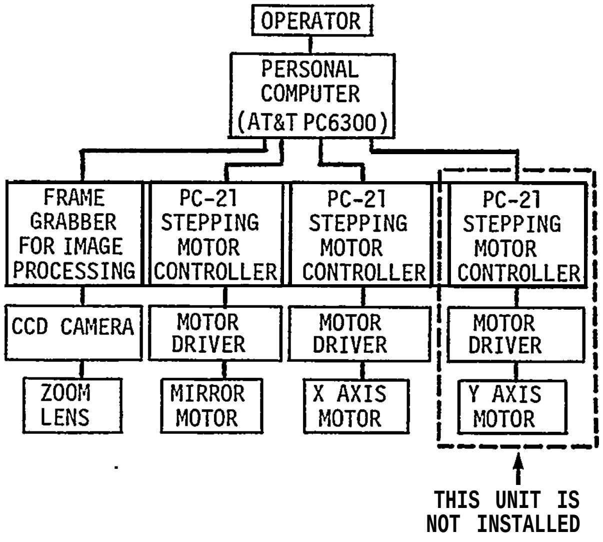
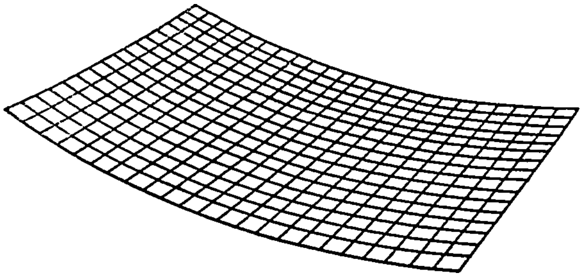


Fig. 11 Block diagram for non-contact distortion measurement device hardware depicting computer interface with major components.

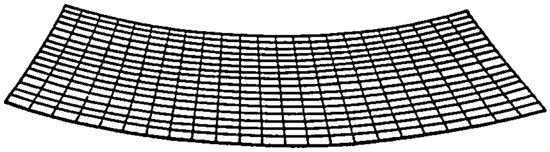
Computer Hardware/Software. Figure 11 depicts a block diagram of the major components and their relationships. Software-generated commands to each of the three NCMD motors are interpreted by stepping motor controllers which activate motor drivers for individual drive shaft positioning. A “frame grabber” interprets optical intensities detected by the CCD camera and provides an electronic image for software interpretation and computer monitor display if desired. Individual circuit boards house each controller and the frame grabber within the personal computer. Power supplies are located -in a cabinet adjacent to the computer.

The NCMD control program primarily consists of interrelated motor commands, image commands, and an automated mode which is executed by user-defined text files. A separate program provides for computer graphics representations of measured contours. During the measurement process, elevations as a function of their x,y positions are automatically stored in a user-named file. Values in such a file may be retrieved for hard-copy listing or accessed via the graphics routine to display a three dimensional representation of the specimen on the computer monitor.

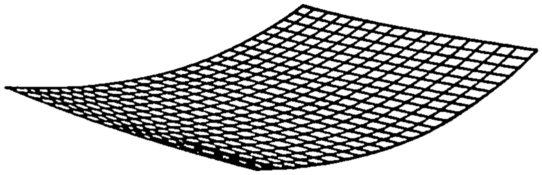
Figures 12 and 13 are reprints of such representations based on actual non-contact measurements of laser-formed “dish” and “sine” plate shapes. Note from the figures that the graphics routine allows specification of viewing angles from both the horizontal (specified value of "θ") and vertical (specified value of "ϕ") perspectives.



DISH(VIEWING ANGLE: $\theta = 210°$; $\phi = 60°$)



DISH(VIEWING ANGLE: $\theta = 180°$; $\phi = 70°$)



DISH(VIEWING ANGLE: $\theta = 130°$; $\phi = 70°$)

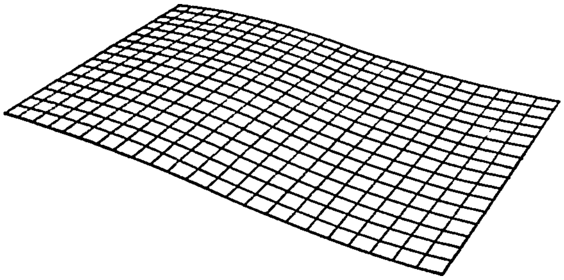
Fig. 12 Computer graphics representation of dish shape measurement using the non-contact distortion measurement device.

Limitations. Within the specified design considerations, major limitations of the NCMD may be grouped as either mechanical or programmatic in nature and represent the current state of device refinement.

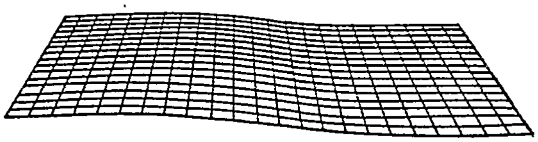
1. Specimen Size. While theoretically there is no practical minimum size, maximum dimensions are dictated by the vertical separation distance between the device and a specimen and the extent to which the camera/mirror motor frame can be rotated by the x and y-axis scanning motors

2. Specimen Orientation/Position. As discussed, specimens must be placed below the NCMD. The present device is not designed to be portable.

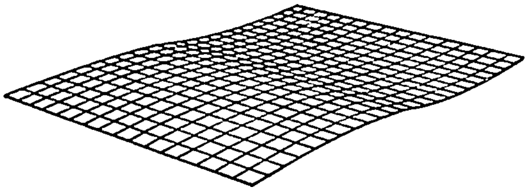
3. Least Discernible Change in Elevation. Although the intervals between successive elevation measurement sites are adjustable via control software, the angular increment of mirror motor rotation will ultimately determine whether or not a change of elevation is sensed. Currently, elevation differences on the order of 0.01″ are detectable.



SINE (VIEWING ANGLE: $\theta = 210°$; $\phi = 60°$)



SINE (VIEWING ANGLE: $\theta = 180°$; $\phi = 70°$)



SINE (VIEWING ANGLE: $\theta = 130°$; $\phi = 70°$)

Fig. 13 Computer graphics representation of sine shape measurement using the non-contact distortion measurement device.

4. X-Axis Drive Motor Torque. To scan the entire width of a plate in the x direction, the x-axis drive motor must rotate the aluminum frame which houses the CCD camera and zoom lens, 45° angle mirror, mirror motor and mirror assembly, and the helium-neon laser tube. The motor torque required to accurately position this assemblage is slightly greater than the present motor's capability. Consequently, slight differences between the commanded and actual motor shaft position may arise during the measurement process, especially as the frame assembly is rotated farther from its initially-horizontal reference position. Since elevation calculations are based on expected (commanded) x-axis motor shaft positions, this is a potential source of measurement error. The condition is considered temporary based on several feasible modifications proposed for the present design.

5. Process Time Required for Plate-wide Measurement. This is the most critical shortcoming of the prototype and is a programmatic problem. At issue here is that the device requires approximately one minute to determine elevation at each measurement site. A majority of each such processing interval is devoted to mirror motor positioning of the laser spot at the computed centroid of the CCD camera's optical image area. Obviously, when many measurement sites are required, e.g. to examine surface countours in detail or when analyzing a large plate specimen, total process time can become excessive.

Measurement Method #3: Contact Distortion Measurement Device

Motivation. Extensive experiments in laser line heating were conducted by MIT researchers beginning in 1984 at laboratories in Washington, DC and 1985 in Hartford, CT. Proposed rapid expansion of a laser-powered thermo-mechanical plate bending data base during these studies dictated that a portable means of rapid yet accurate plate distortion measurement was needed. To fill the gap between slow and error-prone methods involving magnetic-base dial indicators and the relatively slow or inflexible methods previously described (from a plate-wide contour measurement perspective), a device dependent on specimen surface contact was developed(4).

Design Considerations. In addition to the factors listed in the preceding considerations for the NCMD, three more design requirements were mandated.

1. Independent from Specimen Orientation. As would be ideal in an actual production mileau, a deliberate attempt was made to develop a measurement technique not constrained to a particular fixed reference point. For example, if the magnitude of out-of-plane distortion of a vertical steel bulkhead needed to be determined, it may not be feasible to align such a structure with a vertical or horizontal reference frame. Conversely, it may be excessively time consuming to set up a measurement system if its accuracy or ability depended on a similar alignment.

2. Remote Operation Capability. Whether in the laboratory or workplace, the unwieldy nature of steel plating dictates that deflection measurements should occur on-location. Moreover, the measurement device should not be constrained by its necessary proximity to ancillary equipment.

3. Portability. Proper assessment of plate shape may require a number of repetitive deflection measurements-using a device which relies on specimen contact.

Thus, the size and weight of the intended device were expected to be compatible with frequent operator repositioning. Additionally, the dimensions and weight of the device and any peripheral equipment were to be strictly minimized so that on-site transport or relocations between forming facilities were feasible if required.

Principles of Construction and operation. To remain compatible with the design limitations imposed, measurement of local radii of curvature via direct surface contact was undertaken. The well-known geometric tenet that a distinct circle is defined by any three points on its perimeter was selected as the design basis for this decision. Figure 14 illustrates this principle with a choice of three locations on the surface of a deformed plate. There the Greek symbol, “rho”, denotes a unique radius of curvature prescribed by the local surface contour.

Application of this strategy involved using a rigid frame fitted with “legs” whose lengths could vary based on the shape of the contacted surface. Shown in Figure 15 is a side view of the frame atop a distorted plate. With this concept, the length of the center leg is fixed while each side leg length is adjusted for contact. Comparing side leg lengths with the “reference” center leg (lengths LA and RC vs. the fixed center length) and through the appropriate trigonometric relationships, the critical lengths TL = TB = TR = radius of curvature can be determined.

To carry out the above measurement strategy, eight identical rectilinear, direct current, spring-loaded sliding potentiometers were positioned circumferentially (at 45° angles) and parallel to each other on a 3/4” thick, octagon-shaped piece of plexiglas. Figures 16 and 17 depict top and side views of the device respectively. The fixed-length center leg is more visible in the latter photograph.

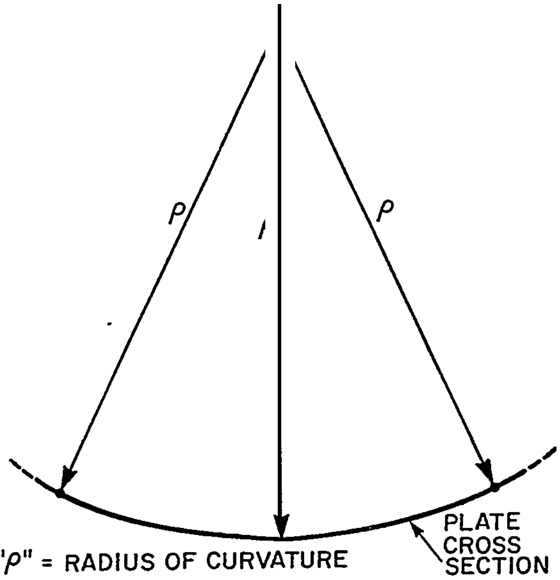


Fig. 14 Geometric principle for plate distortion measurements

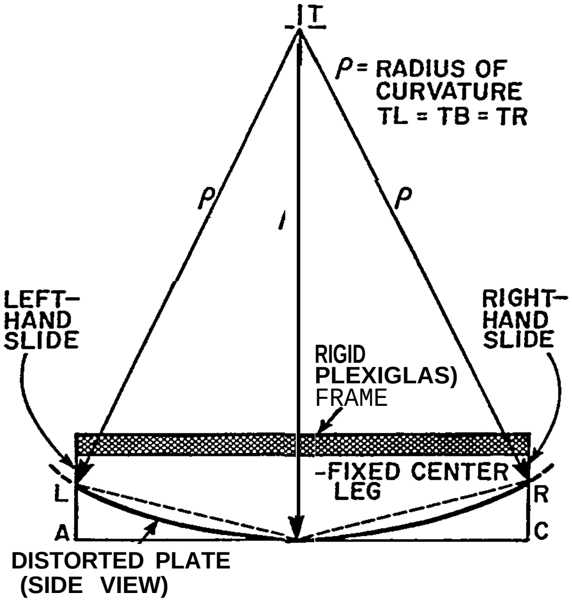


Fig. 15 Application for radius of curvature measurements

Taking advantage of their uniform spacing, diametral pairs of potentiometers were chosen to coincide with the major points of a compass, i.e. north-south, northeast-southwest, etc. This permitted curvature measuraments in fo

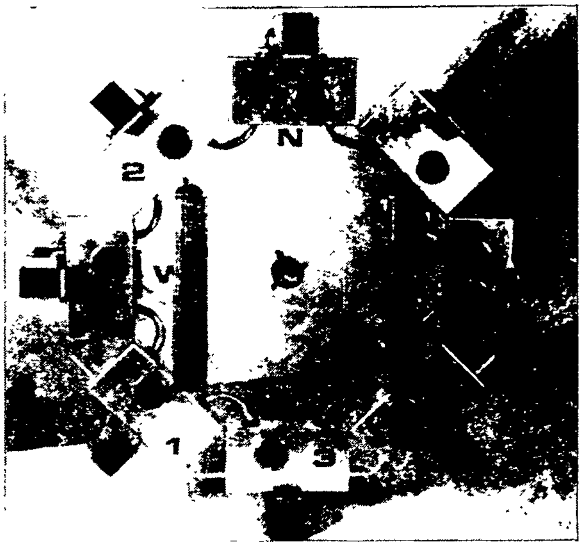


Fig. 16 Top view of contact distortion measurement device. (Illustration positioning of potentiometers around perimeter of plexiglas frame) .

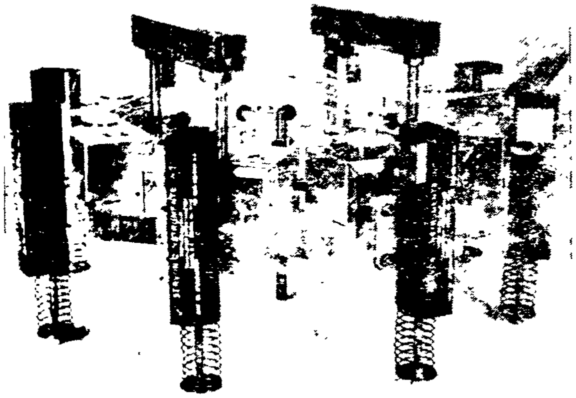


Fig. 17 Side view of contact distortion measurement device. (Illustrates spring-loaded potentiometer slides, fixed center leg, and control button on underside of right handle.)

major directions (using diametrically opposed potentiometers) and standardized device orientation during measurements in multiple locations.

Adjacent to each potentiometer housing, a small aluminum box contains circuitry necessary for potentiometer operation and (electric) calibration. Visible in Figure 16 on the right side of the "0" numbered box is a socket which enables the device to be connected to an AT&T PC 6300 personal computer via multi-conductor umbilical cabling.

The slide position of a potentiometer is determined by the voltage value sensed between a selected pair of its internal contacts. Through cabling, slide voltages become input values for an eight-channel analog-to-digital converter located within the computer. At the converter, analog voltage values are supplanted by their digitized equivalents, the latter of which are used in computer software routines to generate desired radii of curvature values. For remote operation and as shown in Figures 17 and 18, a small push-button trigger is installed in the underside of the right handle. When depressed, its circuitry initiates a round of software-controlled analog to digital conversions. Atypical conversion requires about 25 microseconds.

Through an appropriate choice of software routines written for the device, either curvature or radius of curvature at a specific location in a specific orientation can be determined. When the device is positioned for measurement and a measurement sequence is triggered, the results (in either hard-copy or computer monitor format) are available in approximately two seconds.

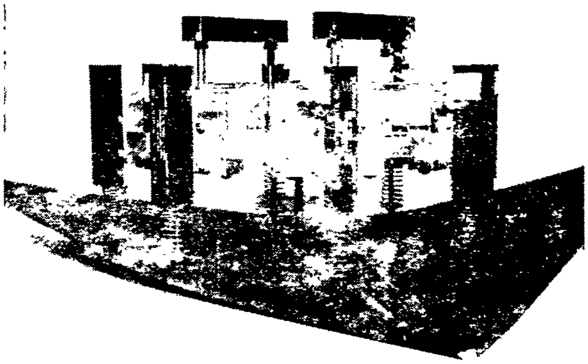


Fig. 18 Measuring distortion′ of a steel plate specimen with tile contact measurement device. (Note variation in potentiometer slide lengths to conform with the specimen's surface topography.)

<u>Limitations/Sources of Error</u>. Note that ~~in its present form, the contact~~ measurement device (hereafter referred to as "Octopus" due to its eight "legs") is totally functional and was used extensively throughout MIT laser line heating research. However, as with any prototype, a list of operability conditions/restrictions exists. A majority of the known limitations of the "octopus" stem from mechanical factors. As with the NCMD, the following summary not only better defines its capabilities but indicates areas of potential future refinement.

1. Minimum Measurable Radius of Curvature. Based on the absolute range of travel of the potentiometers chosen, the minimum radius of curvature is about +14″. (The smallest radius of curvature denotes the greatest amount of locally measurable distortion.) The minimum measurable radius of double curvature is +28″ (coexisting concavity and convexity such as with a "saddle" shape) . These dimensions are well within the degree of bending required in ship production.

2. "Flat Plate Conditions. The radius of curvature for a plane is infinite. However, based on the (installed) analog-to-digital converter resolution, radii of curvature in excess of 25,000″ cannot be accurately determined. To put this limitation in perspective, the edges of a four-foot wide plate whose shape conforms to this degree of curvature would be elevated approximately 0.02 inches above a horizontal reference frame placed at plate center.

3. Plate Contact. The Octopus will not work accurately if positioned so that the legs do not make contact with a specimen's surface. Moreover, although not critical, the best accuracy is achieved when the plane of the plexiglas is kept as parallel as possible to the surface being measured.

4. Computer Locale. Presently, a 25′ cable connects the Octopus to a personal computer. Future applications may dictate that this length be modified for a greater expanse of work area.

5. Smooth, Slowly Varying Plate Contours. Because the device depends on discrete samplings of plate elevation, surface anomalies will not be detected. Further, where such anomalies exist, care should be taken not to position potentiometer slides at their location(s) if the overall (general) degree of curvature is desired. With the contours inherent to ship production and those examined in line heating experiments, this appears to be an insignificant limitation.

6. Analog-to-Digital Resolution. Based primarily on analog-to-digital converter limitations, the smallest discernible change in potentiometer slide deflection is approximately 0.0011 inches.

7. Miscellaneous. Two potential sources of error outside absolute system resolution are associated with improper mechanical calibration and the moment-curvature effects of plexiglas flexure during measurement. For the former, precision laboratory measurements subsequent to a detailed calibration sequence indicated that cumulative slide movement errors could be kept within 0.001″. A similar degree of error is predicted by a worst-case scenario analysis regarding the effects of finite plexiglas frame rigidity.

Special Purpose Adaptations. Aside from numerous potential uses of the Octopus as presently configured, two additional applications are currently under investigation in an effort to extend its future utility. The first involves a “distortion matrix” concept; the second envisions its role as an intermediary in the development of an in-process distortion measurement system.

A distortion matrix (the term was coined at MIT during laser line heating research) is a mathematical representation of a distorted surface and is constructed to represent actual distortion from a prescribed frame of reference. For example, considering a particular steel plate, matrix “size” corresponds to actual surface area. Essentially, each matrix grid element represents the degree of distortion over a localized area of the plate. The number of matrix elements hence determines the resoluticm (accuracy) by which the matrix represents actual distortion.

To construct a distortion matrix for a surface of known dimensions using the Octopus, the number of elements must be chosen; e.g. a 3′ x 3′ plate could be represented by a 3 x 3 distortion matrix whereby each element would mathematically represent one square foot of plate surface The Octopus would be positioned on each “element” of the plate to assess local contours while ensuring that Octopus axes (north-south, etc.) remain parallel among all measurement sites. Data from each triggered measurement would be stored in corresponding elements of the (mathematical) distortion matrix, thereby ultimately recording contours over the entire plate. Where little contour variance occurs (along a particular direction) it would not be necessary to physically place the Octopus at all element sites. In this situation, a distortion contour could be extrapolated fromor interpolated between actual measurement sites. Measurement site quantities could be further reduced by symmetry arguments where possible.

When complete, a distortion matrix would consist of an assemblage of local contours which, in the aggregate, represent the extent of plate-wide distortion. Implicit and fundamental to the accuracy of this method is contour continuity between adjacent matrix elements just as exists on the actual plate surface. A natural and simple extension of such known contours would be deflection determination at any desired location on the plate’s surface (relative to either another location or an established reference frame).

A straightforward second alternative for future Octopus use may be its role in the development of an automated plate bending facility. Although as previously discussed, non-contact measurement would be more ideal, the inherent simplicity and speed of the Octopus at this juncture makes it well suited to provide rapid measurement feedback during a bending iteration process. This may be particularly valid as an interim measure while other components and interfaces of the system are being developed and evaluated.

Current Contact Measurement Device (Octopus) Applications

Because of the success to date in using the Octopus for distortion measurement and its overall versatility, a summary of its applications both in the laboratory and from a ship production perspective is considered warranted.

Research Applications. Three areas, as previously indicated, include:

1. Line Heating Data Base Development. Steel plate bending behavior as a function of heat input, plate thickness, material properties, etc. , can be characterized by evaluating distortion perpendicular to and along the direction of single heating passes or combinations of passes.
2. Contour Inputs to an Automated Plate Forming System. Via the distortion matrix concept, the desired degree of overall bending can become a system input by using the Octopus to measure a prototype surface which exhibits an arrangement of desired surface contours. Such a surface could easily be constructed of cardboard, wood, plastic, etc., with minimum cost and fabrication time.
3. In-Process Feedback During Automated Plate Forming. Again via the distortion matrix concept, the Octopus would provide an input for system comparison with the desired shape, thereby initiating or terminating an interative bending process.

Shipyard/Ship Production Applications.

1. Distortion Measurement. Because of its portability and independence from a required reference frame, the Octopus could be used to accurately assess distortion in virtually any shipboard or fabrication facility location. This ability may be particularly desirable for achieving required tolerances in weld distortion. removal or conversely, in rapidly determining whether a die stamped or rolled plate is properly formed.
2. Fit-up Assessment. The need to make on-site adjustment to plate sections prior to butt welding may be reduced through better accuracy control throughout the pre-fabrication process.
3. Die Construction. The Octopus could not only assist in determining die shape accuracy but also streamline the process of constructing a wide variety of dies
4. Damage Assessment. When collision damage occurs or when other structural deterioration results from heavy weather, fire, etc., in some situations, the degree of damage to a bulkhead, deck or outer hull plating can be rapidly quantified for repair calculations by use of a versatile contact measurement device. Additionally, knowing the absolute amount of distortion could be of assistance in selecting the most efficient repair strategy.
5. Line Heating Training Aid. Apprentice line heating technicians could be provided with near-instantaneous feedback on the results of a particular application of oxy-acetylene torch heat by using a device such as the octopus. This procedure would assist in identifying the most effective line heating procedures under a given set of heating conditions as well as eventually minimize unintentional line heatinq errors and the attendant iterations required to correct them.

Conclusions

Three novel distortion measurement methods have been presented along with particular applications and limitations for their use in a ship production environment. The ultimate pursuit of this and follow-on related research will continue to be toward the advancement of present day ship fabrication processes. As is evident in this paper, these measurement techniques should contribute to current expertise in the field as well as future automation efforts.

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Ship Design for Production—Some UK Experience No. 18

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ABSTRACT

Ship Design for Production is widely accepted in principle. Its successful establishment depends on the, shipbuilder having a well-defined shipbuilding policy, available to the designer, the establishment of a realistic and agreed schedule and adequately trained personnel. Key production engineering techniques include spatial analysis, process analysis and standardization.

The advent of powerful and inexpensive computer software has created new opportunities for producibility to be incorporated from the earliest stages of the design process. Significant progress has been made in recent years in the development of design methods, and in their application.

1: DESIGN FOR PRODUCTION

1.1 Introduction

Ship Design/Production Integration - Design for Production - is an idea that few would disagree with but that almost all would wish to qualify. Dependent on the individual viewpoint, design for production lies somewhere on a scale between building ships with no curves in the hull form and allowing minor modifications to bracket. In reality, it is like most design activity, compromise. A working definition would be:

> Design to reduce production costs to a minimum, compatible with the requirements of the vessel to fulfill its operational functions with acceptable reliability and efficiency. (Ref 1)

The role of the ship designer can be seen in this context as one of arbiter, having the ultimate responsibility of deciding whether performance or production considerations shall take precedence in any particular case or of deciding the nature of the compromise to be reached.

The extension of the design process to include a design for production function has the following primary objectives:

> To produce a design which represents acceptable compromise between the demands of performance and production and where appropriate takes into account the needs of overhaul, repair and maintenance.
>
> To ensure that all design features are compatible with known characteristics of shipyard facilities.
>
> To coordinate the inter-relationship between the machinery, electrical and out-fitting work with the structural work, in order to create a fully integrated design.

It is vital that design for production effort start early in the design process. Designers have the greatest influence on the cost of the vessel during the earliest design stages when main materials and equipment and the basic configuration are being decided.

1.2 The Need for Integration

The need for Design/Production integration arises from changes in the production system itself. Traditionally, construction cycle times were long and the achievement of high throughput were made possible by multiple-ship, simultaneous construction. Steelwork preceded outfit work and outfit work was carried out almost entirely after the erection and launch of the steel hull. Nowadays, production cycle times have become shorter as pressure from the market has dictated lower prices and faster delivery times. Steelwork and outfitting are now carried out in parallel. The change in production system has led to the need for the technical system to provide information in a different timescale, sequence and format.

The need? for people in the technical functions to understand production requirements and for production departments to understand technical procedures and requirements is greater than ever. It is not possible to achieve low production times, short delivery times and high productivity unless technical and production functions work closely together.

1.3 Shipbuilding Policy

Design for production effort can achieve its greatest impact only if the company has developed a shipbuilding policy. The objective in defining a company shipbuilding policy is to establish a "standard" approach to ship construction. This can be achieved through the following step-by-step approach:

1. Develop a product work breakdown structure (Ref 2). The basic aim is to subdivide the ship into a narrow range of interim product types. Each product type may be identified by the sequence and nature of the operations involved in its manufacture and assembly.
2. Establish the "ideal" ship construction method and sequence, to optimize material sizes, subdivide hull into planning units and develop an "ideal" production sequence.
3. Identify shortfalls in the capacity and capability of existing facilities to meet the requirements of the ideal construction method.
4. Determine the best compromise solution and draw up proposals for the removal of the constraints identified above, as the basis for a master plan for future facilities development.
5. Develop standard manufacturing methods and a standard list of operations for each product type. These standard methods must be documented and provided to the designer in order for the design function to be supportive to them.
6. For each ship type and size to be constructed, determine the workload for each product for planning resource requirements.
7. Identify workstations for the manufacture and assembly of each interim product type and determine relevant manning levels.

Shipbuilding policy, of course, must be dynamic and responsive to changes in technology, methods and facilities.

1.4 Design for Function

The prime objective of the ship designer must be to create a vessel which will perform certain functions. It must operate as specified by the shipowner, for example:

- travel at a given speed,
- operate at a given fuel consumption,
- carry a given payload,
- meet classification and other regulations.

Within the lifetime of the vessel, it is inevitable that some of the sub-systems will require to be replaced and their replacement may even be planned from the initial phase. Further, many of the systems will require routine maintenance during their lifetime and there is also the possibility of damage during the vessel's lifetime. In designing for function, all of these additional considerations must be taken into account. In the context of Design for Production, the question must be asked as to what impact a production-oriented approach will have on the various functional requirements specified.

The structured approach to design outlined in this paper based on the development of a vessel as a hierarchy of functional spaces, allows a variety of potentially conflicting requirements to be met. The design which enhances producibility can also enhance operating characteristics.

1.5 Build Strategy (Ref 3)

The planning of large single projects is usually very complex, due principally to the lack of related experience data. It follows that if large sections of any project can be identified as very similar to work done on earlier projects then these may be planned and scheduled with a higher degree of reliability. Those shipyards which have developed a consistent approach to the building of ships have extended this concept to basic design. The fundamental objective with this approach is to develop an established "game plan".

Each new or potential ship contract received by the shipyard requires the formulation of a build strategy. The build strategy applies the shipbuilding policy to a particular contract. Where a shipyard has been working to a relatively uniform construction method over a period of years, much of the work on the build strategy would be produced quickly with most attention being given to those areas identified as being novel.

Products change over a period of years and as production facilities and methods are developed, a considerable drift can occur. Ship designs may not be updated to match new facilities and the production methods may not be optimised for new design requirements. A formal method is therefore needed which will enable changing requirements to be identified and absorbed systematically.

Thus, it is essential that each new ship undergo a systematic scrutiny to determine the proposed construction method, to list key events and their timing with respect to the overall project duraticn, and to identify possible problem areas and bottlenecks so that these can be resolved before production begins. The output from the evaluation of the vessel and the definition of the means of producing it is the contract build strategy. Part of the strategy may include the modification of facilities, or changes in work practices.

1.6 Role of Planning

Following the definition of what production work is to be carried out, and how it is to be done, the planning function has the main task of determining when work is to be carried out. Planning must relate not only to the activities of the production departments, but also to the provision Of information from design, and other technical areas. In this respect, the planning function acts as an important communication link between design and production.

Planning follows production engineering. For example, in the outfitting of a ship, the sequence would be to establish the planning units (zones and steelwork), develop the production sequence and then establish a sequence of work packages for each planning unit. (Figure 1)

The planning department will then work backwards from these dates to establish other key dates in the program. For example:

- Latest date for fabrication of outfit assemblies.

- Latest date for delivery of materials.

- Date for ordering materials.

- Date when technical information from suppliers is required.

- Start date for drawings.

A more detailed level of planning is called for in which the planning office no longer demands the whole of a particular system to be completed by design by a particular date but, instead, demands that all systems within a particular zone are completed and by which date it must be done.

1.7 Training

For design/production integration to be carried out effectively requires properly educated, trained and shop-floor-experienced people. In Japan and Scandinavia in particular, shipbuilders have had a clear policy for many years for the training and development of shipbuilding engineers. Elsewhere too many designers are in the position of having to make major design decisions having barely seen, let alone worked in a shipyard. Another major feature of the successful implementation of design for production is discipline. The preproduction effort will be largely wasted unless production has the discipline to follow the determined program, methods and procedures, and this requires training.

It is not possible merely to prepare “standards” and document them in such a way that a designer with no production knowledge can prepare a design with inherent producibility. Both the vessel technology and the methods of production are dynamic. There are also areas where interpretation of the production or design standard is needed. For this interpretation to reflect the requirements of design/production integration, it is essential that the designer has an understanding of the production process.

One method of resolving the problem is to ensure that all new design staff spend a period before, during or immediately after their formal design training working in a shipyard production area. Even assuming that during the period of initial training, design personnel are well trained with experience of production methods, as these change there will be a need to update the designer’s previous experience.

1.8 Formal Communication

The volume of necessary communication between the design and production functions is such that a formal set of procedures is essential. The basis of such communication is the input and output associated with the main stages of design. Responsibility for the preparation of each element of the total set of information will be defined by terms of reference. Even in cases where the design and production functions are part of the same company, it is not uncommon for the communication between them to be poor. It is possible to find designers who have not seen the production facilities of the shipyard in which they operate.

Determining the information requirements is a function of production engineering. Production engineering will act as a link between the design function, the production function and planning. The formal communication will include a definition of the information to be supplied, the timing of that information and the various sets of standards and regulations which will apply. Not only the form of communication (drawing, sketch, schedule, computer tape) but also the content should be specified, by example.

1.9 Coding

Coding systems are required for item identification, planning and work ordering, cost control and drawing identification. The term "item identification", rather than "part numbering", has been deliberately used since identification in the fullest sense is the primary function of the numbering system. When developing hull steel and outfit numbering systems, it is essential that 'identification" includes at what stage it is made and into which planning unit it is installed. Items which are produced repetitively may be identified as ship standard or stock items. These items would be appended to the planning unit or interim product by item lists.

Coding systems can be for identification or classification. Identification codes can be very simple, and many material control systems use unique part numbering with no structure at all to the identification code. All like items have the same code and the computer system keeps track of which parts go to make up which assembly by holding details of the product structure. At the other extreme, some code systems try to pack very large amounts of information into code.

Classification codes carry information on things like part type, material type and specification, whether or not the part will be installed on a steel unit or block and the number of the work package of which the item will be part. This information classifies the item but is not needed to identify it. Information of this type can be held as attributes of the part and should not be included in the identification coding.

It is likely that the code system will in fact carry a mix of identification and classification elements in order to make it user friendly. The codes should therefore have some structure without becoming too long or complex. The structure should reflect the heirarchy of interim products and the relationship between workstations and departments or cost centers. The way to design or assess a code system is to consider the information required out of the system and then develop the structure that will allow that information to be obtained quickly and easily. The key point to remember is the difference between identification and classification. There is no need to try and hold too much classification type information in an identification code.

2: APPLICATION OF PRODUCTION ENGINEERING

2.1 Spatial Analysis

Process and spatial analysis are the basis for design/production integration. Spatial analysis develops the complete ship design as a series of related functional spaces or spatial envelopes. At preliminary design the designer develops the design by aggregating standard envelopes to define, for example, the arrangement of a machinery space. The designer need not necessarily know the details of the envelope content to define the arrangement. If the arrangement alters this does not delay the lower levels of design as the details of what is contained within an envelope can be developed independently and in parallel. The size of each envelope is determined from standards or an be analysis of outfit assemblies. In the ideal situation the contents of the envelope will themselves be standard. The standards are developed on the basis of previous experience, analyzing vessels to determine how envelopes can be defined for future contracts.

Once the series of spaces have been defined, they are aggregated to build up a picture of the whole vessel. Each spatial envelope includes not only the equipment, or structure within it, but also operating space requirements, access ways, maintenance and withdrawal spaces. (Figure 2)

Spatial analysis determines the layout of a vessel. It must be integrated with hydrodynamic and other requirements defined by the naval architect, to ensure the ship will operate properly. Benefits of the spatial analysis approach for the designer are the ability to use standards and the ability, after the analysis, to work independently on the detail design of the content of the envelopes. For the producer, the benefits are the incorporation of standards and the ability to relate design timetable to production requirements.

2.2 Block Breakdown

In order for the design of a ship to be suited to efficient production in a particular shipyard, the designer must be aware not only of the shipyard facilities but also of standard or preferred processes and methods used by production. This information must be documented and available to the designer in increasing detail through the design process.

At the earliest design stage the need is for a block breakdown, showing the preferred erection method. This is then extended to information on how each block is assembled. At the detail design level information is required, such as welding processes and accuracy control methods. The breakdown for the ship is reviewed and amended as necessary by the design and production departments, taking into account any unusual design features of the ship or changes in production methods.

2.3 Process Analysis

Process analysis is part of both strategic and tactical production engineering. The basis for process analysis is the planning unit, which is the central entity around which production engineering and planning work is organized. Typically a planning unit is a block, or a pair of blocks, an outfit unit or a zone on-board the ship.

Having identified the planning units, production engineers decide upon the sequence of work to complete the planning unit in the required time and to the required level of quality. Production engineers will define what work has to be done at each production stage, and at which work station work has to be done. To be effective, production, design and planning people should be involved in the process analysis work. (Figure 3)

At the strategic level some process analysis will be specific to contracts, for example, identifying where and how planning units for a particular ship differ from the standard. Other work will center around the development of the standards themselves. At the tactical level, process analysis will be carried out in detail for all planning units. Technical inputs will come from transition design and the outputs will be used as the basis for the preparation of work station drawings. (Figure 4)

Process analysis therefore provides detailed information that forms the basis for the preparation of work station drawings and for production. At the same time, the analysis may well lead to the identification of improved production methods. These improved methods would be incorporated in the shipbuilding policy and then in future designs.

2.4 Technical Information for Work Packages

In order to plan, control and monitor production work effectively, the work is best broken down into a number of discrete work packages, where each work package will define a specific amount of work to be done at a particular stage of production. Work packages will initially be generated from the process analysis carried out by production engineers at the tactical level. The object is to produce a coordinated and integrated technical information package for each work package, containing only the information required at that particular stage in the production process. Work packages will be prepared for every stage in production right through to ship completion. (Ref 4)

The following information should be included as a minimum on or with each work instruction:

- flow process of material;
- dimensional data;
- drawings of the interim product;
- work station arrangement;
- production methods;
- material collection.

2.5 Standards

The aim in preparing standards is to reduce variety and ensure suitability for purpose. The benefits that are looked for will differ in emphasis according to the nature of what is being standardized.

The first aim, reduction of variety, is pursued primarily for economic reasons, to reduce the costs of design, manufacture and maintenance. The benefits resulting from series production can become very substantial as the scale of production increases and special-purpose jigs and tools or flow line production are used. The second aim, fitness for purpose, includes factors such as functional suitability, safety, cost effectiveness, reliability, maintainability and quality assurance.

Material standards prescribe the size and scantlings of elementary materials, such as steel plates, sections, pipes, etc, and also include scantlings and configuration of individual fitting pipe pieces, vents, moorings, doors , ladders, etc, which form the basis of design standards. These prescribe the design philosophy criteria, specifications and applications of various structures and systems, and include some basic modules.

Production engineering standards prescribe the methods and criteria of quality control and procedures of testing and inspection. Standard drawings consist of standard equipment layouts of system modules, practices and manuals, etc, which can be utilized as guidance plans.

3: SOME UK EXPERIENCE

3.1 Existing Applications

The concept of design for production is not new, but to some extent it is a concept which has to be continually “rediscovered". Its most recent application dates from around 1980 via programs within British Shipbuilders and in those shipyards which have recently returned to private ownership.

Vaughan (Ref 5) summarises the approach which was adopted as part of an overall productivity improvement program, and which has been developed since. The most significant points made from a design for production perspective are:

- the need for a shipbuilding strategy;
- the development of a contract Build Strategy in parallel with early design;
- subsequent production engineering of the design, ideally within the engineering department.

In the early stages of the program, effort was concentrated on areas of the vessel which have a significant impact on the total work content and on the ship construction program. Thus a considerable effort was expended on the machinery spaces of vessels and deckhouses.

Initially rapid progress was made with small vessels, notably tugs and supply ships. This reflects the short time between contract and delivery (often little more than one year), which allowed feedback from one vessel to be available quickly. There has been a progression from identifying potential modules (outfit units) on existing designs, to re-routing pipes and systems, to defining modules as part of the initial design. This is now routine for several smaller yards.

Progress has been faster where the design has been more or less within the control of the shipyard. Where an external design is used it has been more difficult to obtain change. At the start of a program of change there is additional design work, in re-working drawings to create more producible layouts and in creating production-oriented work instructions. This additional work is only temporary, provided a thorough review of the drawings supplied for production, classification and owners is made and superfluous drawings are removed. This has been successfully achieved by some smaller shipyards. Where this extra cost is within a single company budget, the trade-offs can be made. Where the extra cost is to be incurred by one company to the benefit of another, there is scope for negotiation.

There are also problems in the development of design for production where vessels are particularly complex or novel. In such cases there is more pressure on design, and less lead time available in which producibility can be considered. There is reluctance on the part of the designer to take on additional changes.

In some cases, the shipbuilder may decide to create lead time by delaying the production start, and use the time to revise the detail design in a more producible form. The additional unbudgeted engineering cost is traded off against production manhour savings. Ref 6 describes such a case in the US. Ref 7 describes current experience at Harland and Wolff, in the case of the SWOPS (Single- Well Offshore Production System) vessel. This is designed to extract oil from isolated, marginal offshore oilfields. The vessel includes dynamic positioning, oil production process plant, storage capacity and accommodation. There was exceptionally close cooperation between design and production requirements.

The reported results of this closer integration included the design and production of large sections of the process plant as complete and independent outfit units. Another development was the integration of major cable runs, in an electrically complex ship, with parts of the structure. This allowed a considerable volume of work to be carried out early in the production cycle. In addition, the build strategy called for numerous outfit units, which were designed in from the earliest stage.

3.2 Some Current Developments

There are a number of current development projects in the Design for Production area. These are in the form of cooperative ventures between shipbuilding companies and universities.

Recent research at the University of Newcastle has been concerned with the development of a preliminary ship design system. The system has a modular structure which allows each module either to be used separately, or used in a fully integrated design system. The main procedures cover: hull form design, compartmentation and layout, structural design and mass estimation, seakeeping and cost estimation (Ref 8).

The work has links with production technology in the influence of build strategy on structural configurations. It is essential that such considerations are accounted for when assessing structural layout and its associated mass. Design for production will be influential in future studies of this type and it will be a significant step forward to be able to assess the effect of major production considerations on the ship design at the concept stage. (Figures 5 and 6)

It is important during the development of a design that alternative proposals can be generated and assessed rapidly. This is particularly true at the concept or preliminary design stage where a large number of alternatives may be examined. In today’s competitive environment it is essential that design procedures should be reliable and flexible. The results may be used in pre-contract negotiation and both technical and commercial decisions may be taken on the basis of the data generated. Recent improvements in computing hardware have been accompanied by reduced costs which have made available to the designer a wide range of CAD workstations often incorporating a graphics facility. The advent of this computing power, often in portable “desk-top” form provides an opportunity for the designer to develop design procedures which are highly inter-active, user friendly and can incorporate more rigorous fundamental analysis methods than are traditionally used in preliminary design. These factors allow the adoption at the concept design stage of methods which have features similar to those normally associated with more detailed or post-contract design investigations.

One important requirement is ship production data in a form comprehensive and reliable enough to be of use in design investigations. Such data includes details of work content and estimates of materials and labour costs associated with each stage of the building programme. It can be combined with a knowledge of build strategy, purchasing policy and production technology to form the basis of a ‘design for production” approach when seeking to improve the overall design methodology of marine vehicles. This process has been encouraged by the introduction of sophisticated management and production support systems which are often part of a Computer Integrated Manufacturing System (CIM).

Work has also been carried out to develop a structural design method which incorporates:

Definition of geometry and scantlings using a graphics facility linked to a database of production information.

Use of information on production technology and build methods to determine block and panel arrangement.

Assessment of work content for each phase of production.

Application of facility cost information to determine total cost for each alternative design.

Comparison of alternative design proposals on a cost basis.

There is also work on the application of detailed production cost data to structural design, in this case at the University of Glasgow. Further work is currently underway to extend the approach and apply it to warship structures. (Ref 9)

Development is also being undertaken in layout design (Ref 10).

The paper describes work which is being carried out as part of a collaborative research programme between the British warshipbuilding company, Yarrow Shipbuilders Ltd, and the Department of Naval Architecture at The University of Newcastle upon Tyne, England.

Recent developments in CAD have made available to the designer a wide range of hardware and software which encourage the application of interactive, graphics-based design procedures. Such methods can be of significant benefit in modern warships design where the optimal utilization of “space” is a primary design goal. Two facets which influence and control space management systems are the adjacency of functional areas and the environment into which a space is to be placed. Recent work concerned with the geometric representation and manipulation of architectural arrangements has been adapted for use marine vehicle design. An optimal design procedure which utilizes the theory of fuzzy sets is used to achieve the general layout of space which allows the delineation of the main compartments of a vessel. The hull envelope can be generated using a surface generation module or by using previously faired basis ship offsets held in a data base.

Having defined the compartmental configuration of the functional spaces the next level of design is concerned with a more detailed consideration of compartments, or groups of compartments and the equipment and systems they contain.

Equipment is defined in terms of ergonomic envelopes, geometry and connectivity of services, etc. The attributes of a 3-D graphics workstation are used, in conduction with an equipment library, to provide an effective detailed design procedure. The layout of equipment in spaces usually concerns the achievement of goals whit conflict or have different priorities. The use of optimal goal programming techniques is suggested as a way of solving the multi- objective problem.

3.3 Conclusion

This paper has attempted to re-state the main- objectives and requirements for design for production, to describe the application of production engineering to design and to relate this to current shipbuilding practice.

Initially, the application has been in the form of modifications to existing designs, at the detail level. More recently the integration of producibility into the design process has started earlier. The main factors in Allowing this earlier integration are the existence of reliable production data from a relatively stable production system, and the emergence of sophisticated computer software for initial design. This allows greater depth of analysis in a shorter timescale. The designer has therefore the opportunity to review additional options, and to take into account the impact of design variations on production. The use of these newer methods is being consolidated into a formal design system.

It is to be hoped that the potential being offered to reduce shipbuilding costs will be realized.

ACKNOWLEDGEMENTS

The author is grateful to colleagues at A & P Appledore for advice and assistance. Mr W Hills of the Department of Naval Architecture at the University of Newcastle upon Tyne provided much useful information from his research program.

The opinions expressed are the author’s own .

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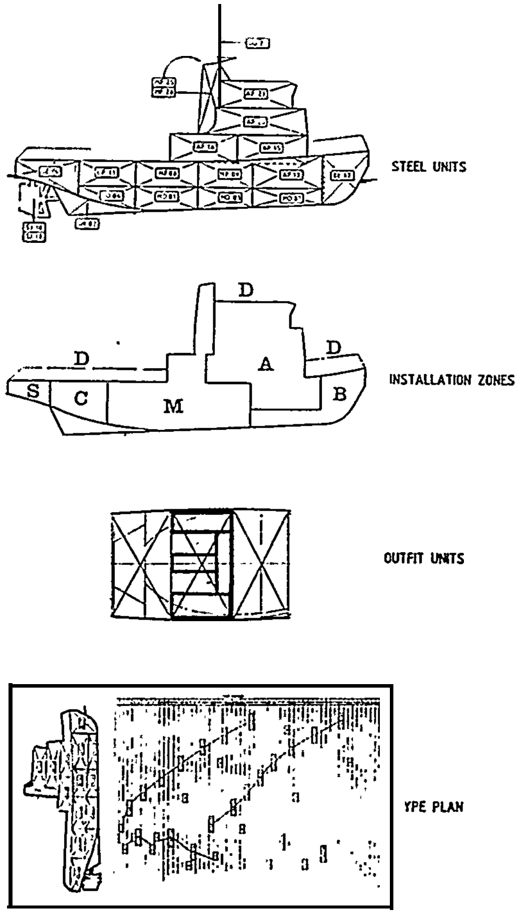


PLANNING UNITS

FIGURE 1 - Identification of Planning Units

These are identified at the earliest stage of the design process, and serve as the basis of all planning activities, detailed design and engineering.

FIGURE 3 - Process Analysis

Each planning unit is analyzed, in the case of outfit to establish at which stage of production items will be installed. A further analysis of each stage will determine work package content.

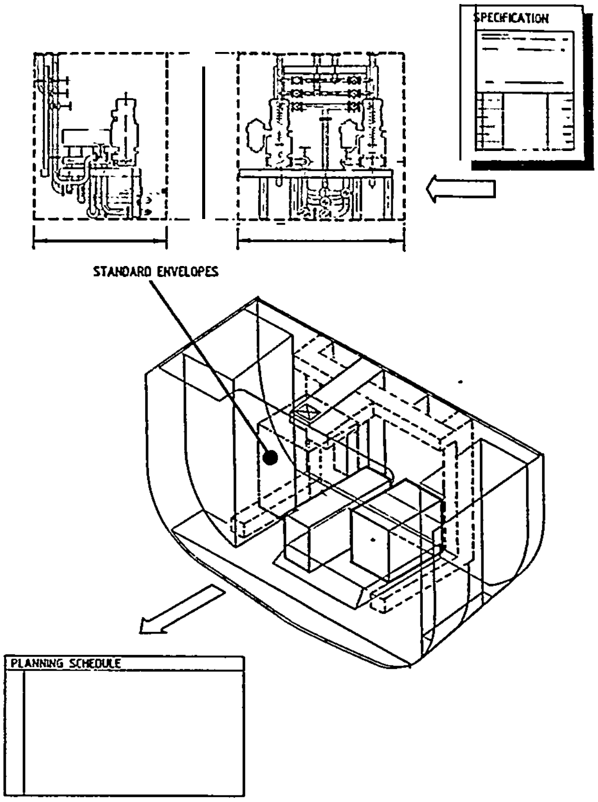
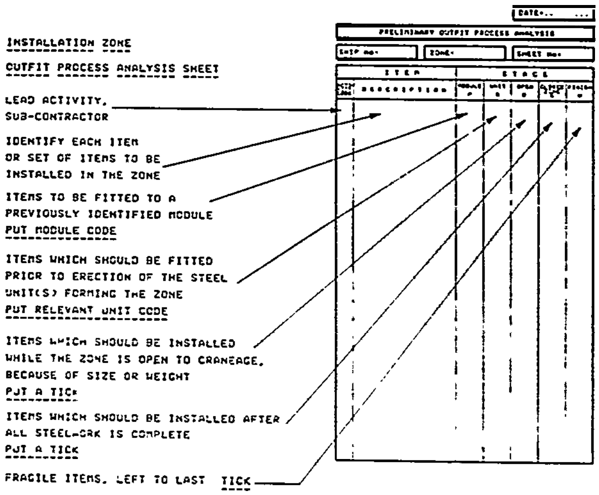


FIGURE 2 - Spatial Analysis

The ship is designed as a set of related functional spaces, based on standards where possible, which provide envelopes for equipment, system, access and maintenance requirements.



INSTALLATION ZONE

OUTFIT PROCESS ANALYSIS SHEET

LEAD ACTIVITY,
SUB-CONTRACTOR

IDENTIFY EACH ITEM
OR SET OF ITEMS TO BE
INSTALLED IN THE ZONE

ITEMS TO BE FITTED TO A
PREVIOUSLY IDENTIFIED MODULE
PUT MODULE CODE

ITEMS WHICH SHOULD BE FITTED
PRIOR TO ERECTION OF THE STEEL
UNIT(S) FORMING THE ZONE
PUT RELEVANT UNIT CODE

ITEMS WHICH SHOULD BE INSTALLED
WHILE THE ZONE IS OPEN TO CRANEAGE,
BECAUSE OF SIZE OR WEIGHT
PUT A TICK

ITEMS WHICH SHOULD BE INSTALLED AFTER
ALL STEELWORK IS COMPLETE
PUT A TICK

FRAGILE ITEMS, LEFT TO LAST TICK

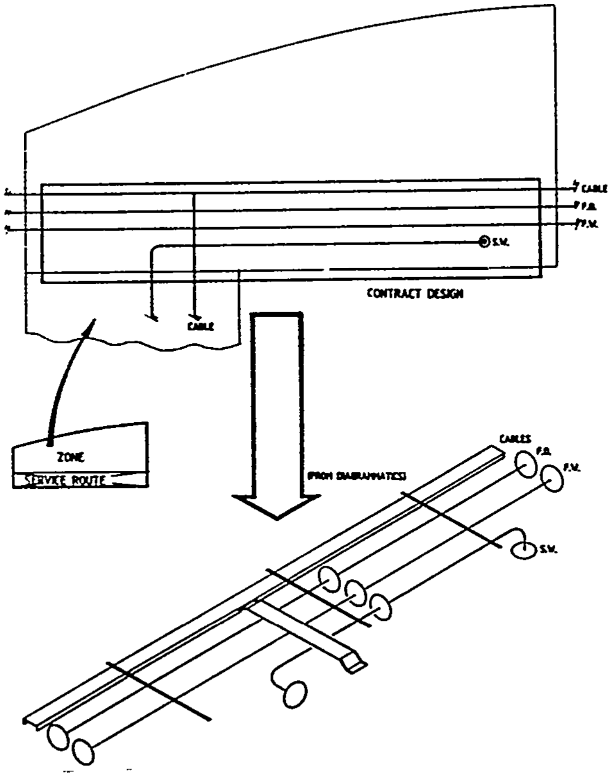


FIGURE 4 - Identification of Outfit Assemblies

The service route, identified as a functional space and part of a planning unit, provides the basis for outfit assemblies and defines detail design requirements.

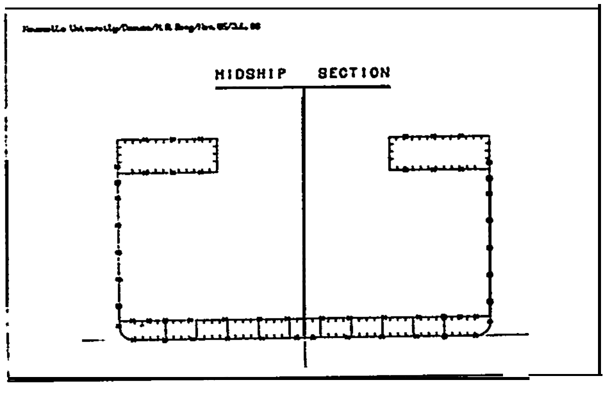


Fig. 6.12 Midship Section (BLOCK/UNIT DIVISION: 7 UNITS)

FIGURE 5 - Concept Design

Recent developments in computer software have provided powerful tools to allow design options to be created and evaluated early in the design process.

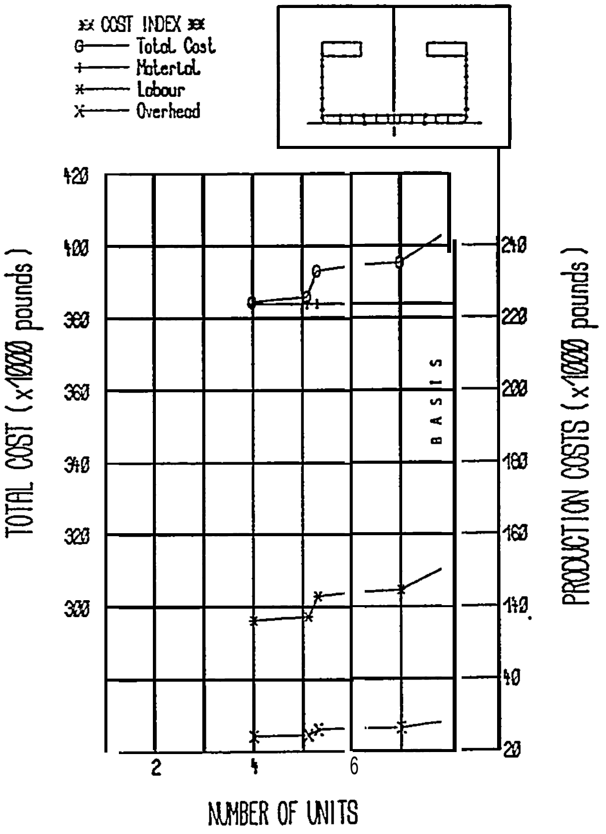


FIGURE 6 - Cost Evaluation

The depth of information which can be produced at an early design stage, linked to a production performance database, allows the production cost of various options to be evaluated.

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Evaluation of Commercially Available Wet Welding Electrodes for Potential Repair of U.S. Navy Ships

No. 19

Thomas C. West, Visitor, Welding Engineering Services, and Gene Mitchell, Visitor, Naval Sea Command

ABSTRACT

As part of a program to determine the viability of underwater wet welding for repair of U. S. Navy surface ships, eight commercially available shielded metal arc wet welding electrodes were evaluated by a series of screening tests. Two E7014 "type" electrodes provided superior results and were used for welding procedure qualification testing on ASTM A-36 steel with a carbon equivalent of 0.35. Qualification testing included visual, liquid penetrant and radiographic inspection, as well as bend testing, reduced section tensile testing, all-weld-metal tensile testing, Charpy impact testing, macroscopic examination, hardness testing, and chemical analyses. The wet welding was performed in the vertical, overhead and horizontal positions. The welding took place at seven and thirty-three feet of sea water.

Nondestructive and destructive test results show that both electrodes exceed the requirements of American Welding Society specification for underwater welding, AWS D3.6 (Ref. 2) Type B. Weld quality and strength were found to be approximately on a par with welds made in an air environment. Weldment ductility and toughness were appreciably lower than would be expected of air welds.

1.0 INTRODUCTION

The term "wet welding" refers to wet hyperbaric welding (welding in the wet at ambient pressures greater than one atmosphere) as opposed to dry hyperbaric welding (sometimes referred to as dry chamber welding). In wet welding, there is no mechanical barrier separating the welding arc from the surrounding water; and the only physical barrier are the bubbles being generated by the heat of welding and decomposition of the electrode flux and waterproofing materials. The work covered by this paper, as well as all comments contained herein, are in reference to wet welding using the shielded metal arc (covered electrode) welding process.

Until the late nineteen sixties and early nineteen seventies, wet welding was considered appropriate only for non-critical applications, such as emergency temporary repairs and salvage work. Until the late nineteen seventies, some ship fabrication documents considered wet welds to be only sixty-percent efficient. Private industry began producing structural quality wet welds, for permanent repair to offshore structures, in the early nineteen seventies. These welds were produced by diving companies using their own in-house, proprietary wet welding electrodes; the welds developed the full strength of the mild steel base metal, and thus were considered one hundred percent efficient. However, weld metal toughness, ductility and internal quality were less than what would be expected of welds made in a normal air environment; and base metal heat-affected-zone hardness was higher than that normally associated with welds made in a dry environment. Today, internal quality of wet welds has improved somewhat; but weld metal ductility and toughness, and base metal heat-affected-zone hardness, are still not on a par with welds made in the dry. However, for commercial applications, wet welds have been shown to exhibit acceptable structural properties under a number of loading conditions.

Because of the success of wet welding in the various commercial applications, and the large costs associated with the drydocking of ships, the U. S. Navy has started a program to evaluate and, where appropriate, develop and implement underwater welding for repair of Navy ships. Both dry habitzt and wet welding are encompassed in the program. The work described herein represents a portion of the overall program. Wet welding has been successfully used in permanent and temporary repairs on ships and other commercial floating structures. The scope of this work was as follows:

- Evaluation and comparison of commercially available wet welding electrodes, to determine those exhibiting superior properties.

- Performance of wet welding procedure qualification testing using those electrodes found to be superior during the electrode evaluation or screening tests. The qualification testing used steel produced to the requirements of MIL-s-22698 (Ref. 5).
- Development of welding procedure specifications based on the qualification welding performed.

2.0 PROGRAM TESTING AND EVALUATION

2.1 Facilities

Diving and welding facilities were provided by Global Divers and Contractors of New Iberia, Louisiana; The Global test tank is shown in Figure 1. The wet welding tank was 36 feet high, 20 feet in diameter, and contained sea water. The filtering system maintained clear water throughout the welding operations. The air compressor and volume tank were adequate for the support of two welder/divers working at the same time. The welding machines were both 400 ampere Miller diesel driven generators.

2.2 Materials and Examinations

The base metal consisted of both high carbon equivalent (CE) and low CE steel plate meeting the requirements of MIL-S-22698. Mill certificates were obtained for each steel, and independent chemical analyses were also made. The following represents the properties of these steels:

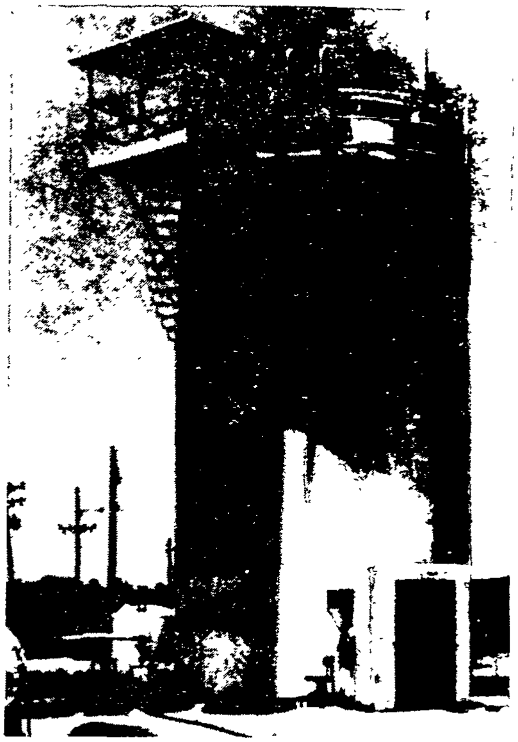


FIGURE 1. Global Divers Test Tank

Steel	Thickness	*Carbon Equivalent	UTS KSI/MPa	YS KSI/MPa	Elongation
ASTM A36	3/8″	0.280	67.7/467	50.6/349	25%
"	1/2″	0.376	67.6/466	47.7/329	29%
"	3/4″	0.350	71.1/490	50.0/345	29%
DH 36	3/8″	0.449	80.0/552	60.0/414	25%
"	1/2″	0.443	78.3/540	55.3/381	21%
"	3/4″	0.435	77.7/536	60.3/416	25%

$${}^{*}CE = C + Mn/6 + (Cr + Mo + V)/5 + (CU + Ni)/15$$

Six mild steel and two austenitic steel electrodes were evaluated. The electrodes are identified by numbers 1 through 8. All electrodes, except Number 8, were 1/8″ in diameter; Electrode Number 8 was 5/32″ in diameter. Electrode Numbers 1, 2, 3 and 8 were E7014 "types"; Electrode Numbers 6 and 7 were E6013 "types"; Electrode Number 4 was E309-16; Electrode No. 5 was an E310-16 "type".

All nondestructive examination was accomplished in accordance with MIL-STD-271 (Ref. 4). Destructive examination specimens were prepared and tested in accordance with AWS B4.0 (Ref. 1) and AWS D3.6.

2.3 Environmental Conditions

The temperature of the water in the tank ranged from 75F to 85F. Welding was accomplished at depths of 33 FSW and 7 FSW. Visibility was excellent at all times. The divers' breathing medium was air. The pressure at depth was 14.7 PSI gage at 33 FSW, and 3.1 PSI gage at 7 FSW. Allowable times at 33 FSW were determined using the 40-foot criteria of the U.S. Navy dive tables.

2.4 Test Plate Design & Testing

2.4.1 The eight commercially available wet welding electrodes were initially tested during the screening tests. Based on these tests, two electrodes were chosen for qualification testing.

2.4.2 Screening tests. All screening tests were accomplished at a 33 foot water depth using two welder/divers. This allowed duplication of all tests, reducing the chances of accepting an electrode which would run successfully only when a unique style of welding was utilized. Test plates consisted of cruciform specimens and grooved plate specimens, the design of which is shown in Figure 2. DH 36 steel, 3/8″ thick, was used for the cruciform specimens following the welding sequence shown in Figure 3. The object of the welding sequence was to induce relatively high restraint to allow determination of any propensity for cracking in either the weld or base metal heat-affected-zone. The cruciform specimens were liquid penetrant inspected after welding. They were then sectioned to provide two MACRO sections, 1 1/2″ from each end; the MACROS were sanded to a 120 grit finish, etched, and examined at a magnification of 7x. The welding electrodes which were found acceptable were further evaluated using the grooved plates.

The grooved plates were prepared to allow both a vertical and an overhead weld to be made in each plate. Both high CE (DH 36) and low CE (A36) steel were used for the grooved plates. After welding and visual inspection, the plates were liquid penetrant inspected, radiographed, and sectioned to provide two MACROS and 12 face bend specimens for each weld. The MACROs were prepared and evaluated as specified above for the cruciform MACROS. Four face bends were performed over radii of 6T, 4T and 2T, T being the bend specimen thickness (3/8″). When four bends passed the 6T bend test, four more specimens were. then tested over the 4T bend radius; success over the 4T bend radius warranted four additional bends over the 2T bend radius. The 6T bend radius is specified by the American Welding Society specification for underwater welding AWS D3.6 for Type B welds, whereas the 2T radius is typical of that specified for in-air surface welding and dry hyperbaric underwater welding.

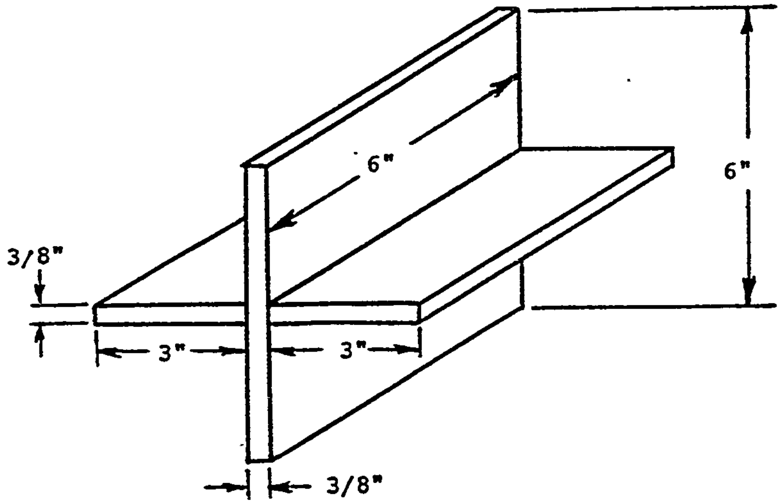
The cruciform and grooved plate weldments were evaluated using the form shown in Figure 4; one of these forms was completed, for the vertical and overhead positions, for each wet welding electrode being evaluated. Those electrodes with the highest total scores were selected for qualification testing at 33 and 7 FSW respectively. As can be seen from the form shown in Figure 4, the "GRADING CRITERIA" specifies three grades for each type of test -- the lowest grade being one, and the highest grade being three. The grade is multiplied by the weight factor (indicates the relative importance of the specific evaluation criterion) to obtain the score for each test performed.

2.4.3 Qualification tests. Test plates consisted of 3/4″ ASTM A36 steel. Test plate X, which was 20″ long, was used to obtain two reduced section tensiles, four side bends, one VICRO section with Vickers hardness readings, five weld metal Charpy impact specimens, and five base metal heat-affected-zone Charpy impact specimens. Charpy impact test temperature was 28F. Test plate Y, which was 16″ long, was used to obtain two all-weld-metal tensile specimens and weld metal chemistries. Test plate X and Y designs are shown in Figure 5.

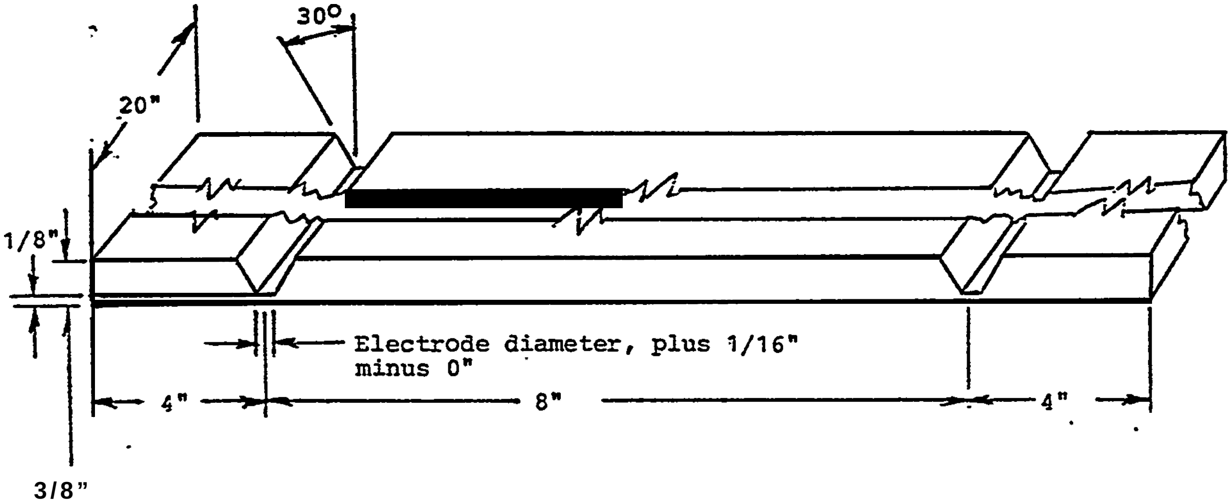
Each wet welding electrode, selected for qualification testing, was qualification tested in accordance with the following:

Position	Test Plate Type	Depth, FS?W
V	X & Y	33 & 7
H	X	33
OH	X & Y	33 & 7

Accordingly, a total of nine butt welds (five for Test Plate X and four for



CRUCIFORM SPECIMEN



GROOVED PLATE SPECIMEN

FIGURE 2. Screening Test Plates

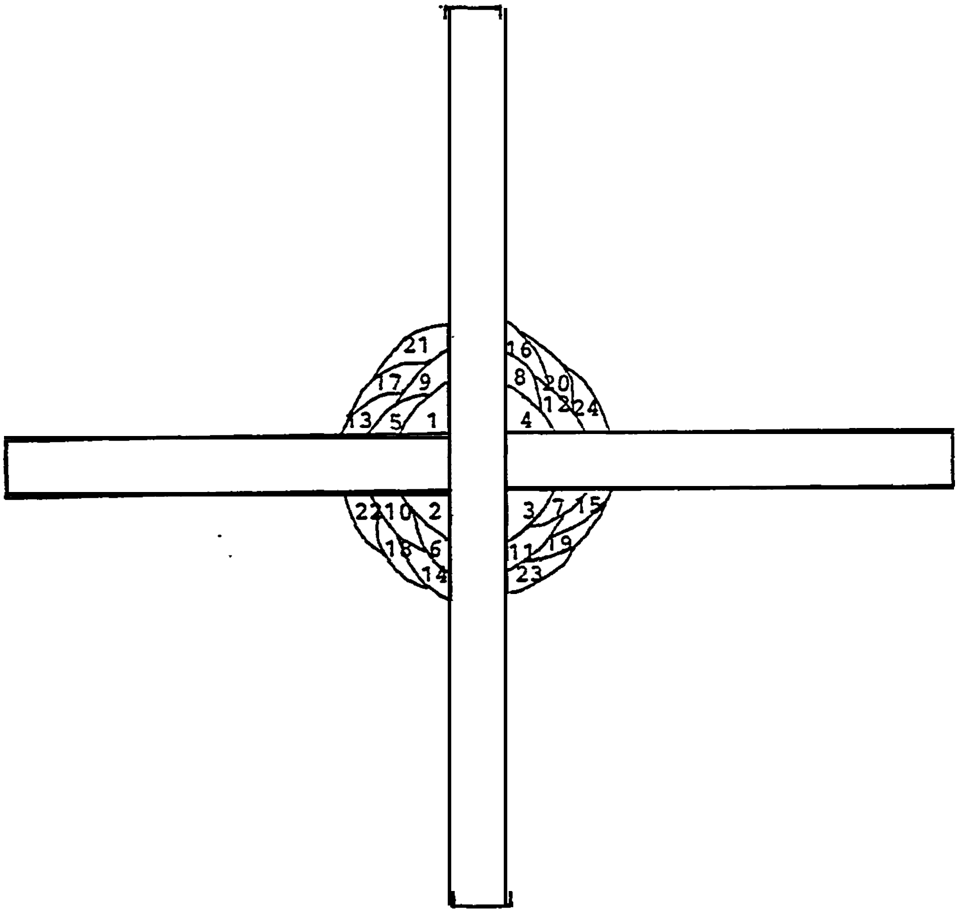


FIGURE 3. Typical Welding Sequence for Cruciform Specimen

Test Plate Y) were attempted for each wet welding electrode chosen for qualification testing. Qualification tests were summarized using the form shown in Figure 6.

2.5 Test Results

2.5.1 Screening tests

2.5.1.1 Cruciform. All cruciform were made using the high CE DH 36 steel. Cruciform bead appearance ranged from good (Figures 7 and 8) to poor (Figures 9 and 10). The cruciform were welded in the vertical and overhead positions at a water depth of 33 feet. Three layers of weld metal were deposited in each corner (see Figure 3).

Weldability, visual and liquid penetrant inspection, and MACRO sections were evaluated and graded using the form shown in Figure 4. Representative photographs of the MACRO sections are shown in Figures 11 through 18. Mild steel electrode Numbers 2, 6, 7 and 8 were rejected based on weldability and surface appearance; each of the electrodes suffered arc outages during welding -- resulting in rough weld beads. Electrode Numbers 2, 6 and 7 MACROS are shown in Figures 13, 17 and 18. MACRO sections were not taken from the electrode No. 8 cruciform, since the irregularity of the weld beads were obviously unacceptable. The electrode would hardly sustain an arc (see Figure 9) with the electrode negative -- which is the polarity normally used with the mild steel electrodes; when the polarity was changed to electrode positive (see Figure 10) , better, but unacceptable, results were obtained. The waterproof coating integrity of the electrode was poor, allowing some of the electrode flux coating to dissolve in the water, which probably caused most of the problems.

The austenitic stainless steel electrodes, Numbers 4 ad 5, were rejected based on longitudinal, center

WET WELDING SCREENING EVALUATION FORM

EVALUATION CRITERIA	weight FACTOR	CRUCIFORM FILLET		GROOVED PLATE		TOTAL SCORE
		GRADE	SCORE	GRADE	SCORE	
Arc stability 1/	1					
Arc start/restart 1/	1					
Puddle control 1/	1					
Puddle visibility 1/	1					
Slag removal 1/	1					
Gen. visual weld appearance 1/	1					
Interpass grinding 2/	2	N/A	N/A			
Visual Inspection 3/	3					
MT/PT inspection 3/	4					
MACRO examination 4/	4					
RT inspection 5/	4	N/A	N/A			
Bend testing 6/	5	N/A	N/A			

*CF-
Weld I.D. Number

*GP-
Weld I.D. Number

Welder/diver

Position

- *CF (cruciform fillet)*
- GP (grooved plate)

SCORE: weight factor x grade

GRADING CRITERIA

1/Poor---1
Fair---2
Good---3

2/Complete weld pass(es)---l
Starts/stops, occas. pinhole---2
None---3

3/Meets AWS D3.6, Type B---1
Meets N/S 0900-003-8000, Cl. 2---2
Neets N/S 0900-003-80001 Cl, 1---3

4/Meets AWS D3.6, Type B---1
Meets AWS D3.6, Type A---2
Meets MIL-STD-248---3

5/Meets AWS D3.6, Type B---1
Meets AWS D3.6, Type A---2
Meets N/S 0900-003-9000, Cl. 1--3

6/6T meets MIL-STD-248---1
4T meets MIL-STD-248---2
2T meets MIL-STD-248---3

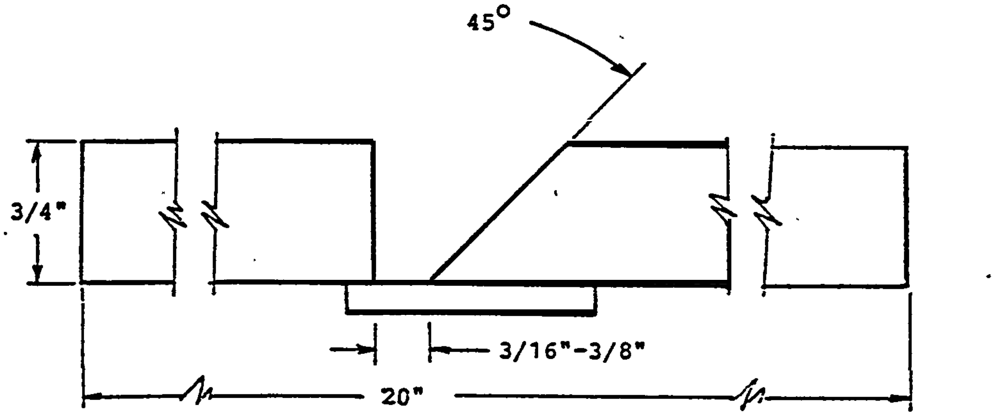
Electrode Diameter, Brand & Type ____________________

Start Time (cruciform): __________ Finish Time: __________ Date : __________

Start Time (grooved plate) : __________ Finish Time: __________ Date : __________

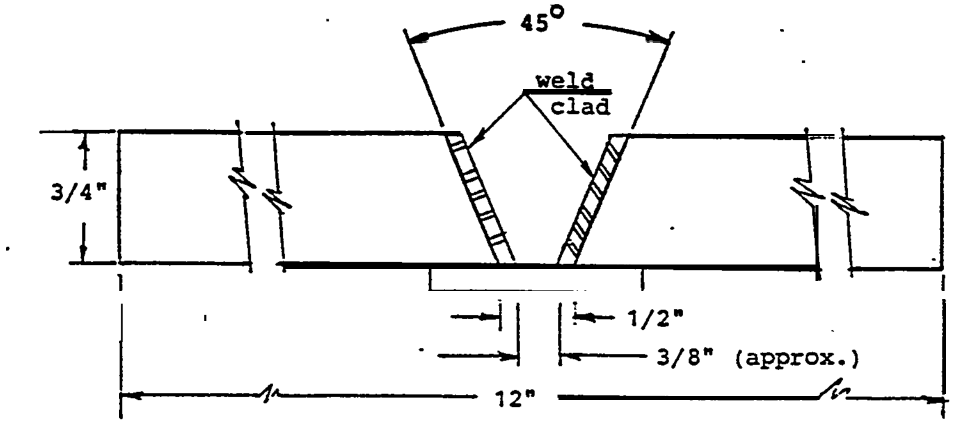
Name of Evaluator 6 Firm: ____________________

FIGURE 4. Grading Form



Joint land (nose): None
Joint length: 20"

X PLATE



Joint land (nose): None
Joint length: 16"

Y PLATE

FIGURE 5. Qualification Test Plates

bead, cracking. This cracking tendency was most pronounced in the root pass of the welds. It is not known whether this cracking tendency is a result of the dilution by the carbon steel base metal, or due to the small weld cross section of the initial (root) pass coupled with high restraint and a known tendency for hot cracking of the austenitic stainless steels. The No. 5 electrode did not show the cracking tendency during cruciform welding; however, the cracking manifested itself through the entire thickness of the root pass of the first grooved plate weld. As a result, the grooved plate weld was not completed, and no further welding was attempted using this electrode. Electrode No. 4 and No. 5 NACROS are shown in Figures 15 and 16.

No base metal or heat-affected-zone cracking was detected in any weldment by visual or liquid penetrant inspection.

PROCEDURE QUALIFICATION TEST RESULTS

TYPE OF TEST	TEST RESULTS OR ACCEPTANCE STANDARDS MET
Visual Inspection 1/	Test Plate X: Test Plate Y:
Magnetic Particle Inspection 1/	Test Plate X: Test Plate Y:
Liquid Penetrant Inspection 1/	Test Plate X: Test Plate Y:
Radiographic Inspection 1/	Test Plate X: Test Plate Y:
Side Bends 2/	
Reduced Section Tensiles 2/	Fail. Locat.: UTS : Ys Elong.
MACRO Evaluation 1/ 2/	
wardness Values 2/	Avg. BM: Avg. IIAZ: Avg. WM:
Charpy-V-Notch 2/	Avg./Min. IIAZ: / Avg./Min. WM: ; /
AWM Tensile 3/	UTS : Ys : Elongation:
WM Chemistry 3/	C: Mn: Si: P: S: Cut Ni: MO : V: Cr: oxygen:

1/ The test plan specifies a range of acceptance standards for these inspections. The most stringent acceptance standard passed shall be recorded.

2/ Test Plate X only

3/ Test Plate Y only

Electrode Brand, Diameter & Type: ____________________

Base Metal; ____________________

Welding Position: ____________________

Name of Evaluator: ____________________

Firm; ____________________

Weld I.D. Number: TEST PLATE X: ____________________

Water Depth: __________

TEST PLATE Y. ____________________

FIGURE 6. Qualification Test Summary Form

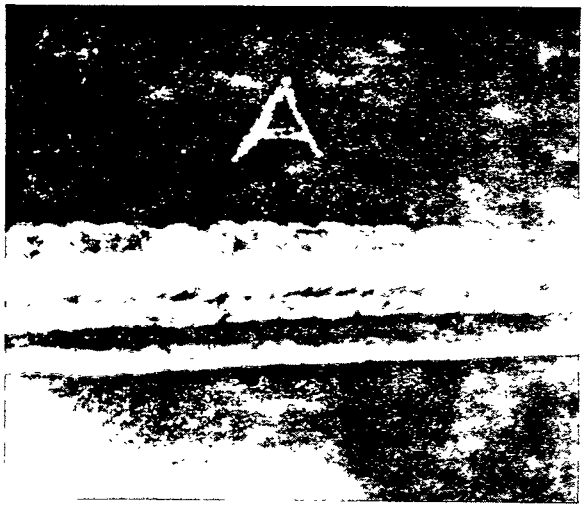
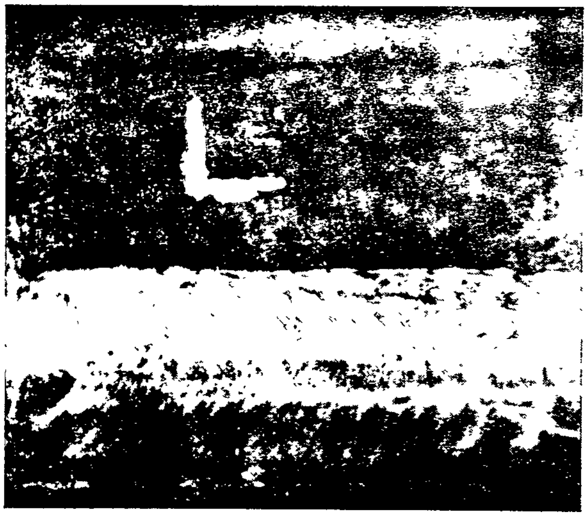


FIGURE 7. Electrode No. 1
Vertical Fillet, 33 FSW

FIGURE 9. Electrode No. 8
Vertical Fillet, 33 FSW



FIGUPW 8. Electrode No. 3
Overhead Fillet, 33 FSW

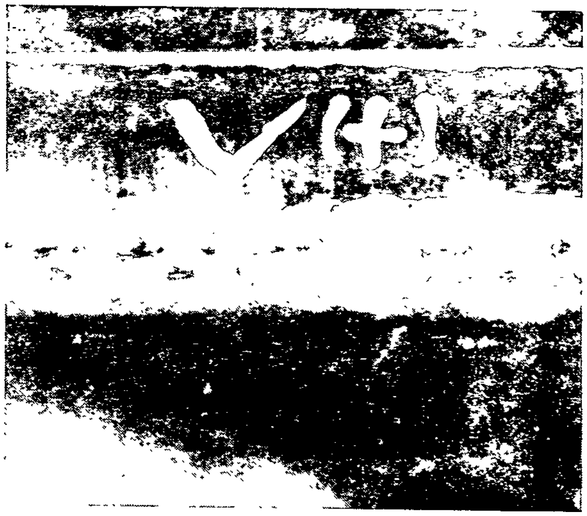


FIGURE 10. Electrode No. 8
Vertical Fillet, 33 FSW
Electrode Positive

This is particularly significant for the DH 36 steel, which had a carbon equivalent of 0.449. Neither was underbead cracking observed on the MACRO surfaces when prepared to a 120 grit finish and examined at a 7x magnification. However, upon closer examination, all the mild steel weldments in the DH 36 steel showed underbead cracking. This will be discussed in Section 2.5.1.2 below.

Based on the cruciform scoring us***ing*** the form of Figure **4**, Electrode Nos. 1, **3** and 5 were chosen for further testing using grooved plates.

2.5.1.2 Grooved plates. The austenitic stainless steel electrode, No. 5, was eliminated as described in **2.5.1.1** above based on root pass cracking.

The two mild steel electrodes, Nos. 1 and 3, were further evaluaked ***using*** **3/8"** high CE DH 36 steel grooved plates. With respect to visual inspection, liquid Penetrant inspection, bend testing, and MACRO evaluation, both Electrode Nos. 1 and 3 produced similar results. With respect to radiographic inspection, Electrode No. 3 generslly produced a cleaner weld due to a significantly lower porosity level. Representative MACROS of these welds are shown in Figure 19.

Bend testing of the high CE (DH 36 steel) grooved plate weld~~s produced some~~ interesting results. Of the 16 6T bend

FIGURE 11. Electrode No. 1
Vertical Fillet, 33 FSW

FIGURE 13. Electrode No. 2
Vertical Fillet, 33 FSW

FIGURE 12. Electrode No. 1
Overhead Fillet, 33 FSW

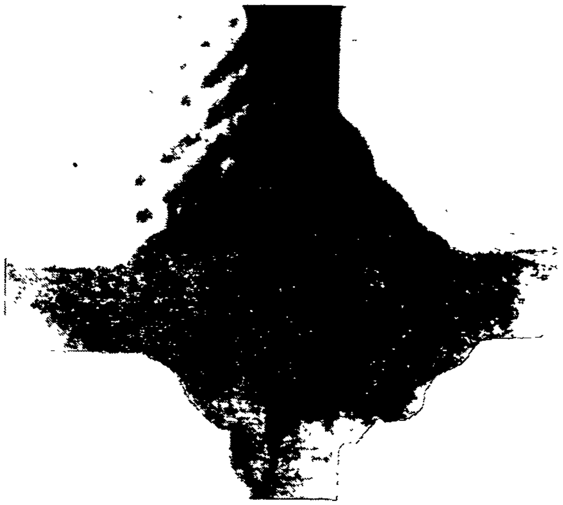


FIGURE 14. Electrode No. 3
Overhead Fillet, 33 FSW

specimens tested for each electrode, only one specimen per electrode failed to pass the test; and these failures were a result of a single linear indication, slightly longer than 1/8″, which was clearly visible but did not “open up” (crack-like indication, as opposed to a tear). Of the 16 4T bend specimens tested for each electrode, nine specimens failed for each electrode; although most of these failures were fractures, a few had only small -- but rejectable -- linear indications. The significance of these results is that all failures were in the heat-affected-zone of the base metal, which attests somewhat to the integrity of the wet welds. However, the failures caused some concern as to whether or not underbead cracking was present, but had not been detected in the MACRO evaluations. Underbead cracking is usually predicted when wet welding high CE steels (CE greater than 0.40) using ferritic electrodes. Accordingly, a cruciform MACRO and a grooved plate MACRO were prepared to a 400 grit finish (the earlier finish was 120 grit, which is normal for MACRO examination), etched and re-examined. Underbead cracking, in the heat-affected-zone, was found in both samples. Figure 20 shows two of the underbead cracks in a cruciform MACRO.

As a result of the underbead cracking problem with the DH 36 steel/ferritic electrode combination, the grooved plate welds were repeated using

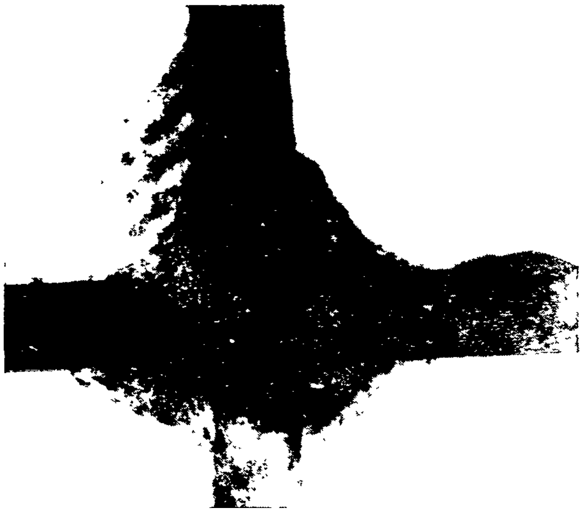


FIGURE 15. Electrode No. 4
Vertical Fillet, 33 FSW

FIGURE 17. Electrode No. 6
Vertical Fillet, 33 FSW

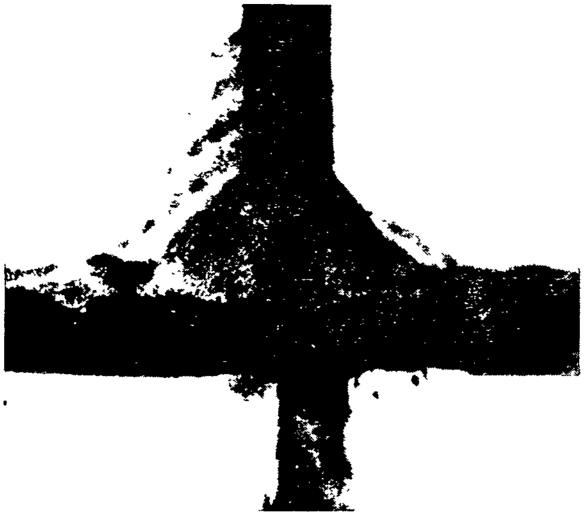


FIGURE 16. Electrode No. 5
Overhead Fillet, 33 FSW

FIGURE 18. Electrode No. 7
Overhead Fillet, 33 FSW

the low CE A36 steel plate. These tests show results similar to those obtained with the DH 36 steel grooved plates, except for the bend tests. All the 6T and 4T bends passed for Electrode Numbers 1 and 3. However, none of the 2T bends passed; these failures occurred in the weld metal -- as opposed to the heat-affected-zone -- when bent to an angle of approximately 30 to 45 degrees.

2.5.1.3 <u>Screening tests summary and conclusions</u>. Using the grading sheet of Figure 4. the total score was 109.67 for Electrode Number 1 and 115.29 for Electrode Number 3. The higher score for Electrode Number 3 is a result of cleaner welds as shown by radiographic inspection; the Number 3 electrode tended to produce less weld metal porosity in all positions of welding. This was also confirmed in the MACRO evaluations. Otherwise, the two electrodes tended to be fairly equal in terms of weldability and overall weld quality.

Both Electrode Numbers 1 and 3 caused underbead cracking in the high CE DH 36 steel; this underbead cracking was found in both the cruciforms and the grooved plates. Physical evidence of the underbead cracking was manifested in the heat-affected-zone failures of the bend tests. However, when used on the low CE ASTM A36 steel plate, there was no evidence of the underbead cracking, and all the bends for the low CE metal successfully passed the 6T and 4T tests.

Both Electrode Numbers 1 and 3 exceeded the bend test requirements of AWS D3.6 fcr Type B welds, in that they successfully passed testing over a 4T bend radius (one-third smaller than the 6T radius required by AWS D3.6). Also, each electrode occasionally met the Class 1 radiographic acceptance standards of NAVSHIPS 0900-LP-003-9000 (Ref. 7), which are more stringent standards than those of AWS D3.6 for Type B or A Welds. Based on these test results,and the fact that the MACRO specimens met the requirements of MIL-STD-248 (Ref. 3), both these electrodes were considered suitable for welding procedure qualification testing.

FIGURE 19. Grooved Plate MACROS

A - Elect. No. 1, Vertical 33 FSW
B - Elect. No. 1, Overhead 33 FSW
c - Elect. No. 3, Vertical 33 FSW
D - Elect. No. 3, Overhead 33 FSW

2.5.2 <u>Qualification tests</u>

2.5.2.1 <u>Electrode Number 1.</u> Qualification testing was performed for Electrode Number 1 as shown in Table I. The electrode number is the first digit of the specimen identification number. Maximum and minimum mechanical properties are shown in Table II. Typical completed welds are shown in Figures 21 through 24 (weld nomenclatures are shown in Table I) . Electrode Number 1 was found to consistently meet the following conditions at *7 FSW and 33 FSW:

a. Radiographic acceptance standards of AWS D3.6 for Type B welds.

FIGURE 20. HAZ Underbead Cracking
DH 36 Steel, 17.5 X

b. Class 2 visual inspection standards of NAVSHIPS 0900-LP-003-8000, Ref. 6, (except as indicated below).

c. Class 1 liquid penetrant inspection standards of NAVSHIPS 0900-LP-003-8000.

d. More stringent bend test requirement- (4T vs 6T) than those specified by AWS D3.6 for Type B welds.

e. Tensile strengths exceeding that of the ASTM A36 base metal.

* Overhead position qualification could not be accomplished at 7 FSW.

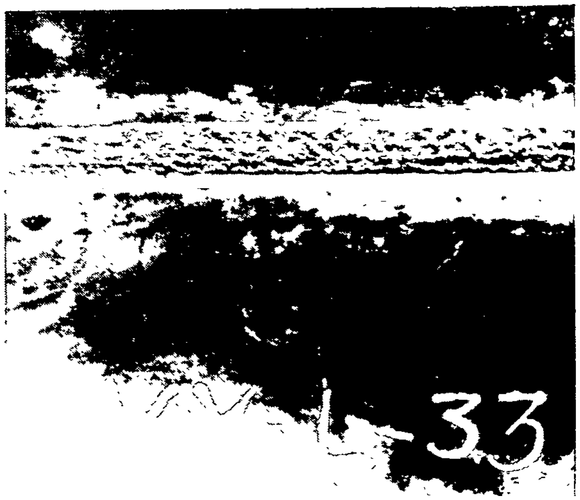


FIGURE 21. Electrode No. 1
Vertical Qualification
33 FSW

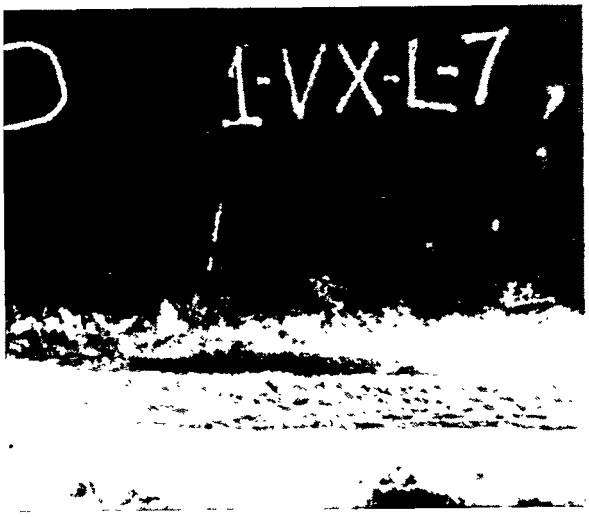


FIGURE 22. Electrode No. 1
Vertical Qualification
7 FSW

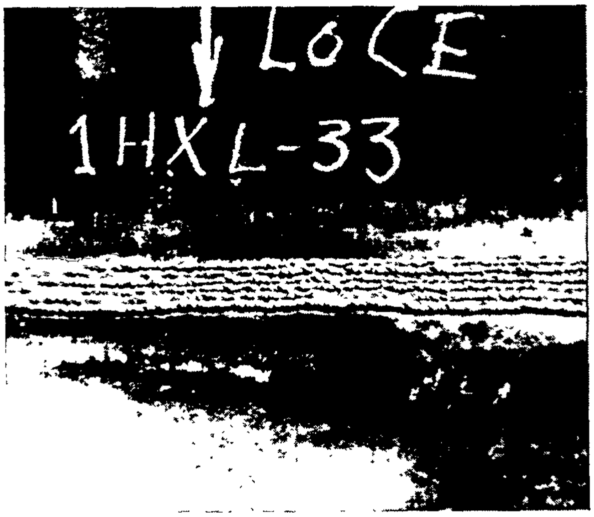


FIGURE 23. Electrode No. 1
Horizontal Qualification
33 FSW

Electrode Number 1 did not demonstrate the same degree of weldability at 7 FSW as at 33 FSW. The electrode could not be qualified in the overhead position at 7 FSW due to the high crowned, narrow beads. The Y plate could not be completed; the X plate was completed at 7 FSW in the overhead position, and the rough capping beads were ground off prior to radiographic inspection; however, the weld failed the AWS D3.6 Type B acceptance standards due to extensive slag and lack of fusion.

Electrode Number 1 also demonstrated significant undercutting tendencies in the overhead position at both water depths, such that one test plate (10Y-H-33, Figure 24) failed to meet any surface inspection acceptance standards. The electrode also tended to undercut in the horizontal welding position, but to a lesser extent than in the overhead position.

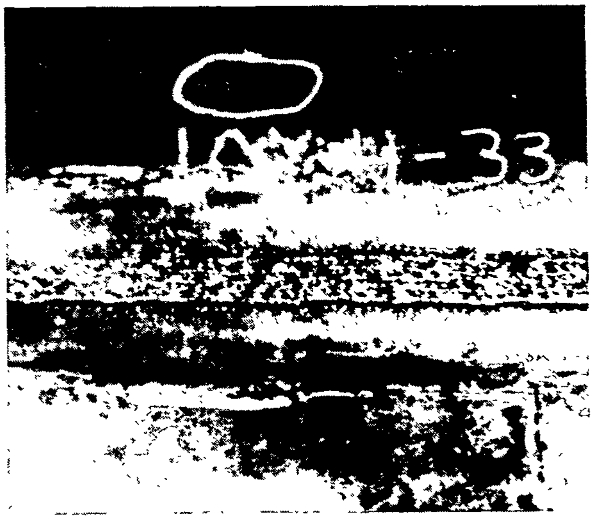


FIGURE 24. Electrode No. 1
Overhead Qualification
33 FSW

The waterproof coating of Electrode Number 1 is soft and must be protected from the water until the electrode is ready for use. Accordingly, each electrode comes in an individual plastic bag, taped around the electrode stub end. This allows the stub to be inserted into the electrode holder prior to removing the bag. The bag can be removed completely, or the electrode tip can be punched through the bag, allowing the bag to be pushed up around the electrode toward the electrode holder. The welder/divers found the bags to present visibility problems unless completely removed. Since water sometimes leaked into the taped end of the bags, the in-water life of the electrodes can be somewhat limited. The maximum water exposure time for the electrodes was not determined; however, it was found that exposure (in the bag) overnight resulted in poor electrode performance.

Electrode Number 1 can be used with either the drag or the oscillation welding technique; however, the oscillation technique (type of swirling motion) seemed to produce better results and was essential in the overhead welding position. The electrode deposited a fairly tenacious "sooty" substance at the weld toes in the horizontal and overhead positions; this had to be removed prior to making the next weld pass. Slag removal was easy for the electrode.

Electrode Number 1 can be described as a high deposition, moderately easy to use wet welding electrode. Weld quality is good except for moderate porosity which easily meets the requirements of AWS D3.6 for Type B welds; this porosity is more pronounced in the vertical position. The porosity does not appear to be detrimental in terms of the mechanical testing which was accomplished for the electrode. Overhead welding, at the seven foot depth, produced unacceptable weld bead profiles.

2.5.2.2 Electrode Number 3. Qualification testing was performed for Electrode Number 3 as shown in Table I; maximum and minimum mechanical properties are shown in Table II. The completed welds are shown in Figures 25 through 29 (weld nomenclatures are shown in Table I). Electrode Number 3 was found to consistently meet the following conditions at 7 FSW and 33 FSW:

a. Type B radiographic acceptance standards of AWS D3.6.

b. Class 2 visual inspection standards of NAVSHIPS 0900-LP-003-8000.

c. Class 1 liquid penetrant inspection standards of NAVSHIPS 0900-LP-003-8000.

d. More stringent bend test requirements (4T vs 6T) than those required by AWS D3.6 for Type B welds.

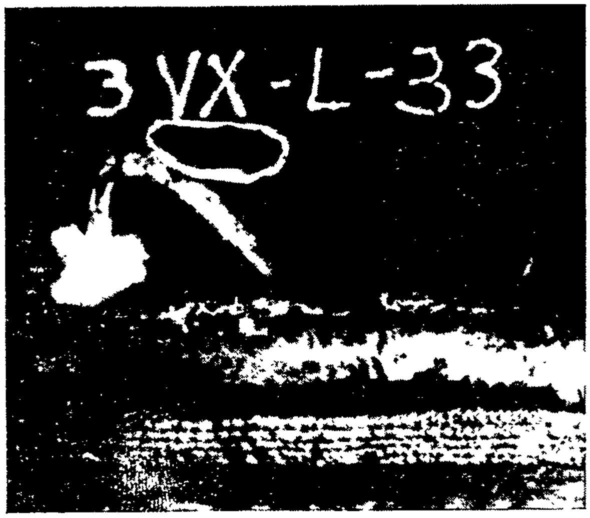


FIGURE 25. Electrode No. 3
Vertical Qualification
33, FSW

FIGURE 26. Electrode No. 3
Vertical Qualification
7 FSW

e. Tensile strength exceeding that of the ASTM A36 base metal.

Electrode Number 3 showed a decreased weldability in the overhead position at 7 FSW; as with Electrode Number 1, the weld beads tended to be narrower and higher crowned than at 33 FSW. However, both the X and Y plates were successfully qualified in the overhead position at 7 FSW. Radiographs of the X plate showed linear indications at the weld toes in the root. Removal of backing strap showed "wagon track" type slag, sometimes associated with root undercut. The weld was then background and rewelded; radiographic inspection was again performed and showed the weld to meet the acceptance standards of AWS D3.6 for Type B welds. Therefore, at 7 FSW, Electrode Number 3 may be considered qualified for plate butt welds in the overhead position only where the weld can be cleaned and welded from the back side.

Electrode Number 3 had a paraffin coating over the primary waterproof coating. The paraffin tended to "bloom out" at the arc, reducing visibility. The welder/divers sometimes removed the paraffin by short circuiting the electrode for three or four seconds (causing the electrode to heat up slightly) and sliding the entire layer of paraffin off the electrode. (The paraffin was added by the electrode manufacturer after the screening tests were completed; it was added due to the reported oxidation of the primary waterproof coating, although the primary waterproof coating never failed to adequately protect the electrode from the water.)

Electrode Number 3 can be described as a high deposition, easy to use wet welding electrode. The overall weldability and puddle control were slightly better than Electrode Number 1, and weld porosity was significantly lower than that of Electrode Number 1. However, the mechanical properties of the two electrodes were equivalent. Electrode Number 3 can be used with either the drag or the oscillation technique. Electrode Number 3 had easy slag removal.

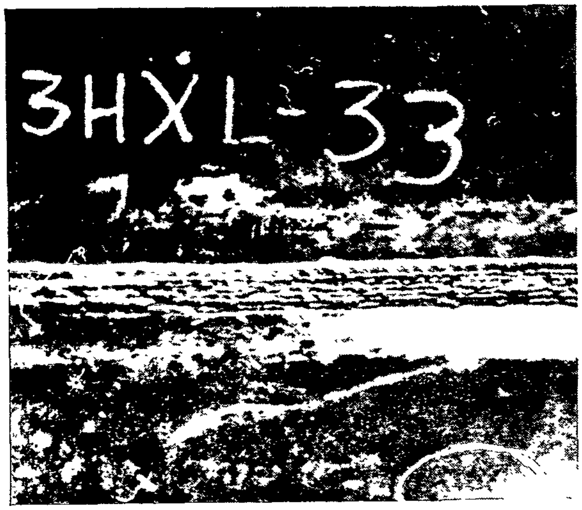


FIGURE 27. Electrode No. 3 Horizontal Qualification 33 FSW

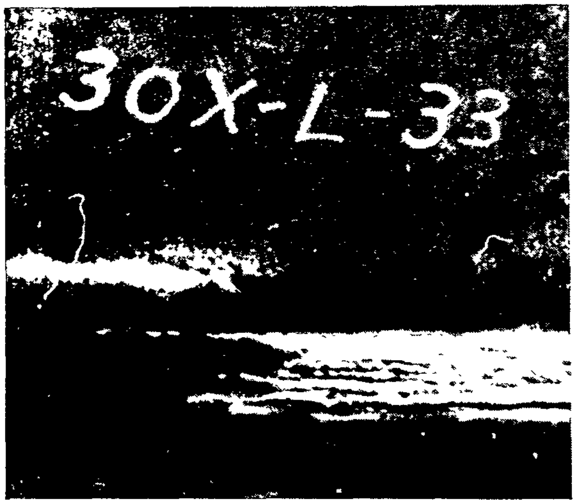


FIGURE 28. Electrode No. 3 Overhead Qualification 33 FSW

2.5.2.3 <u>Qualification testing summary and conclusions</u>. Both Electrode Numbers 1 and 3 were found to be suitable for making all-position welds in mild steel, with the exception of Electrode No. 1 in the overhead position at 7 FSW. Both electrodes can be used by a welder/diver with average welding ability; weldability and ease of slag removal make the electrodes usable with minimal training. Overhead welding is more difficult than the other positions due to decreased visibility of the welding arc; this is a result of the bubbles being hindered, by the plate, in their movement toward the water surface. This results in capping beads which are a little more irregular than those of other welding positions (see Figures 24, 28 and 29). Figure 28 shows 50 percent of the length of the cap removed by grinding; this was done to determine whether or not the irregular ("ropy") bead profile would interfere with radiographic film interpretation. It was found that the cap did not interfere with film interpretation. The undercut shown in Figure 28 is less than 1/16 inch in depth.

FIGURE 29. Electrode No. 3 Overhead Qualification 7 FSW

Weld quality for both Electrode Number 1 and 3 is considered good and represents state-of-the-art technology. The weld quality for both electrodes can be further described as follows, where the visability is good and properly trained welder/divers are used for the welding:

a. Visual weld appearance should consistently meet the Class 2 requirements of NAVSHIPS 0900-LP-003-8000 and the Type B weld requirements of AWS D3.6. Figures 30 and 31 show close-up views of Electrode Number 3 welds made in the vertical position at 33 FSW.

b. Magnetic particle and liquid penetrant inspections should consistently meet the Class 1 requirements of NAVSHIPS 0900-LP-003-8000.

c. Radiographic inspection should consistently meet the Type B weld requirements of AWS D3.6. Where porosity less than 1/16 inch is ignored, both electrodes are capable of meeting Class 1 requirements of NAVSHIPS 0900-LP-9000 in certain instances, and they should meet the Class 3 requirements in most cases. Based on mechanical test results, the varying degrees of porosity (from none, to that allowed by AWS D3.6 Type B) showed no effect on either strength or toughness. A comparison of porosity levels between Electrode Number 1 and 3 for identical 33 FSW vertical welds, as shown by radiographic film comparison, can be seen in Figures 32 and 33; Electrode No. 3 is shown to produce significantly less porosity.

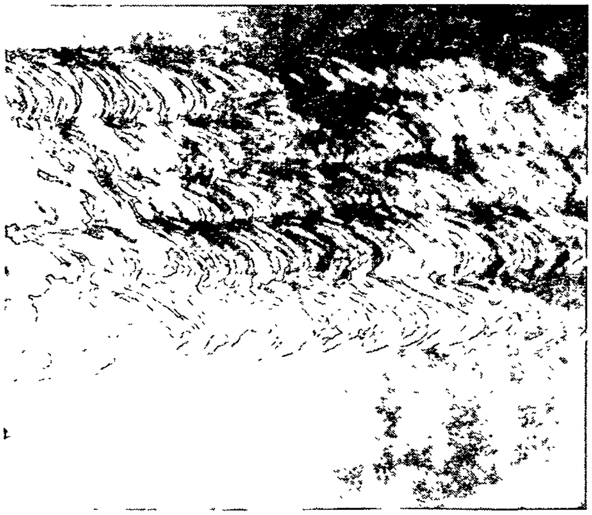


FIGURE 30. Electrode No. 3 Vertical Qualification 33 FSW

The strength, in terms of yield and tensile, of both Electrode Numbers 1 and 3 is satisfactory. In comparing base metal properties of 2.2 with weld metal properties of Table II, and as summarized in Table III, the following can be concluded:

a. Based on average values, the weld metal ultimate strength exceeds that of the A36 steel by approximately 13 percent; the weld metal yield strength exceeds that of the A36 steel by approximately 45 percent.

b. Based on average values, the weld metal ultimate strength is less than that of the DH 36 steel by approximately one percent. However, the weld metal yield strength exceeds that of the DH 36 steel by approximately 22 percent.

FIGURE 31. In-Air Butt Weld (E7018, Single Pass Cap) Intersecting a Wet Butt Weld (Electrode No. 3) Vertical, 33 FSW

FIGURE 32. Electrode No. 1 Radiograph of 33 FSW Vertical Butt Weld

Weld ductility for both Electrode Numbers 1 and 3 is obviously less than that of the base metals. It can be seen from Table III that the weld metal elongation is less than one-third that of the base metals and well below the 17 percent minimum required for air welds. However, successful bend testing using 6T (4½ inch diameter) and 4T (3 inch diameter) radius plungers showed reasonable ductility (air welds are usually bent using a 1½ inch diameter plunger). Since the tensile and yield strengths of the weld metal were considerably higher than that of the A36 steel base metal, the base metal sustained more of the bend elongation than did the weld; however, since the radius of the bend specimens was fairly constant around the circumference of the bend (no flat spots in the higher strength weld area), the weld metal apparently had reasonable elongation and thus ductility. It should also be kept in mind that 30 of 32 face bend specimens passed the 6T radius bend during the screening tests, and that the base metal was DH 36 steel. In addition, 14 of 32 specimens passed the 4T tests; those that failed did so in the heat-affected-zone, as opposed to the weld metal.

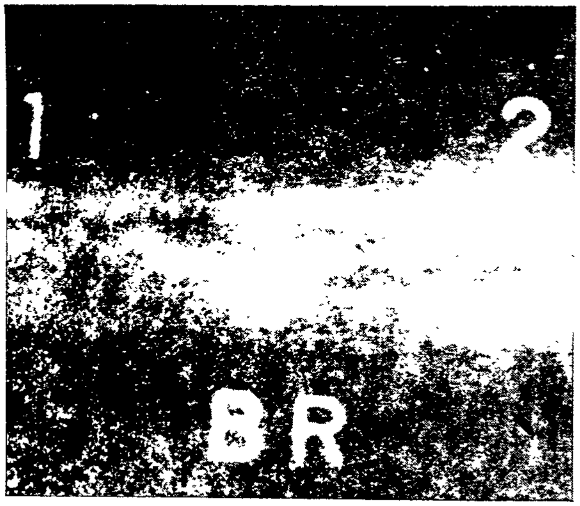


FIGURE 33. Electrode No. 3
Radiograph of 33 FSW
Vertical Butt Weld

The weld metal toughness of Electrode Number 1 and 3, as shown by the Charpy impact test, is less than 1/2 that of the A36 base metal (see Table III). However, the Charpy breaks exhibited a ductile fracture mode (80 to 100 percent shear). The work of Ref. 8, which will be further discussed in Section 3, showed that wet welds, displaying similar results, were at or near upper shelf at 28 F. Porosity shown in some heat-affected-zone specimen fracture surfaces, along with erratic heat-affected-zone energy values, indicate that the heat-affected-zone Charpys were not always failing in only the heat-affected-zone. The failures were sometimes veering off toward the weld metal. Heat-affected-zone Charpy impact average values ranged from 28 to 61 foot-pounds.

With respect to macroscopic examination, all the wet welds met the Type A (dry weld) requirements of AWS D3.6 -- except that some specimens had minor root cracking associated with slag inclusions or gaps between the plate and backing bar; AWS D3.6 allows no cracking in the MACRO specimens. Most of the MACRO specimen root cracking was not in excess of 1/32 inch. However, some of the specimens had slag inclusions which exceeded 1/32 inch, which is rejectable to the requirements of MIL-STD-248C. Representative MACROs are shown in Figures 34 through 40. MIL-STD-248C recognizes that backing bar butt welds have an occasional tendency for minor cracking in the root, and will accept these indications if not longer than 1/32 inch. This cracking tendency was demonstrated in the wet welds, but only associated with minor root slag or, on one occasion, a gap between the plate surface and the backing bar.

FIGURE 34. Electrode No. 1
Overhead Qualification
33 FSW (3X)

There was no case where the weld metal hardness exceeded the 325 H_v10 maximum allowed by AWS D3.6 for Type A welds. In fact, the weld metal hardness never reached 250 H_v10, and the majority of the readings were below 200 H_v10. The only areas exceeding 325 H_v10 were in the base metal heat-affected-zone just beneath the weld cap. In other work, excessive HAZ hardness, just under a wet weld cap, have been reduced to acceptable values by using the "temper bead technique". However, this requires a well trained welder/diver and good in-water visibility.

FIGURE 35. Electrode No. 1
Vertical Qualification
7 FSW (3X)

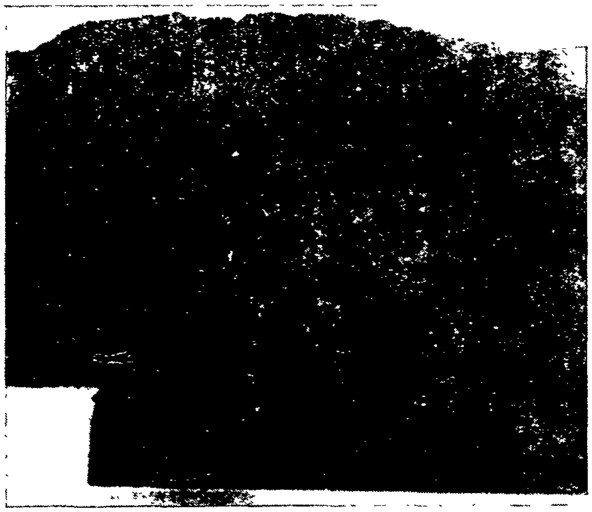


FIGURE 36. Electrode No. 1
Vertical Qualification
33 FSW (3X)

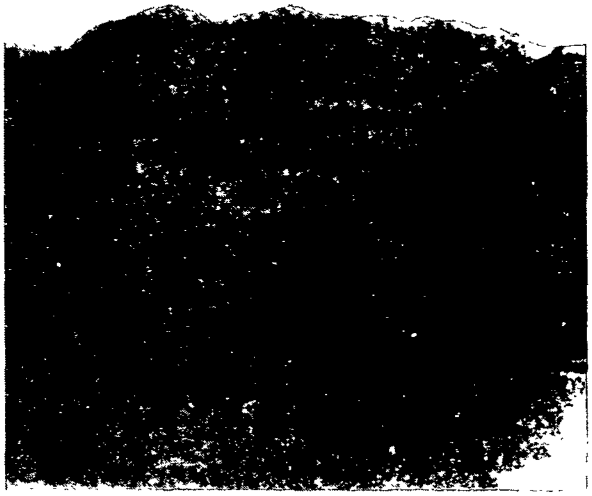


FIGURE 37. Electrode No. 3
Vertical Qualification
33 FSW (3X)

FIGURE 38. Electrode No. 3
Overhead Qualification
33 FSW (3X)

3.0 DISCUSSION

Two commercially available mild steel wet welding electrodes have been qualified to the requirements of AWS D3.6 for wet welding ordinary strength structural carbon steel; as allowed by AWS D3.6, this qualification extends to a water depth of 66 feet. Based on the requirements of AWS D3.6, this qualification is limited to steels with a maximum carbon equivalent of 0.350 and a maximum carbon content of 0.17 percent by weight. Additional testing would be required to qualify the electrodes to weld steels with a higher carbon content and/or carbon equivalent. (A very promising stainless steel electrode, for use in welding the higher carbon equivalent steels, underwent initial screening tests; however, the screening tests could not be completed, because most of the electrodes were damaged in shipment. Refer to Figures 41 and 42.)

FIGURE 39. Electrode No. 3
Overheat Qualification
7 FSW (3X)

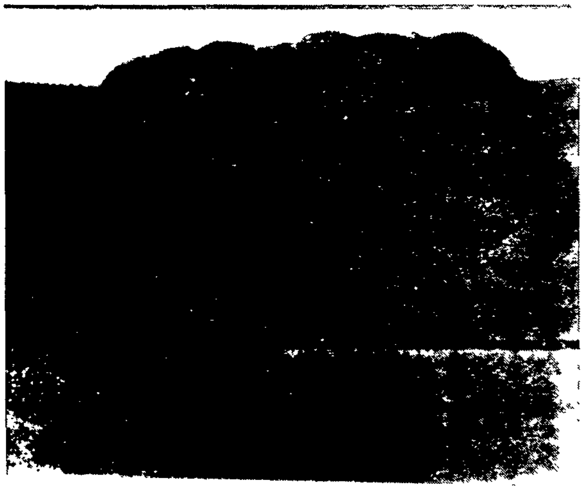


FIGURE 40. Electrode No. 3
Vertical Qualification
7 FSW (3X)

The qualification testing has established that the mild steel electrodes meet a weld quality standard somewhere between that considered acceptable for wet welds by the American Welding Society, and that considered acceptable for dry welds by the U. S. Navy. The primary weld discontinuity was porosity -- the degree of which had no observable impact on any of the mechanical test results. Neither did the minor cracking, associated with root discontinuities, have any impact on the mechanical test results. Of the initial 36 side bend specimens, two failed due to slag/incomplete root penetration; two additional bend specimens, for each failed specimen, passed the bend test for a total of 40 bends.

FIGURE 41. Experimental Stainless
Steel Electrode
Vertical Fillet, 33 FSW

Bend tests exceeded AWS D3.6 requirements for Type B welds, and tensile and yield strengths far exceeded minimum base metal requirements and the requirements of applicable filler metal specifications. Weldment toughness and ductility are reduced compared to air welds, but may be considered adequate for certain applications. Weldment hardness exceeded AWS D3.6 requirements for Type A welds only in the heat-affected-zone just under the weld cap.

Ref. 8, which is an underwater welding study performed by the Southwest Research Institute for the Ship Structures Committee through the U. S. Coast Guard, makes the following observation in the opening statement of the "ABSTRACT": "Data reported herein indicate that the wet......welding (SMAW) process can produce welds suitable for structural applications provided certain limitations of the welds are considered in design." The SWRI Report includes the same mechanical testing as covered in this report, and in addition, fracture toughness (J_{IC}) testing. However, the SWRI work covered welds made only in the flat position, and the welding took place in fresh water. All test results in this report pretty much paralleled these corresponding tests of the SWRI Report. The mechanical properties of electrode Numbers 1 and 3 (E7014 "type" electrodes) appear to be equivalent to those of the E6013 "type" electrodes tested in the SWRI work. It would be considered worthwhile to make a detailed comparison between the results of this study and the results of the SWRI work. The applicability of the fracture toughness calculations and weld design recommendations, established in the SWRI work, could then be assessed for the two wet welding electrodes of this study.

Another previous study, Ref. 9, addresses crack growth rate of wet welds made with E6013 electrodes. The welds were made in fresh water at a depth of approximately 33 feet. Two meaningful conclusions of the Ref. 8 study are as follows:

a. Crack growth rates increased with porosity level.

b. At stress intensity factors of approximately 30 KSI$\sqrt{in}$ and below, depending on porosity level, crack growth rates for the wet welds were less than for surface or dry habitat welds.

FIGURE 42. Experimental Stainless Steel Electrode Overhead Bead-on-Plate 33 FSW

In regard to depth, the following was found:

a. There was no significant difference in mechanical properties at 7 FSW, as compared to 33 FSW, except a slight increase in ultimate and yield strengths.

b. Weld metal carbon and manganese decreased somewhat at the deeper depth, which may account for the lower strength levels. Weld metal oxygen levels at 7 FSW were only on the average about 1.4 percent of that at 33 FSW.

c. Overhead welding became more difficult at 7 FSW, such that Electrode Number 1 could not be qualified.

The results achieved in this project have shown that wet welding can have a degree of integrity such that its use may be justified for limited applications in Naval surface ship repair. Such applications would include:

- Permanent nonstructural repair in low carbon equivalent steels.
- Temporary structural repairs, performed on an emergency basis, where replacement or rewelding of the repaired area might be deferred until the next scheduled drydocking.

4.0 ACKNOWLEDGEMENTS

The work was sponsored by Code OOC of the Naval Sea Systems Command under the technical direction of NAVSEA Code O5M2. Administration and technical support were provided by the CASDE Corporation and Welding Engineering Services. The authors wish to express their gratitude to Cal Dive Companies and S & H Diving for the welder/diver personnel used for the duplicate welding. Special appreciation is expressed to Mr. C. E. "Whitey" Grubbs of Global Divers and Contractors; Mr. Grubbs, who is presently the chairman of the American Welding Society sub-committee for underwater welding, provided valuable technical input during the life of the project.

5.0 REFERENCES

(1) ANSI/AWS B4.0-85 Standard Methods for Mechanical Testing of Welds.

(2) ANSI/AWS D3.6-83 Specification for Underwater Welding.

(3) MIL-STD-248C Welding and Brazing Procedure and Performance Qualification.

(4) MIL-STD-271E (SHIPS) Nondestructive Testing Requirements for Metals.

(5) MIL-S-22698B (SH) Steel Plate; Carbon, Structural for Ships.

(6) NAVSHIPS 0900-LP-003-8000 Surface Inspection Acceptance Standards for Metals.

(7) NAVSHIPS 0900-LP-003-9000 Radiographic Acceptance Standards for Production and Repair Welds.

(8) Norris, E. B., Dexter, R. J., Schick, W. R., and Watson, P. D., "Underwater Wet And Wet-Backed Welds: Toughness, Mechanical Properties and Design Guidelines", Southwest Research Institute (Draft) Report 7168, 31 March 1986.

(9) Matlock, D. K., Edwards, G. R., Olson, D. L., and Iberra, S., "An Evaluation of the Fatigue Behavior in Surface, Habitat and Underwater Wet Welds", Submitted to the Second International Conference on Offshore Welded Structures, London, England, 16-18 November 1982.

TABLE I. QUALIFICATION TESTING PERFORMED

WELD I.D. NO.	POSITION/ DEPTH	TESTING/INSPECTION									
						CHARPY					
		PT	RT	BENDS	RST	W/M	B/M	HAZ	MACRO/ HARD	AWM	W/M CHEM.
1VX-L-33	VERT/33	X	X	X	X	X		X	X		
3VX-L-33	VERT/33	X	X	X	X	X		X	X		
1HX-L-33	HORZ/33	X	X	X	X						
3HX-L-33	HORZ/33	X	X	X	X						
10X-L-33	OVERHD/33	X	X	X	X	X		X	X		
30X-L-33	OVERHD/33	X	X	X	X	X		X	X		
1VY-L-33	VERT/33	X	X							X	X
3VY-L-33	VERT/33	X	X							X	X
10Y-L-33	OVERHD/33	X	X							X	X
30Y-L-33	OVERHD/33	X	X							X	X
1VX-L-7	VERT/7	X	X	X	X	X		X	X		
3VX-L-7	VERT/7	X	X	X	X	X	X		X		
10X-L-7	OVERHD/7	X	X								
30X-L-7	OVERHD/7	X	X	X	X	X		X	X		
1VY-L-7	VERT/7	X	X							X	X
3VY-L-7	VERT/7	X	X							X	X
10Y-L-7	OVERHD/7										
30Y-L-7	OVERHD/7	X	X							X	X
30X-ST-7-5/32	OVERHD/7	X	X								
30X-ST-7-3/8	OVERHD/7	X	X								

1/ First digit: Electrode Number
Second digit: Position of welding
Third digit: Type of test plate
Fourth digit: Carbon equivalent, high vs low
Remaining digits: Water depth

TABLE II. TENSILE AND IMPACT QUALIFICATION TEST RESULTS

ELECTRODE AND WATER DEPTH	TENSILE STRENGTH, PSI		YIELD STRENGTH, PSI		ELONGATION, %		IMPACT ENERGY AT 28° F, FT.LBS.	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	*Minimum	*Maximum
Electrode No. 1 33 FSW	73,400	74,500	65,300	68,100	6.6	9.3	29.8	31.8
Electrode No. 1 7 FSW	74,700	75,900	65,800	68,350	8.0	8.8	33.5	33.5
Electrode No. 3 33 FSW	77,050	83,050	70,900	76,550	6.0	8.3	25.1	32.0
Electrode No. 3 7 FSW	78,350	84,050	74,500	82,400	4.8**	8.8	28.2	24.5

* Based on average values for each weldment tested.

** Questionable value.

TABLE III. COMPARATIVE WELD METAL/BASE METAL PROPERTIES

Properties	Average Weld Metal	Average Base Metal A36	Average Base Metal DH 36	Base Metal Spec. A36	Base Metal Spec. DH 36
Tensile Strength** KSI	77.6	68.8	78.7	50-80	71-90
Yield Strength** KSI	71.5	49.4	58.5	36 Min.	51 Min.
Elongation, %**	7.6	27.7	23.7	23 Min.	22 Min.
Impact Energy at 28° F, Ft.Lbs.	29.8	75.5	No Tests Run	Not Req'd.	N/A*

* Different temperature requirements.

** From all-weld-metal testing.

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Proven Benefits of Advanced Shipbuilding Technology—Actual Case Studies of Recent Comparative Construction Programs

No. 20

A. B. Nierenberg, Associate Member, and **S.G. Caronna**, Visitor, Avondale Industries, Inc., Avondale, LA

INTRODUCTION

Much has been written and discussed in the past decade concerning improved shipbuilding productivity meth-ods in U.S. Shipyards and a substantial amount of progress has been made in the implementation of methods, facilities and shipyard dedication to achieve a reduction in U.S. shipbuilding costs. Although productivity savings are often difficult to quantify, we will attempt to compare and contrast two (2) sets of comparable shipbuilding programs such that the definitive results of a comprehensive advanced shipbuilding methodology as employed at Avondale Shipyards since 1979 can be evaluated.

The programs to be evaluated are of excellent comparative nature, both in terms of ship characteristics as well as the contract environment under which they were executed.

The first set of comparable ships are both 40,000 DWT coastal tankers, one series built from a traditional approach for Ogden Marine with a contract authorization date in August 1978, and its counterpart program being a 1981 contract with Exxon Company which utilized the maximum implementation of the Avondale advanced shipbuilding methods from contract design throughout the construction program. Both programs were for shipyard developed designs and the ability to incorporate producibility oriented details was available in both programs. The principal characteristics of these vessels are contained in Table I [1-2].

The second set of comparable ships are Fleet Oiler programs for the U.S. Navy, in which the AO-177 Class Fleet Oilers were initially contracted for 1976 and processed through a traditional design and construction approach, as contrasted to the T-AO 187 Class Fleet Oilers which were contracted for in 1982 and developed with the full benefit of the advanced shipbuilding systems which had been under development and implementation at Avondale since 1979. The principal characteristics of these vessels are contained in Table II.

It is the intent of this paper to present a comparative study of the resultant ship construction process, methods and details, as compared to a dissertation on advanced shipbuilding methodology itself. For a discussion of the methodologies employed, the reader is referred to references [3-7].

Major Milestones

The first major quantification of the impact of advanced construction methods is obtained by reviewing the program major milestones including intervals between events and total contract completion (labor and material) at each stage of activity. Table III and IV indicate the intervals between major events for each of the vessels.

The significant improvement derived on both vessels built utilizing advanced shipbuilding techniques as compared to their predecessors is the high percentage of completion at the keel laying and launch milestones as well as the sizable time compression from keel to trials. These key factors are both highly influential in controlling shipbuilding costs as the maximum amount of work performed prior to keel is indicative of the more efficient shop fabrication and on-unit installation activities. Additionally the reduced keel to delivery time frame shortens the less efficient and manpower intense onboard activities. In general the advanced outfitted vessels had completed systems installed at time of launch, enabling post launch activities such as shaft alignment, operational testing, etc. to commence immediately upon launch. Figures 1, 2, 3, and 4 show each vessel during construction on the building ways where the degree of outfitting is evident. Figures 5, 6, 7 and 8 show each vessel at launch where the overall completion of each hull can be readily ascertained.

Table I Principal Characteristics - 40,000 DWT Coastal Tankers

	Ogden	Exxon
Length Overall	629'-3½"	635'-6"
Length, BP	610'-0"	610'-0"
Beam	105'-10"	105'-10"
Depth	60'-0"	60'-0"
Design Draft	38'-0"	38'-0"
Scantling Draft	43'-6"	42'-0"
Block Coefficient	.76	.80
Midship Coefficient	.997	.997
Length of Parallel Midbody	60'	180'
Horsepower, BHP	14,100	17,000
Cargo Capacity, Ft3	1,939,125	2,134,810
No. of Cargo Tanks	18	43
Ballast Capacity, Ft3	535,212	652,715
Fuel Oil Capacity, Ft3	108,064	53,900
Fresh Water Capacity, Ft3	11,800	12,400
Accommodations	36	27
Deadweight Tonnage @ Design Draft, LT	41,851	41,568
Lightship Weight, LT	11,186	14,473
No. of Cargo Pumps	18	43
Electrical Capacity, Kw	4 X 800	3 X 1600
Trial Speed, Kts	16.1	16.95
Type of Propulsion Machinery	Single Screw Medium Speed Geared Diesel	Single Screw Slow Speed Direct Coupled Diesel
Propeller	Fixed Pitch	Fixed Pitch

Table II Principal Characteristics - U.S. Navy Fleet Oilers

	AO-177 Class	T-AO 187 Class
Length Overall	591'-6"	677'-6"
Length, BP	550'-0"	650'-0"
Beam	88'-0"	97'-6"
Depth	48'-0"	50'-0"
Design Draft	32'-0"	34'-6"
Scantling Draft	35'-0"	37'-10"
Block Coefficient	.61	.64
Midship Coefficient	.977	.981
Length of Parallel Midbody	None	None
Cargo Capacity, Barrels	120,000	180,000
Ballast Capacity, Ft3	305,695	415,077
Fuel Oil Capacity, Ft3	67,500	71,400
Fresh Water Capacity, Ft3	2,448	4,176
Total Deadweight @ Design Draft, LT	18,333	25,564
Lightship Weight, LT	9,053	14,711
Horsepower, BHP	26,700	33,000
Electrical Capacity, Kw	3 @ 2500	4 @ 2500
No. of Cargo Pumps	8	8
Accommodations	200	137
Trial Speed, kts	21.4	22.1
Type of Propulsion Machinery	Single Screw 600 psi Steam	Twin Screw Medium Speed Geared Diesel
Propeller	Fixed Pitch	CRP

Engineering

The two major impacts to the engineering effort as a result of the advanced shipbuilding methods are:

1) a highly structured drawing and material management approach such that individual unit by unit drawing presentation and staged material heirachy is provided to improve the planning capability and process flow through the shipyard, and

2) a condensed total period of performance such that all work which is capable of being performed in the shops or on units in defined in time to support this more efficient work stage.

Tables V and VI provide some engineering statistics for each program and vividly illustrates the increase in drawing count as a result of unit by unit or zone in lieu of complete system presentation of fabrication and installation details. Figure 9 graphically depicts the overall inpact to the engineering time period of performance. This requirement obviously increases the peak manning in engineering and when combined with the additional information required on engineering documentation explains the critical need to effectively plan the engineering and material procurement functions to support the ship construction effort.

Hull Structure

The hull structure for the types of vessel's under discussion is still the single largest cost group in the vessels construction and therefore careful attention to the method of construction, unit configuration, construction details and shipyard process flow are critical factors in minimizing shipyard costs. Furthermore, the basic concept of increasing the extent of on-unit outfitting of distributed systems must be accomplished without a negative impact to the basic cost of steel construction.

The primary producibility improvement in steel construction has been the process lanes concept, whereby all steel fabrication is grouped by common work process and performed in uniquely equipped work centers each designed to achieve the highest possible productivity. The key to obtaining the benefits from a process lanes approach is to properly plan each part of the steel fabrication process and to refine the design such that a maximum amount of repetitive type processes are possible.

Tables VII and VIII identify some of the key parameters of each vessels hull structure. Figure 10 depicts the mid-ship section unit breaks for each of the four (4) vessels. Extensive study and evaluation is performed prior to finalization of the basic hull unit break up on any vessel to assure that the best compromise of fabrication cost, unit erection cost and outfitting considerations are achieved. The relatively low average unit weights identified by tables VII and VIII are due to the inclusion of all units on the total count including masts, king-posts, bilge keels, rudders, etc., which tend to distort the absolute value. In general, main hull units at Avondale are limted to 120 tons from the fabrication platens and to 400 tons for combined unit erection lifts, such as superstructure sections.

Table III Major Milestones - Coastal Tankers

	Ogden		Exxon	
Interval	Months	% Complete	Months	% Complete
Contract to Start of Fab	13 months	-----	13 months	-----
Start of Fab to Keel Laying	6 months	20%	4 months	35%
Keel Laying to Launch	9 months	65%	8 months	85%
Launch to Builder's Trial	8 months	96%	4 months	98%
Builder's Trial to Delivery	1 month	100%	1 month	100%
Contract to Delivery	37 months	-----	30 months	-----
Keel to Delivery	18 months	-----	13 months	-----
Start of Fab to Delivery	24 months	-----	17 months	-----

Table IV Major Milestones - U.S.Navy Fleet Oilers

	AO-177 Class		TAO-187 CLass	
Interval	Months	% Complete	Months	% Complete
Contract to Start of Fab	18 months	-----	17 months	-----
Start of Fab to Keel Laying	3 months	15%	5 months	38%
Keel Laying to Launch	11½ months	60%	11 months	82%
Launch to Builder's Trial(BT)	15 months	97%	10½ months	98%
BT to Acceptance Trial (AT)	3½ months	99%	1½ months	99%
AT to Delivery	1 month	100%	1 month	100%
Contract to Delivery	52 months	-----	46 months	-----
Start of Fab to Delivery	3 months	-----	29 months	-----

Table V Engineering Deliverable Parameters - Coastal Tankers

	Ogden	Exxon
No. of Engineering Drawings	916	1612
Time Period-Contract to Engineering Essentially Complete	24 Months	18 months
Engineering Percentage Complete at Keel Laying	45%	70%
Relative Manhour Cost per Drawing	1.0	1.15
Peak Engineering Spending MHrs/Month	18,000	30,000

Table VI Engineering Deliverable Parameters - U.S. Navy Fleet Oilers

	AO-177 Class	T-AO 187 Class
No. of Engineering Drawings	1417	1844
Time Period-Contract to Engineering Essentially Complete	30 months	24 months
Engineering Percentage Complete At Keel Laying	40%	65%
Relative Manhour Cost per Drawing	1.0	.90
Peak Engineering Spending MHrs/month	23,000	44,000

Table VII Hull Steel Comparison - Coastal Tankers

	Ogden	Exxon
Hull Steel Weight, LT	9836	10,446
No. of Hull Units	128	144
Average Weight/Unit, LT	77	70
Percent Complete at Keel Laying	15	25
Percent Complete at Launch	98	100
Relative Hull Steel Cost	1.0	0.80

Table VIII Hull Steel Comparison - U.S.Navy Fleet Oilers

	AO-177 Class	T-AO 187 Class
Hull Steel Weight, LT	6,482	10,756
No. of Hull Units	136	191
Average Weight/Unit, LT	47	56
Percent Complete at Keel Laying	10	20
Percent Complete at Launch	95	100
Relative Hull Steel Cost	1.0	0.72

Package Units

One of the most significant improvements in ship construction methods has been the development of large multi-system machinery/ piping package units. These shop fabrication assemblies encompass a sizable physical portion of a space or flat and include equipment, foundations, walkways, piping, instrumentation, etc. The package units are fully assembled, pressure tested and finally painted prior to mounting on individual hull units or loading onboard after the erection of adjacent hull units. Figures 11 and 12 illustrate typical machinery and deck package units.

Tables IX and X illustrate the extensive application of package units on the advanced construction vessels. In the case of the Exxon vessels, the package units represented a full 6% of the vessels lightship vessel and contained over 30% of the vessels piping footage.

Piping

Piping historically has been the second largest cost group in the ship production process In conventional construction methods piping installation usually dictated the total post launch schedule, as system and compartment completion and testing could not commence until piping installation was complete. The single most dramatic accomplishment of the advanced shipbuilding methodology was that piping installation and completion no longer became the pacing element of ship construction. This total change in ship construction priorities occurred as a result of package unit ap-

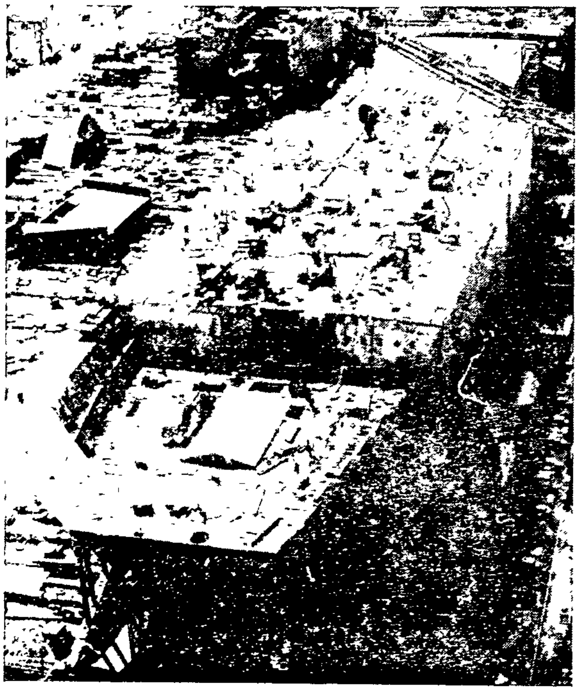


Figure 1
Ogden Dynachem Under Construction.

Figure 2
Exxon Charleston Under Construction

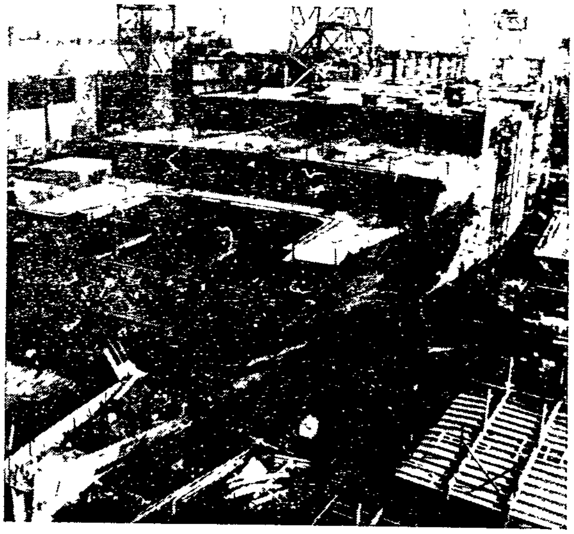


Figure 3
AO-177 Under Construction

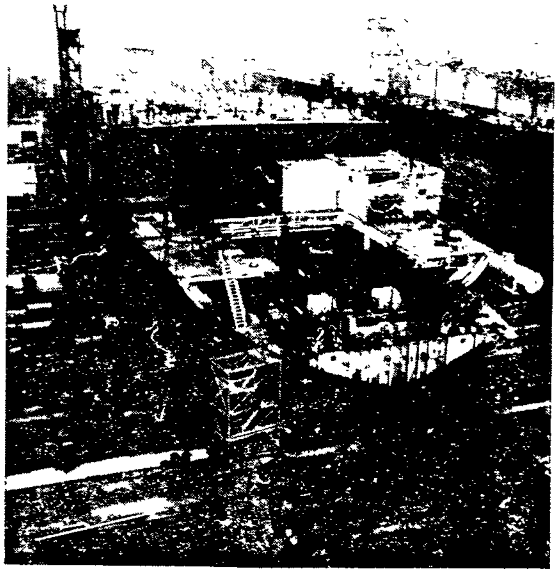


Figure 4
T-AO187 Under Construction

plication, extensive on-unit pipe installation and total material definition for the piping installation at the drawing level. The structure of tables XI XII vividly demonstrate the improvement in piping system installations with the later vessels having virtually all pipe installed at launch.

The changes in this cost group directly affect the costs of other supporting and interfacing crafts and the total contribution to improved shipbuilding costs are therefore even greater than actually indicated.

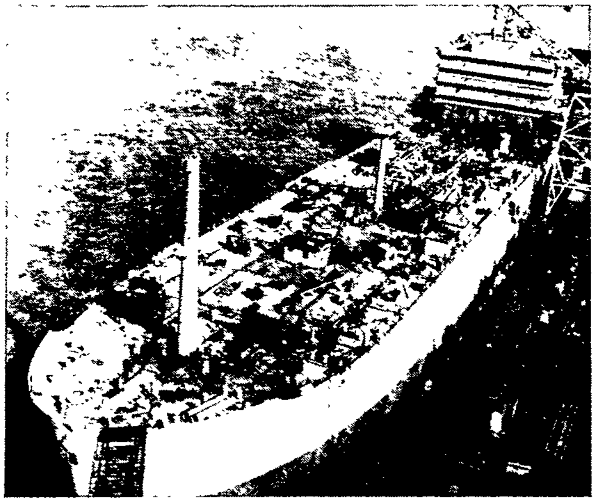


Figure 5 Ogden Dynachem at Launch

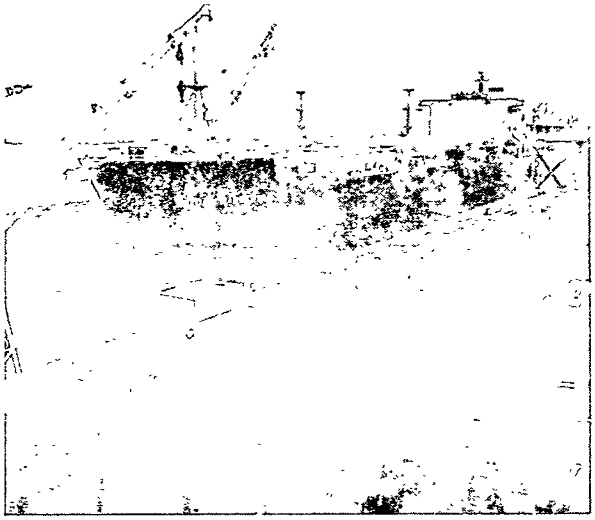


Figure 6
Exxon Charleston At Launch

Machinery

The machinery crafts have basically been an indirect beneficiary of the advanced shipbuilding methods, but the improvement in their costs have been substantial as well. Generally speaking, the advent of package units and on-unit outfitting has enabled the final installation of many pieces of equipment to take place in more accessible shop and platen environments with readily available handling gear in lieu of having to load equipment into the hold of the ship after unit erection.

Conscious efforts have been put forward to pre-machine foundations before installation and to adopt improved machinery and technology to further reduce machinery costs.

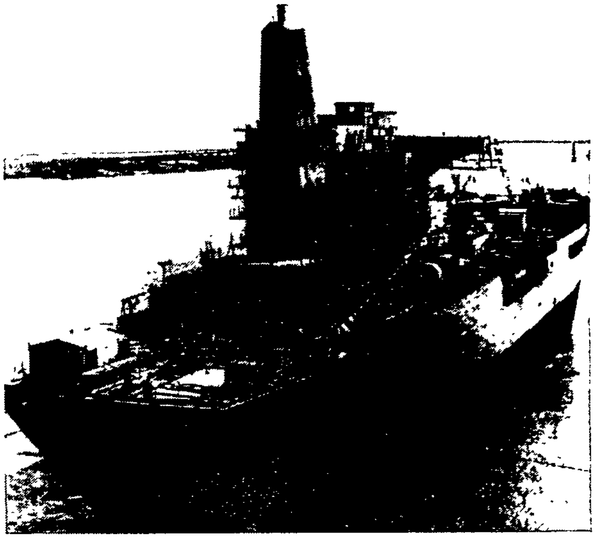


Figure 7 AO-177 At Launch

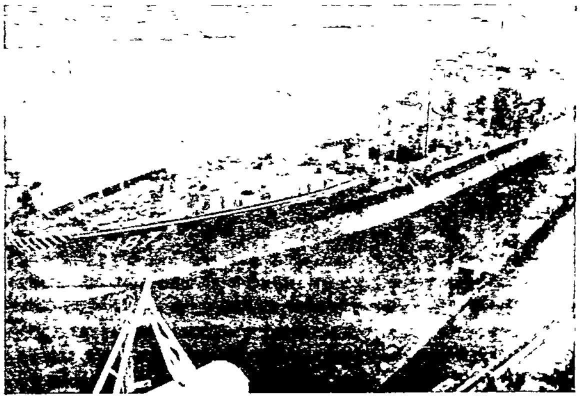


Figure 8 AO-187 At Launch

Table IX Package Unit Application - Coastal Tankers

	Ogden	Exxon
No. of Package Units	0	58
No. of Equipments Included	-	93
Footage of Pipe Included, Ft	-	45,000
Square Footage of Included Area, Ft^2	-	25,300
Weight of Package Units, LT	-	875

Table X Unit Application - U.S.Navy Fleet Oilers

AO-177 Class	T-AO 187 Class	
No. of Package Units	0	51
No. of Equipments Included	-	135
Footage of Pipe Included, Ft	-	25,000
Square Footage of Included Area, Ft^2	-	9,500
Weight of Package Units, LT	-	475

Table XI Piping Installation Comparison - Coastal Tankers

	Ogden	Exxon
Total Pipe Footage, LF	150,000	140,000
Percentage Shop Fabricated	60	65
Percentage Field Run	40	35
Number of Pipe Details	9,500	12,000
Average Length of PD, FT	9.5	7.6
Footage Installed on Package Units	0	45,000
Footage Installed On-Unit	10,000	55,000
Footage Installed Onboard	140,000	40,000
Pipe Installed At Launch, Percent	72	97
Relative Total Pipe Cost	1.0	0.85

Table XII Piping Installation Comparison - U.S. Navy Fleet Oilers

	AO-177 Class	T-AO 187 Class
Total Pipe Footage	125,000	165,000
Percentage Shop Fabricated	60	68
Percentage Field Run	40	35
Number of Pipe Details	10,200	12,238
Average Length of PD	7.4	8.8
Footage Installed on Package Units	0	25,000
Footage Installed On-Unit	6,000	90,000
Footage Installed Onboard	119,000	50,000
Pipe Installed At Launch, Percent	60	98
Relative Total Pipe Cost	1.0	0.78

Special tools are designed as part of the engineering process as the "how to build" is now an integral part of the engineering design process.

Coatings

Coatings have grown to be an ever more complex part of the shipbuilding process and now represent the third largest cost constituent in ship construction costs. This is attributable to both the increased sophistication of coating systems intended to reduce long term maintenance as well as greater awareness of surface preparation requirements, system compatibilities, etc. Direct cost comparisons between different contracts are still difficult due to the varying specification requirements invoked by different customers. However, the most significant contribution by the coating process to the total shipbuilding cost structure has been the early individual subassembly and on-unit surface preparation and coating emphasis. This approach has reduced the extent of final surface preparation and coating to be done onboard and in conjunction with the earlier installation of other distributed systems a minimum of onboard blasting is therefore required. The coating process, although still re-

Table XIII Machinery Installation - Coastal Tankers

	Ogden	Exxon
No. of Package Unit Installations	0	93
No. of On-Unit Installations	0	160
No. of Onboard Installations	343	195
Percentage Complete at Time of Launch	55	80
Relative Cost	1.0	0.85

Table XIV Machinery Installation - U.S.Navy Fleet Oilers

	AO-177 Class	T-AO 187 Class
No. of Package Unit Installations	0	135
No. of On-Unit Installations	0	300
No. of Onboard Installations	708	225
Percentage Complete at Time of Launch	40	85
Relative Cost	1.0	0.80

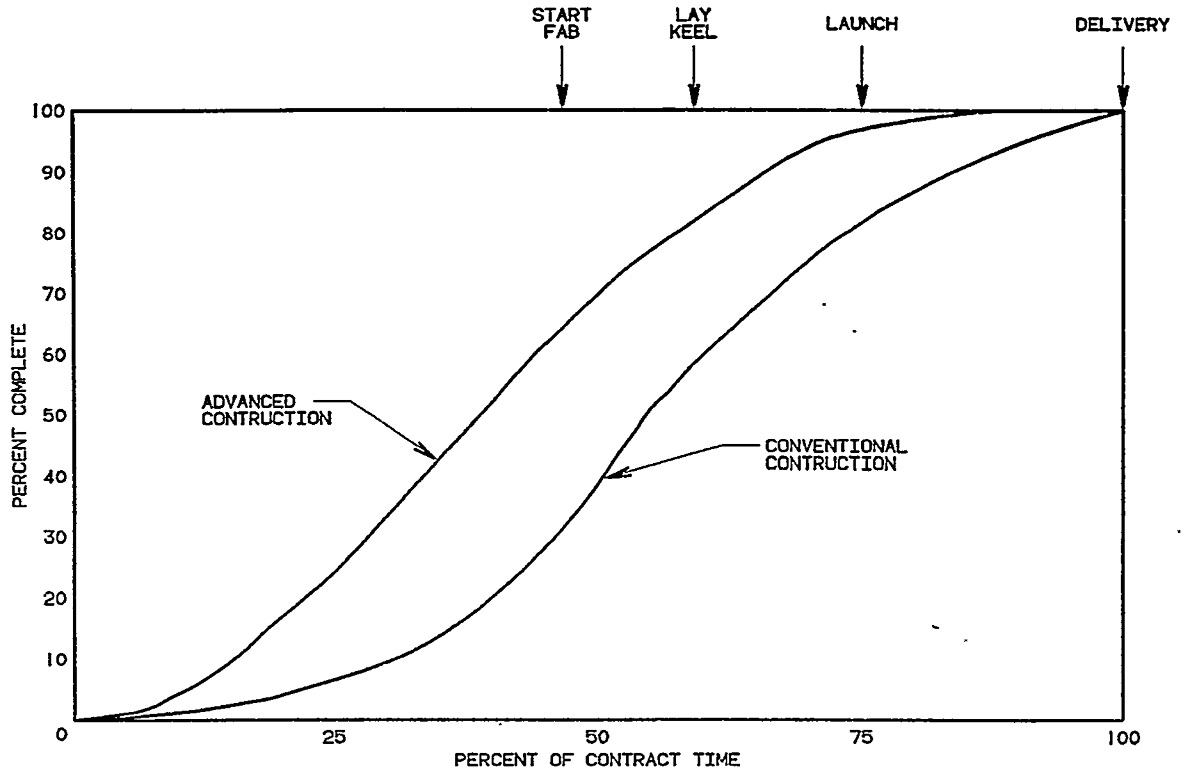
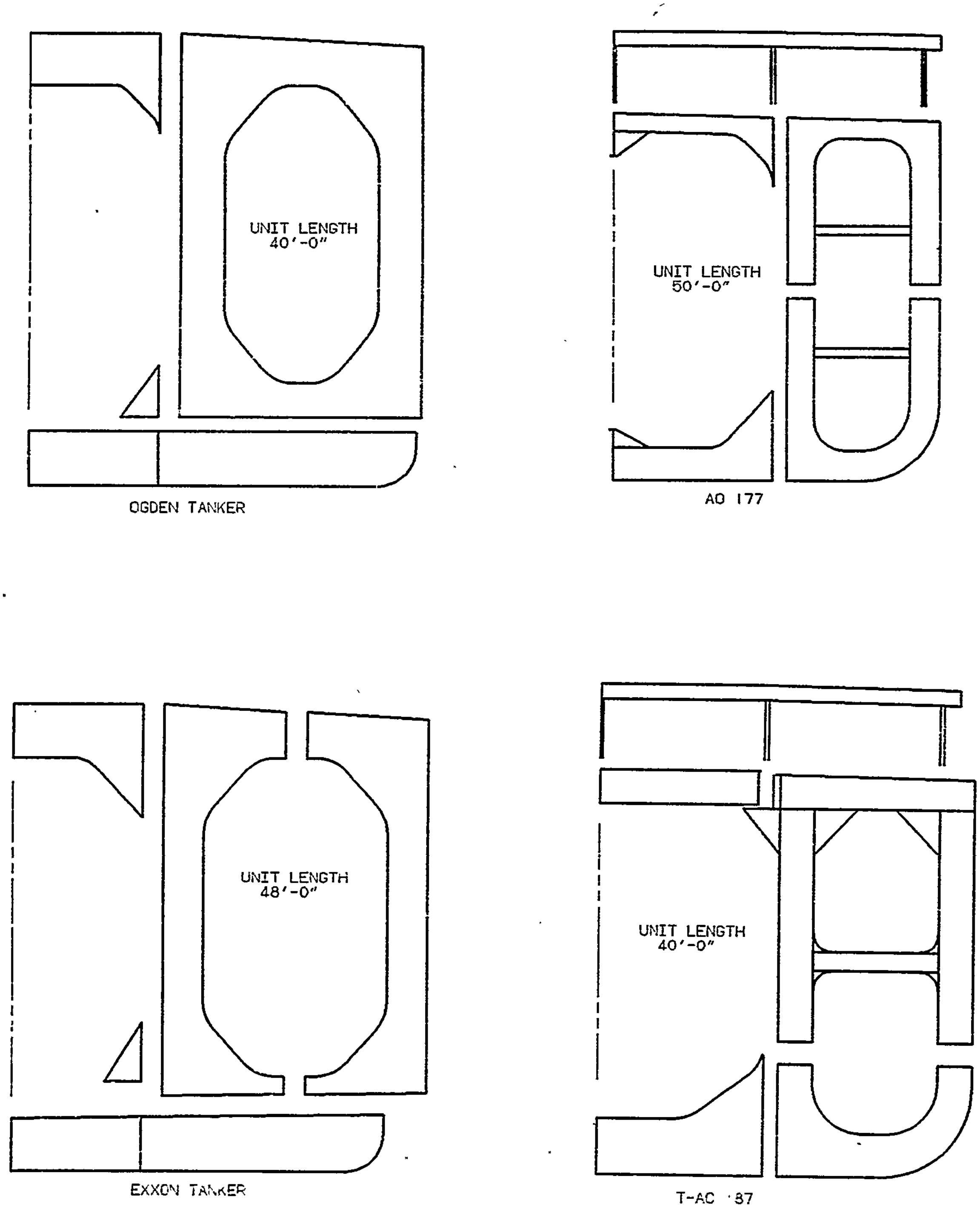


Figure 9 Engineering Progress

quiring its fair share of time prior to ship completion, is less of a governing factor in ship schedule and cost than in the past.

Sheetmetal

Sheetmetal work breakdown was often difficult to quantify to the outsider as product definition and ship detailing was generally handled directly by the crafts. The outgrowth of a disciplined advanced shipbuilding process has been to quantify the extent of shop fabricated ventilation details, identify the subassembly material re-



OGDEN TANKER

AO 177

EXXON TANKER

T-AC 187

Figure 10 Midship Section Unit Breakup

Table XV Coatings Comparison - Coastal Tankers

	Ogden	Exxon
Square Footage Coated	1,850,000	2,135,000
Weight of Coating System, LT	130	210
% Complete at Launch	30	80
Relative Cost	1.0	.90

Table XVI Coatings Comparison - U. S. Navy Fleet Oilers

	AO-177 Class	T-AO 187 Class
Square Footage Coated	1,400,000	2,360,000
Weight of Coating System, LT	100	160
% Complete at Launch	40	80
Relative Cost	1.0	.85

Table XVII Sheetmetal Installation - Coastal Tankers

	Ogden	Exxon
Percent on-Unit	10	55
Percent Onboard	90	45
% Installed at Launch	30	90
Relative Cost	1.0	0.85

Table XVIII Sheetmetal Installation - U.S.Navy Fleet Oilers

	AO-177 Class	T-AO 187 Class
Percent On-Unit	10	80
Percent Onboard	90	20
% Installed at Launch	30	95
Relative Cost	1.0	0.82

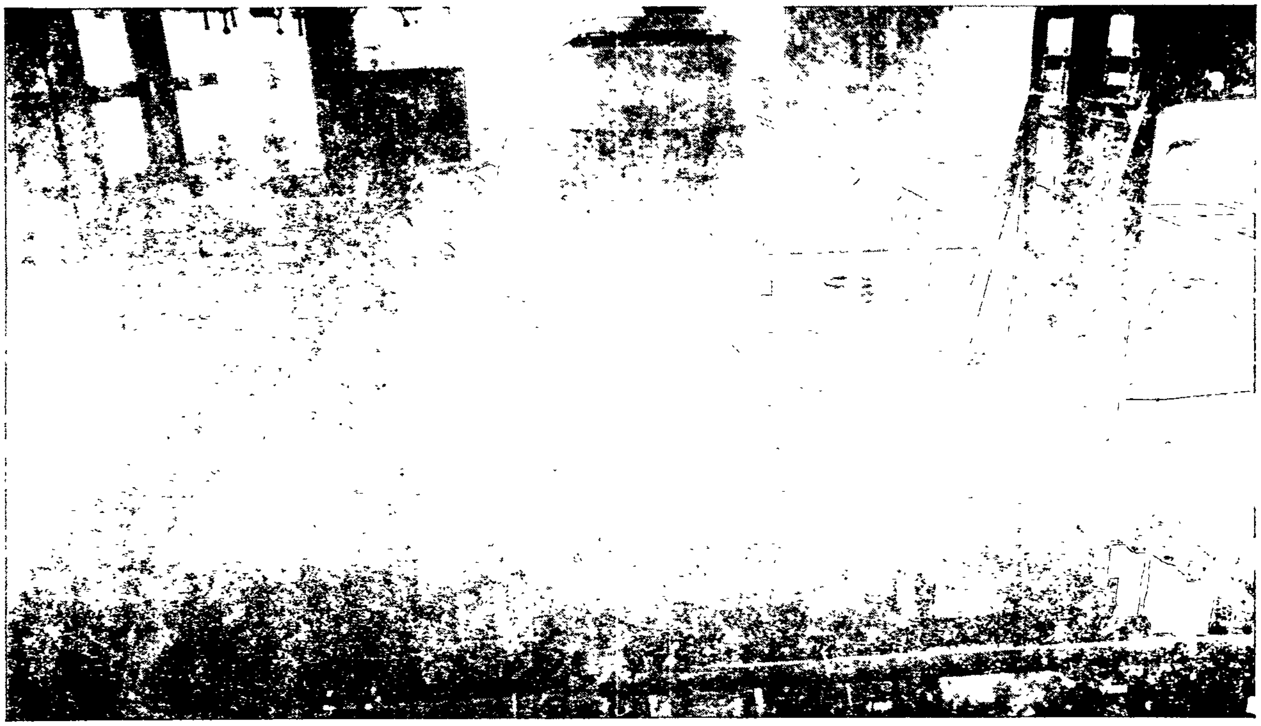


Figure 11 Typical Machinery Space Package Unit

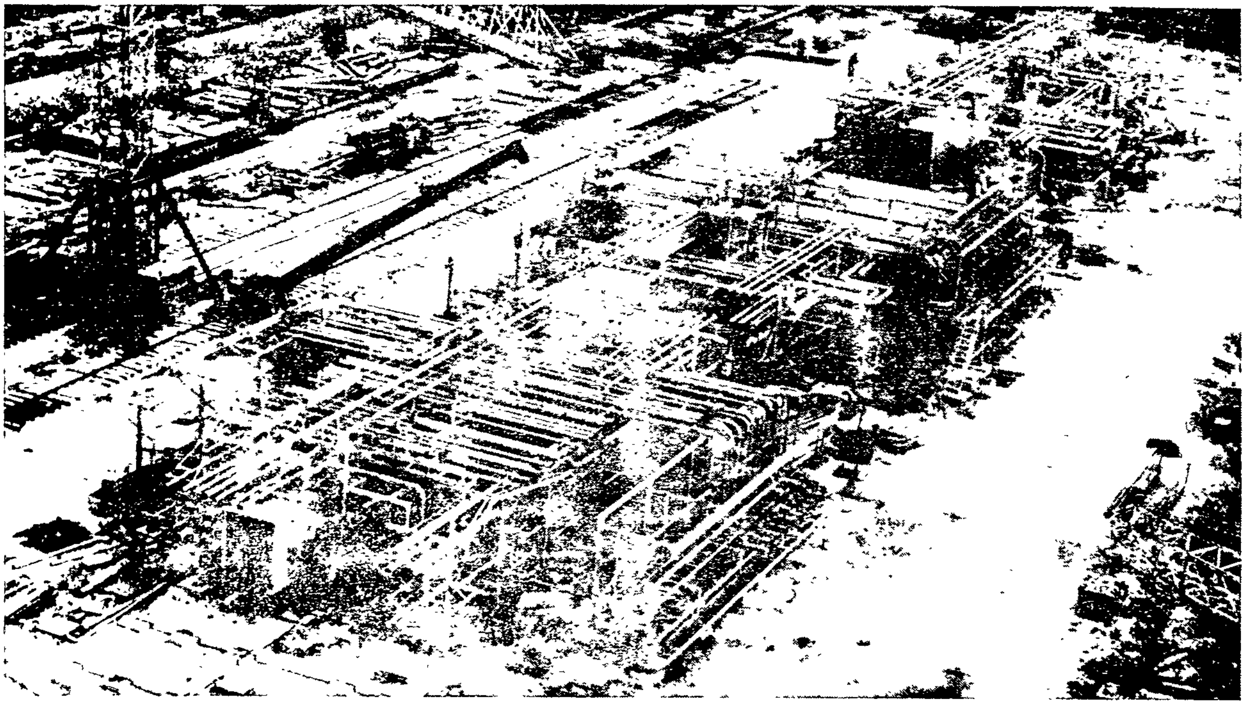


Figure 12 Main Deck Package Unit Assembly

quirements, and enable detailed planning and schedule monitoring to be performed.

The on-unit installation of sheetmetal has taken several forms, one being an increased reliance on built in trunks where the arrangement and weight considerations allow, and secondly the on-unit installation of extensive portions of the ventilation systems. Where large sections of sheetmetal exist, a highly integrated approach to assure proper coating and hull insulation prior to sheetmetal installation has been required.

Electrical

Advances in electrical productivity may at first seem less pronounced if one only focuses on cable installation and hookup which obviously requires a fairly substantial portion of the vessel to exist in order to be cost effective. However, when one looks at the extensive amount of effort required independent of cable installation, substantial productivity improvements can be made in wireway installations, local layout, equipment layout and installation, etc. Additionally, the earlier completion of all other craft work enables the earlier start of cable installation onboard with dramatic improvements in cable installation completion at launch. All vessels launched at Avondale since 1979 have had sufficient electrical installation complete and tested such that the ship's shore power electrical distribution system was able to be energized at time of launch.

Facilities

The continued investment in shipyard facilities obviously plays a large role in improving construction capability and enhancing productivity. Avondale has made substantial investments in facilities over the past 15 years, including the past eight (8) years during which the four (4) classes of vessel under discussion were constructed. Highlights of the major facilities improvements in this time period are as follows:

1979 - Activation of Semi-Automated Pipe Shop
1980 - Application of Line Heating
1982 - Installation of Pin Jigs
1982 - Establishment of Process Lanes Construction Platens
1983 - Installation of 265 Ton Gantry Crane
1985 - Installation of 400 Ton Turn-Over Crane

Each of the classes of vessels were basically constructed in the same physical areas of the shipyard and the restraints of physical unit weight and dimensions were basically unchanged during this time period. The increased lifting capacity gantry crane was installed to enable installation of the

Table XIX Electrical Installation - Coastal Tankers

	Ogden	Exxon
Cable Footage	325,000	490,000
Cable Percent Installed at Launch	65	85
On-Unit Installations, %	5	20
Relative Cost	1.0	.90

Table XX Electrical Installation - U.S.Navy Fleet Oilers

	AO-177 Class	T-AO 187 Class
Cable Footage	612,000	905,000
Cable Percent Installed at Launch	65	80
On-Unit Installations, %	5	40
Relative Cost	1.0	,85

completely asembled T-AO main engine in lieu of reassembly of the engine in the ship as done on the Ogden and Exxon vessels. This increased lifting capacity in the hull erection area does not affect unit size due to other process lane and painthouse size and weight restraints. The larger total lift capacity now available in the assembly area does enable the "blocking" of several units prior to erection. This capability is principally utilized for large volume, lower weight type superstructure units.

Conclusion

We have attempted to depict through the tables and figures that the benefits of advanced shipbuilding methods at Avondale have been considerable in the period of implementation from 1979 to the present. It is often difficult to clearly quantify the improvements that have been made, as we clearly live in an ever changing environment of increased contract requirements, changing social and economic factors,and the absence of a series of standard ship designs. However, the results in every measure of shibuilding productivity support the implementation of improved methodology as done at Avondale and other domestic shipyards.

I believe the U. S. Shipbuilding Industry has made significant progress in improved productivity gains in the recent past and we see these techniques being just as effectively implemented on complex U. S. Navy construction programs as well. I'm sure we all look forward to the return of a domestic commercial shipbuilding market such that our newly acquired skills can be applied to a greanter volume of ship production.

Acknowledgements

We would like to express our sincere appreciation to all the individuals of IHI who worked with Avondale over the past several years in developing the improved methods now in place. Additionally, we would like to acknowledge all of the employee owners at Avondale that work hard every day to achieve the benefits of what is very advantageous, but also a very vigorous methodology of ship construction.

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High Strength Steels Produced by Advanced Metallurgical Processes

No. 21

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BACKGROUND

Increased strength of steels used for ship structural applications have traditionally been achieved with higher alloy content. Depending on the alloying elements chosen, the increased strength is achieved at a cost in weldability and toughness.

Recent developments in the control of properties through precise thermomechanical processing (control of rolling temperature regimes, rolling thickness reductions and cooling rates) and advanced steelmaking techniques, have led to the creation of steel with increased strength and toughness, while maintaining modest carbon equivalents to provide good weldability. There is reason to believe that excellent results will be attainable with the new families of high strength steels which are now or are expected to become commercially available in the near future. A more detailed description of the metallurgical processing is included in Appendix A.

It is expected that the use of the new high strength steels will prove attractive in many marine applications, because of their potential relative insensitivity to heat input, HAZ hardening, and their potential for reduced requirements for preheat.

Data generated in a current SP-7 project studying high heat input effects on 50 ksi yield strength steels produced by thermomechanical processing has indicated superior notch toughness and resistance to heat input [1]. Data in the technical literature has indicated similar promise for higher yield strength steels.

OBJECTIVE

The immediate objective of this investigation was to explore the potential advantages of new high strength (65 to 120 ksi yield) steels produced by advanced steelmaking and on-line processing techniques for marine applications.

A longer term objective is to facilitate the introduction to the shipbuilding industry of the new high strength steels processed by advanced on-line processing techniques with toughness and weldability properties beyond those currently available.

ACHIEVEMENT

The study has provided a preliminary characterization of newly developed steels with yield strengths varying from 65 ksi to 120 ksi. On the basis of the preliminary data obtained, it appears that by use of advanced metallurgical processes, high strength steels can be produced which provide improved toughness and weldability; the alloying elements required for such steels could be substantially lower than that required for conventionally processed quenched and tempered steels of the same strength and toughness levels.

APPROACH

Candidate steels over the strength range of interest which were being made by thermomechanical controlled rolling with on line cooling were obtained. In addition, a fourth steel produced by conventional quench and temper techniques was included. Each steel was subjected to appropriate tests to indicate tensile, Charpy V-Notch, Nil-Ductility Transition (NDT) (drop weight) and dynamic tear properties. Controlled thermal severity (CTS) testing was also conducted to provide preliminary information as to weldability.

Small-scale weldments of sample steels selected by means of evaluation of previous base metal and CTS test results were produced and tested.

BASE MATERIAL SELECTION

On the basis of commercial availability, the target properties of the candidate steels as manufactured by thermomechanical rolling and on-line cooling are as follows:

Target Properties

Candidate Steel Source	Thickness, in inches	Minimum Yield Strength, in ksi	Minimum Charpy V-Notch, in ft-lb	Maximum IIW Carbon Equivalent
A	1.25	65	100 at -75C	0.40
B*	2.00	65	100 at -75C	0.40
C	2.00	80	30 at -60C	0.50
D	2.00	100	30 at -60C	0.60

* replaced by 80 ksi yield strength conventional quenched and tempered steel

TESTING PROCEDURES

Chemical Analysis

The composition of the four candidate steels and the two HY steels used in the weldability test (see Weldability Test below) was determined.

Metallography

The micro-structure and austenitic grain size were determined for each candidate steel at three locations: surface, quarter-thickness, and mid-thickness.

Mechanical Testing

1. Tensile Test: Longitudinal and transverse tensile properties were determined with 1/2" diameter, 2" gage length specimens removed from the quarter-thickness location.

2. Charpy V-Notch Test: Longitudinal and transverse Charpy V-Notch impact properties were determined with standard-sized specimens removed at three locations: surface, quarter-thickness, and mid-thickness.

3. NDT Drop Weight Test: The NDT temperature was determined with 5/8" thickness specimens with the weld bead located at the plate surface for all steels, at the quarter-thickness location for Steels B/C/D, and at the mid-thickness location for Steel A.

4. Dynamic Tear Test: The dynamic tear energy was determined with longitudinal 5/8" thickness specimens removed from the plate surface.

5. Hardness Survey: A through-thickness hardness survey was conducted for each candidate steel.

Weldability Test

Preliminary data concerning the weldability of the four candidate steels was obtained on the basis of Controlled Thermal Severity (CTS) tests (2). The data is presented as a HAZ cracking rating: i.e., the number of HAZ cracks observed by 100X examination of four metallographic sections taken through each test weld. Each test assembly consisted of one bithermal weld (thermal severity number of 16) and one trithermal weld (thermal severity number of 24). In general, two test assemblies were used for each evaluation. The pertinent welding parameters are shown in Table C1. For comparison purposes, CTS tests were conducted with HY80 and HY100 steels.

Small Scale Weldment Test

Steels A and C were selected for welding (by SMAW) and testing of small-scale weldments. The pertinent welding parameters are shown in Table C2. Testing consisted of transverse tensile, Charpy V-Notch and hardness at the quarter-thickness where practicable.

RESULTS

The results of tests are shown as follows:

Chemical Composition	Table One
Metallography	Table Two and Figures One through Three
Tensile Properties	Table Three and Tables B1/B2
Charpy V-Notch Properties	Figures Four through Seven and Tables B3/B4/B5
NDT Temperature	Table Four
Dynamic Tear Properties	Figure Eight and Table B6
Hardness Survey	Figure Nine and Table B7
CTS Test	Table Five
Small-Scale Weldment	Tables Six through Eight

DISCUSSION OF RESULTS

Steel A

1. Composition: Steel A is a microalloyed carbon-manganese steel with a very low carbon content (0.04%). The microalloying elements present are columbium, titanium and boron. The carbon equivalent (0.32) easily met the target value, 0.40 maximum.

2. Metallography: The average McQuaid-Ehn austenitic grain size was eight (8). The accepted requirement for fine grain steel is five (5) or finer. Determinations taken at the mid-thickness indicated a grain size of seven (7), slightly coarser than at other locations.

The microstructure consisted of bainite and ferrite as shown at Figure 1, 500X magnification. The microstructure was uniform through the thickness of the plate. The sulfide inclusions were spheroidal, typical of shape-control processing.

3. Tensile Properties: The yield strength determined for the longitudinal and transverse orientations met the target value of 65 ksi minimum. The transverse tensile and yield strength determinations were somewhat higher than the values determined in the longitudinal orientation. The reason for this is not apparent.

4. Charpy Impact Properties: Steel A showed a lower bound Charpy V-Notch temperature transition between approximately -100F and -120F. The lower bound curve indicates that the steel met the target value of 100 ft-lbs at -75C (-103F). The lower bound was comprised of data points from all (three) locations, in contrast with Steels C and D where the lower bound was defined almost exclusively by surface data. It is interesting to note that Steel A has been accelerated cooled, while Steels C and D have been directly quenched and tempered. The upper shelf data was over 170 ft-lbs.

The Charpy V-Notch data meets the ABS MODU requirement for special application service at -30C, i.e., 25 ft-lbs at -60C.

5. NDT Drop Weight Test: The (NDT) temperature was -65C (-85F) at the plate surface. This temperature corresponds to the near upper shelf regime for Charpy V-Notch and to the transition range for dynamic tear. The mid-thickness NDT temperature was slightly lower, -75C (-103F), and corresponds to the dynamic tear lower shelf.

6. Dynamic Tear Test: Steel A exhibited dynamic tear energies over 1100 ft-lbs at temperature down to -60C, where a very steep transition occurred. The transition range correlated with the surface nil-ductility transition temperature as determined by the drop-weight test.

7. Hardness Survey: Steel A showed minor variations in hardness on a through thickness traverse. The hardness ranged from 93 to 98 in the Rockwell B Scale. The value of 98 was recorded only at the plate surface.

8. CTS Test: No CTS testing was conducted for Steel A, 1-1/4" thickness, in that the yield strength and the thickness did not permit correlation to the HY80/100, 2" thickness, used for a comparison basis, and a steel of comparable yield strength and thickness was not available.

FIGURE 1
Steel A: 500X, 2% Nital etch

9. Small Scale Weldment: Steel A exhibited generally satisfactory although somewhat irregular results. The tensile strength was approximately 4-1/2% below that previously recorded for the base metal; however, it was noted that the fracture occurred in the weld metal and not in the base metal. With the exception of one fusion-line specimen the Charpy V-Notch impact data met the ABS MODU requirement for weldments for special application service at -30C: i.e., 17 ft-lb at -60C. The Charpy V-Notch impact data was somewhat lower (especially two fusion-line specimens) than the previously determined base metal data indicating a degrading effect of the heat of welding. Subsequent metallorgaphic examination indicated that the fracture path for the 10 ft-lb specimen was contained wholly within the weld metal adjacent to the fusion line, and that the fracture path for the 17 ft-lb specimen generally followed the fusion line although it did at some locations pass solely through the weld metal adjacent to the fusion line.

The above results suggest that the low tensile strength and Charpy V-Notch impact values recorded for Steel A were resultant from the weld metal characteristics and did not indicate substandard performance of Steel A in the small scale weldment test. The Vickers Hardness data showed no abnormally high hardness values.

Steel B

As previously noted, Steel B is an 80 ksi yield strength quenched and tempered steel which has been used as a substitute for the originally intended 65 ksi yield strength thermomechanically processed steel. The test results are evaluated in terms of 80 ksi yield strength target properties noted in BASE MATERIAL SELECTION as Candidate Steel C.

1. Composition: Steel B is a low carbon (0.10%) conventional quenched and tempered carbon-manganese-molybdenum steel with a high manganese content (1.84%). Columbium is present as a microalloying addition. The carbon equivalent (0.50) met the target value, 0.50 maximum.

2. Metallography: The average McQuaid-Ehn austenitic grain size was seven (7). The accepted requirement for fine grain steel is five (5) or finer. Determinations taken at three thickness locations indicated that a grain size gradient extended from the surface to the mid-thickness where the smallest grain size, eight (8), was observed.

The microstructure consisted of tempered martensite as shown in Figure 2, 500X magnification. No significant differences were noted among the microstructures at the three locations: surface, quarter-thickness, and mid-thickness. The sulfide inclusions were spheroidal, typical of shape-control processing.

3. Tensile Properties: The yield strength determined for the longitudinal and transverse orientations met the target value of 80 ksi minimum. The ductility parameters were satisfactory. Steel B met the tensile requirements for HY80.

4. Charpy Impact Properties: The lower bound Charpy V-Notch data met the target value, 30 ft-lbs at -60C (-76F).

Extrapolation of the lower bound to 0F (testing higher than -40F was not conducted) indicates that Steel B also meets one requirement for HY80, 60 ft-lbs at 0F. In addition, the transverse/mid-thickness data meets the second requirement for HY80, 35 ft-lbs at -120F specified for specimens of transverse orientation and mid-thickness location (for plate thicknesses 7/8" and over). It should be noted, however, that data from many surface/longitudinal and quarter-thickness/longitudinal specimens developed less than 35 ft-lbs when tested at -120F.

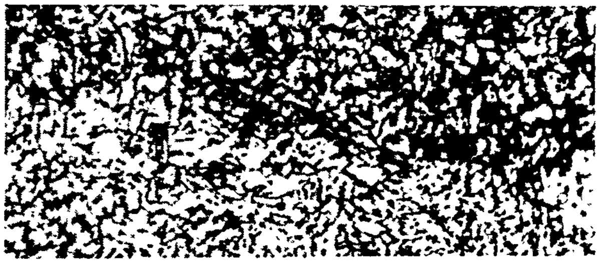

FIGURE 2
Steel B: 500X, 2% Nital etch

The Charpy V-Notch data meets the ABS MODU requirement for special application service at -30C, i.e., 25 ft-lbs at -60C.

5. NDT Drop Weight Test: The (NDT) temperature was -45C (-49F) for the plate surface and also for the quarter-thickness location. This temperature corresponds to the near upper shelf regime of Charpy V-Notch data; the lower bound value at the NDT temperature is approximately 100 ft-lbs. The NDT temperature is within the transition for the dynamic tear data.

6. Dynamic Tear Test: Steel B exhibited dynamic tear energies over 1100 ft-lbs at temperature down to -20C (-4F), where a gradual transition commenced. The approximate mid-point of the transition range correlated with the nil-ductility transition temperature. The dynamic tear data, 800 ft-lbs at -40F, indicates that Steel B will meet the requirement for HY80, 450 ft-lbs at -40F.

7. Hardness Survey: With the exception of several high values at one surface of the plate, Steel B exhibited a relatively uniform through thickness hardness ranging from 96 to 98 in the Rockwell B Scale. High values of Rockwell C Scale 27 (approximately 103 in the Rockwell B Scale) were recorded at one surface of the plate; this could be resultant from higher quenching rates at this surface.

8. CTS Test: Steel B demonstrated greater resistance to HAZ cracking than the baseline HY80 steel when welded in the controlled thermal severity (CTS) test. No HAZ cracking (i.e., a crack rating of zero) was noted for the bithermal test weld with a thermal severity number (TSN) of 16. In comparison, the baseline HY80 showed a HAZ cracking rating of one (1). For the trithermal test weld (TSN = 24), Steel B developed a HAZ cracking rating of one (1), while the baseline HY80 exhibited a HAZ cracking rating of four (4).

Steel C

Steel C was submitted as an 80 ksi yield strength steel. Testing indicated that this steel is a 100 ksi yield strength steel. The test results are evaluated in terms of both 80 ksi and 100 ksi yield strength requirements.

1. Composition: Steel C is a low carbon (0.12%) thermomechanically processed steel. The principal alloying elements are manganese, nickel, chromium and molybdenum. Vanadium and boron are present as microalloying additions. The carbon equivalent (0.49) met the target values for 80 ksi yield strength (0.50 maximum) and 100 ksi yield strength (0.50 maximum).

2. Metallography: The average McQuaid-Ehn austenitic grain size was six (6). The accepted requirement for fine grain steel is five (5) or finer. At the mid-thickness location, the grain size was seven (7), slightly finer than at other locations.

The microstructure consisted of tempered bainite and martensite, as shown at 500X magnification in Figure 3. The microstructure was uniform through the thickness of the plate. The sulfide inclusions were spheroidal, typical of shape-control processing.

3. Tensile Properties: The yield strength determined for the longitudinal and transverse orientation was 106 ksi. This strength met the target property for 100 ksi yield strength steel. The ductility data was satisfactory. Steel C met the tensile requirements for HY100; however, the yield strength exceeded the upper limit of the yield strength range specified for HY80, 99.5 ksi.

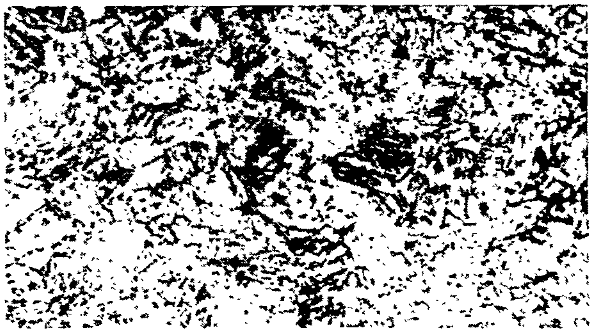

FIGURE 3

Steel C/D: 500X, 2% Nital etch

4. Charpy Impact Properties: The lower bound Charpy V-Notch data met the target value, 30 ft-lbs at -60C (-76F), and met the impact requirements for HY80/100. The Charpy V-Notch data also meets the ABS MODU requirement for special application service at -30C, i.e., 25 ft-lbs at -60C.

The lower bound is defined exclusively by transverse specimens removed from the plate surface. In addition, longitudinal/surface data generally represents the lower bound for specimens of longitudinal orientation. The data suggests that the surface toughness is less than the toughness for other plate locations. This is not interpreted as being detrimental in that all Charpy V-Notch toughness values were quite high and met requirements and the target values.

5. NDT Drop Weight Test: The NDT temperature was determined for the plate surface and the quarter-thickness. The results suggested that the fracture toughness properties of the plate surface are different and lower than those of the quarter thickness. The surface NDT temperature was -29C (-20F) while the quarter-thickness NDT temperature was -75C (-103F).

6. Dynamic Tear Test: Steel C exhibited dynamic tear energy over 1100 ft-lbs at temperature down to -50C (-58F), where a sharp transition commenced. The dynamic tear data indicates that Steel C will meet the requirements for HY80/100: at -40F, 450 ft-lbs (for HY80) and 500 ft-lbs (for HY100).

7. Hardness Survey: The hardness traverse data was uniform ranging from 21 to 23 in the Rockwell C Scale. No significant variation in tensile strength through thickness of the plate is indicated.

8. CTS Test: The CTS test results for Steel C were superior to the results for both baseline materials, HY80 and HY100. Steel C developed HAZ cracking ratings of one-half (1/2) for the bithermal test weld (TSN = 16) and for the trithermal test weld (TSN = 24).

9. Small Scale Weldment: Steel C exhibited satisfactory results. The tensile strength was equivalent to that determined previously for the base metal. All Charpy V-Notch impact data met the ABS MODU requirement for weldments for special application service at -30C: i.e., 17 ft-lbs at -60C. The Charpy V-Notch impact data was somewhat lower (especially two fusion-line specimens) than the previously determined base metal data, indicating a degrading effect of the heat of welding. The Vickers Hardness data showed no abnormally high hardness values.

Steel D

Steel D was submitted as a 100 ksi yield strength steel. Testing indicated that this steel is a 120 ksi yield strength steel. For comparison purposes, the criteria and requirements for 100 ksi yield strength steel are used.

1. Composition: Steel D is a low carbon (0.11%) thermomechanically processed steel. The principal alloying elements are manganese, nickel, chromium and molybdenum. Vanadium and boron are present as microalloying additions. The carbon equivalent (0.51) easily met the target value for 100 ksi yield strength (0.60 maximum).

2. Metallography: The average McQuaid-Ehn austenitic grain size was six (6). The accepted requirements for the fine grain steel is five (5) or finer. No variation with thickness location was noted.

The microstructure consisted of tempered bainite and martensite, as shown at 500X magnification in Figure 3. The microstructure was uniform through the thickness of the plate. The sulfide inclusions were spheroidal, typical of shape-control processing.

3. Tensile Properties: The yield strength determined for the longitudinal and transverse orientations was 124 ksi and 122 ksi, respectively. These values met the target values of 100 ksi, but exceeded the upper limit of the yield strength specified for HY100, 115 ksi. The ductility data was satisfactory.

4. Charpy Impact Properties: In general, the Charpy V-Notch data met the target value, 30 ft-lbs at -60C (-76F). The transverse/mid-thickness data met the HY100 requirements, 30 ft-lbs at -120F and 55 ft-lbs at 0F, which are specified for specimens of transverse orientation and mid-thickness location (for plate thicknesses 7/8" and over). It should be noted, however, that data from the transverse/surface developed less than 30 ft-lb when tested at -120F. For information, the Charpy V-Notch transverse/mid-thickness data meets the requirements for HY130, i.e., (1) 60 ft-lbs minimum at 0F, (2) and at 70F, a maximum of the 0F data value plus 15 ft-lbs. The Charpy V-Notch data also meets the ABS MODU requirement for 100 ksi yield strength steel for special application service at -30C, i.e., 25ft-lbs at -60C.

The lower bound is defined almost exclusively by transverse specimens removed from the plate surface; at -120F the value was less than 10 ft-lbs. In addition, longitudinal/ surface data generally represents the lower bound for specimens of longitudinal orientation.

The data suggests that the surface toughness is less than the toughness for other plate locations. It is further noted that this lower-toughness surface effect, which for Steels C and D defines the lower bound, is more severe for Steel D than for Steel C in terms of absolute values and in terms of percentage decrease below the average data plots. This suggests that the severity of the surface effect increases with increasing yield strength.

5. NDT Drop Weight Test: The NDT temperature for the surface was -29C (-20F); the NDT temperature for the quarter-thickness was -55C (-67F). The surface NDT temperature corresponds to the transition ranges of the Charpy V-Notch impact lower bound data and the dynamic tear data. The lower bound Charpy V-Notch data at the NDT temperature is approximately 40 ft-lbs. The dynamic tear energy at the NDT temperature is approximately 400 ft-lbs. The quarter-thickness NDT temperature corresponds to the upper transition of the Charpy V-Notch impact non-surface data. The difference in the NDT temperatures again suggests that the surface of the plate has a lower toughness than the quarter-thickness location.

6. Dynamic Tear Test: Steel D exhibited dynamic tear energy over 1100 ft-lbs at temperature down to 0C (32F), where a gradual transition commenced. The dynamic tear data did not meet the requirements for HY100, 450 ft-lbs at -40F; however, the specimens tested were longitudinal/surface and probably developed a lower absorbed energy than the specified transverse/mid-thickness specimens. For information, the dynamic tear data indicates that Steel D will meet the requirement for HY130, 500 ft-lbs at 0F.

7. Hardness Survey: The hardness traverse data ranged from 24 to 29 in the Rockwell C Scale. With the exception of several readings of R_c 25 near the mid-thickness of the plate and one high value of R_c 29, the hardness was uniform ranging from 26 to 28 in the Rockwell C Scale.

8. CTS Test: The CTS test results for Steel D were superior to the results for both baseline materials, HY80 and HY100. Steel D developed a HAZ cracking rating of one-half (1/2) for the trithermal test weld (TSN = 24); no cracking was developed for the bithermal test weld.

Mechanical Property Correlations

1. Strength and Toughness: The thermomechanically processed steels A/C/D exhibit a decrease in toughness as the yield strength increases. This is shown by the dynamic tear energy-temperature transition (Figure 8) where the dynamic tear curve shifts to the right with increasing yield strength. The inverse relationship of toughness and yield strength is generally valid for steels that are not vastly different in chemistry. Thus, it is interesting to note that the dynamic tear curve for the conventionally processed quenched and tempered Steel B generally falls with the curve for the thermomechanically processed Steel C, although the yield strength of Steel C is over 20 ksi higher than the yield strength of Steel B. This data suggests that the toughness of thermomechanically processed steel is superior to that of an equivalent strength conventionally processed steel.

A comparison of the Charpy V-Notch impact absorbed energy-temperature transition (Figures 5 and 6) for Steels B and C illustrates that although the energy at -40C is approximately equivalent, the Steel C transition commences at lower temperature than for Steel B. This indicates a superior low temperature toughness, which is also indicated by the lower NDT temperature for Steel C (-103F) than for Steel B (-49F). It should be noted that the above comparisons are based upon "non-surface" data for Steel C, i.e., data from the quarter thickness and from the mid-thickness, and all data for Steel B.

2. NDT, Dynamic Tear and Charpy V-Notch: In general, there was not good correlation among the toughness data for the thermomechanically processed steels A/C/D. NDT temperature specimens prepared and tested in accordance with ASTM E208 demonstrate that the NDT temperatures are too high for classical correlation to dynamic tear energy-temperature transitions where the NDT temperature corresponds to the lower shelf (4). Comparisons with Charpy V-Notch impact energy-temperature transition also show that the NDT temperatures are too high; although correlation is better with the lower bound curve for Steel D where the lower bound curve is defined by surface specimens. The upper shelf NDT/CVN correlation is documented in the literature (3) although for steels with considerably higher yield strengths.

A more classical correlation between NDT and dynamic tear lower shelf was demonstrated with drop weight specimens prepared with the tension surface and crack-starter weld bead located at the quarter-thickness of the plate or at the mid-thickness of the plate. These results, i.e., a lowering of the NDT temperature, were anticipated based upon comparison of surface and non-surface Charpy V-Notch impact data which indicated a lower-toughness surface effect (previously discussed in "Charpy Impact Properties" for Steel C and "Charpy Impact Properties" for Steel D). For Steel C, the absolute value for the Charpy V-Notch absorbed energy for the non-surface data at the quarter-thickness NDT temperature and for the lower bound (surface data) at the surface NDT temperature is very similar, approximately 115 ft-lbs. This value is much higher than that generally reported for indexing an NDT/CVN correlation (4)(5). Steel D did not exhibit a CVN correlation similar to Steel C.

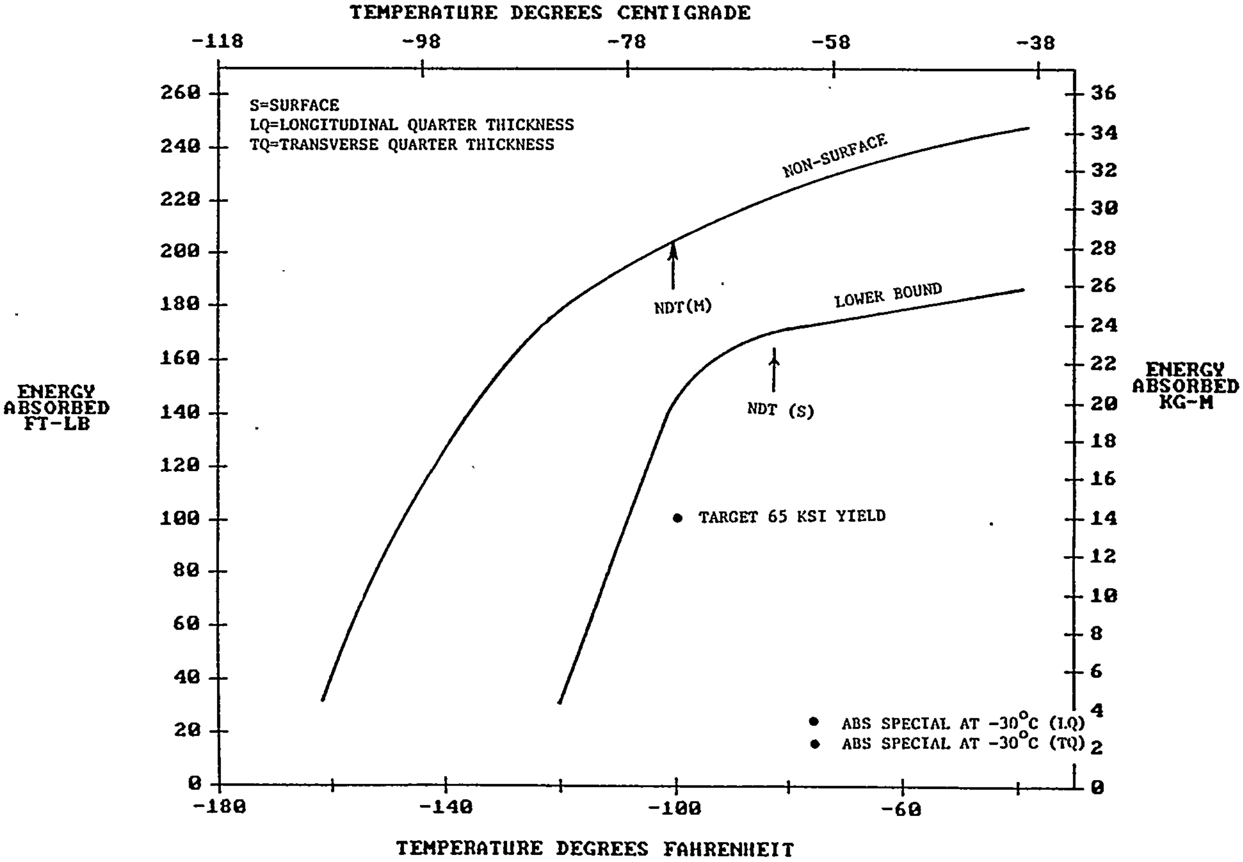

FIGURE FOUR STEEL A
CHARPY V-NOTCH ABSORBED ENERGY
TEMPERATURE TRANSITION

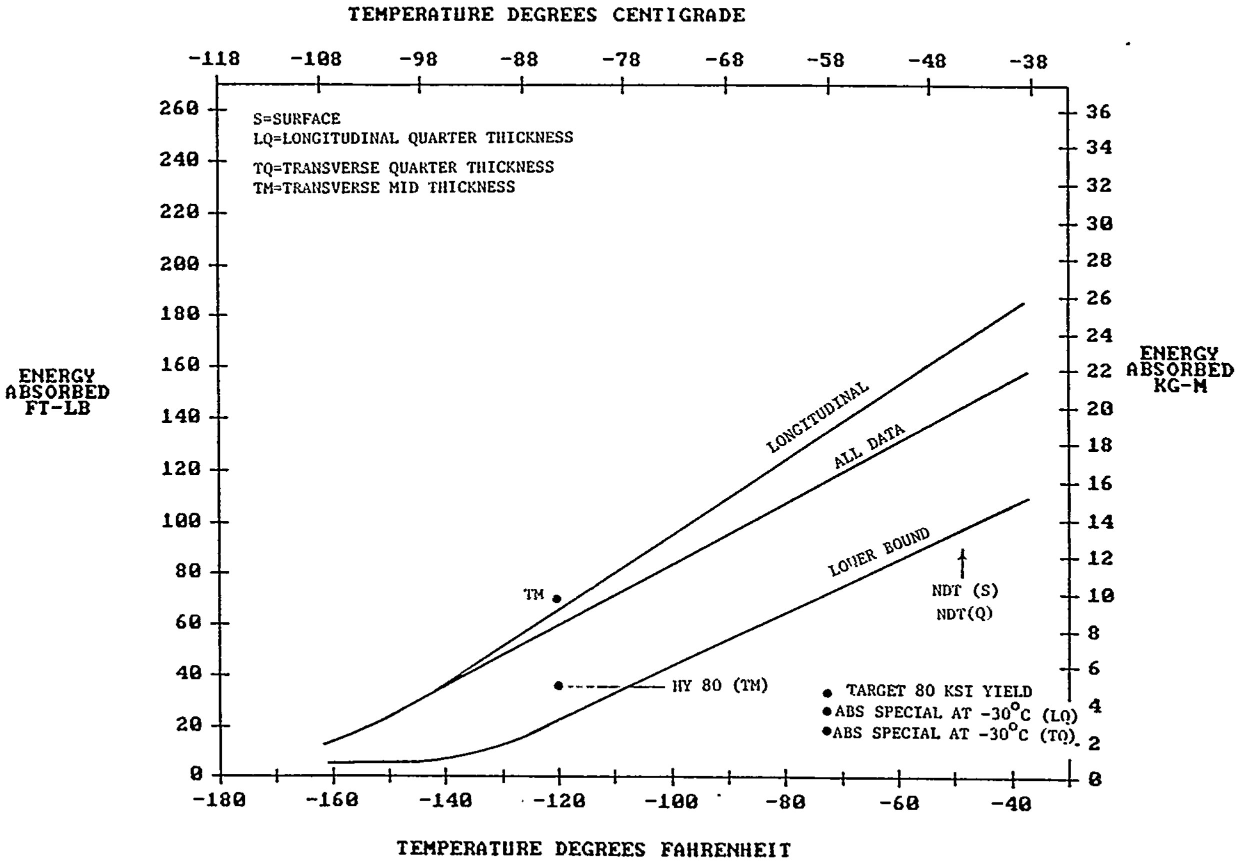

FIGURE FIVE STEEL B
CHARPY V-NOTCH ABSORBED ENERGY
TEMPERATURE TRANSITION

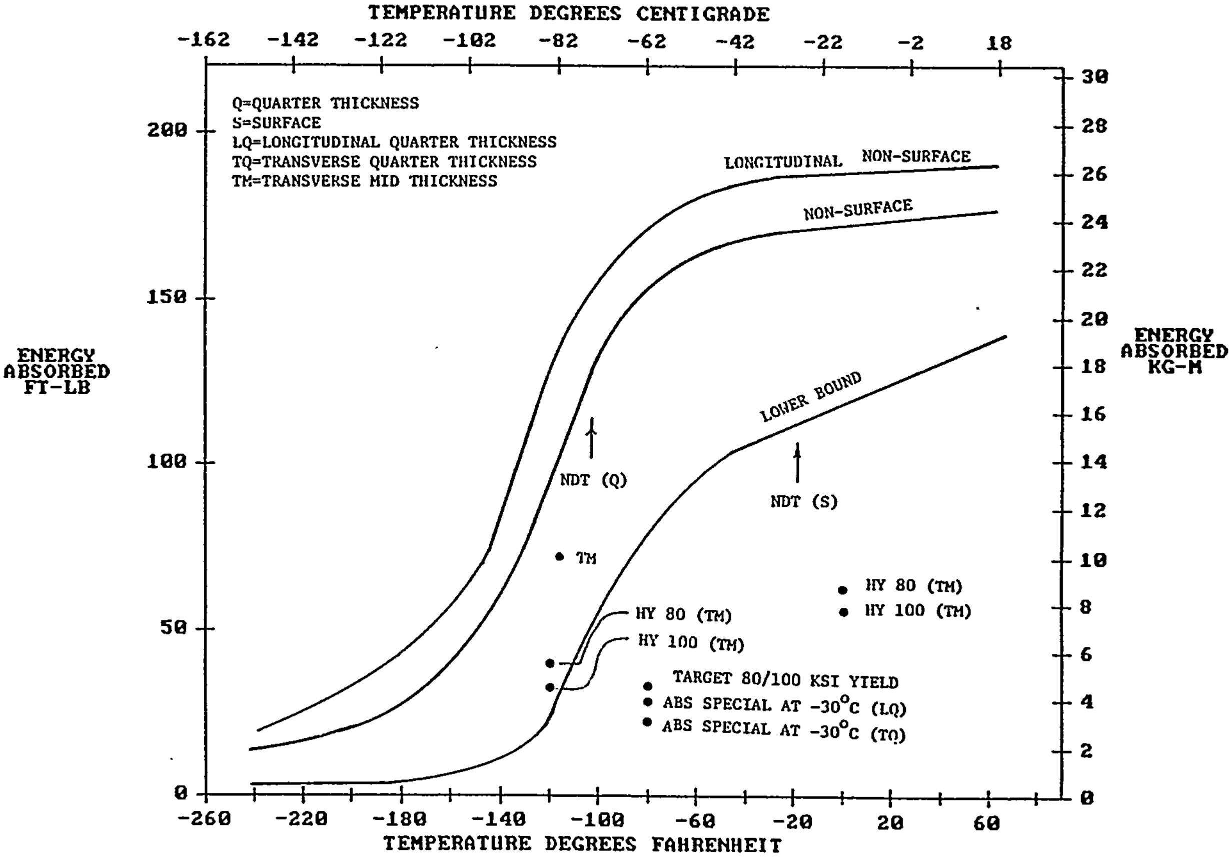

FIGURE SIX STEEL C
CHARPY V-NOTCH ABSORBED ENERGY
TEMPERATURE TRANSITION

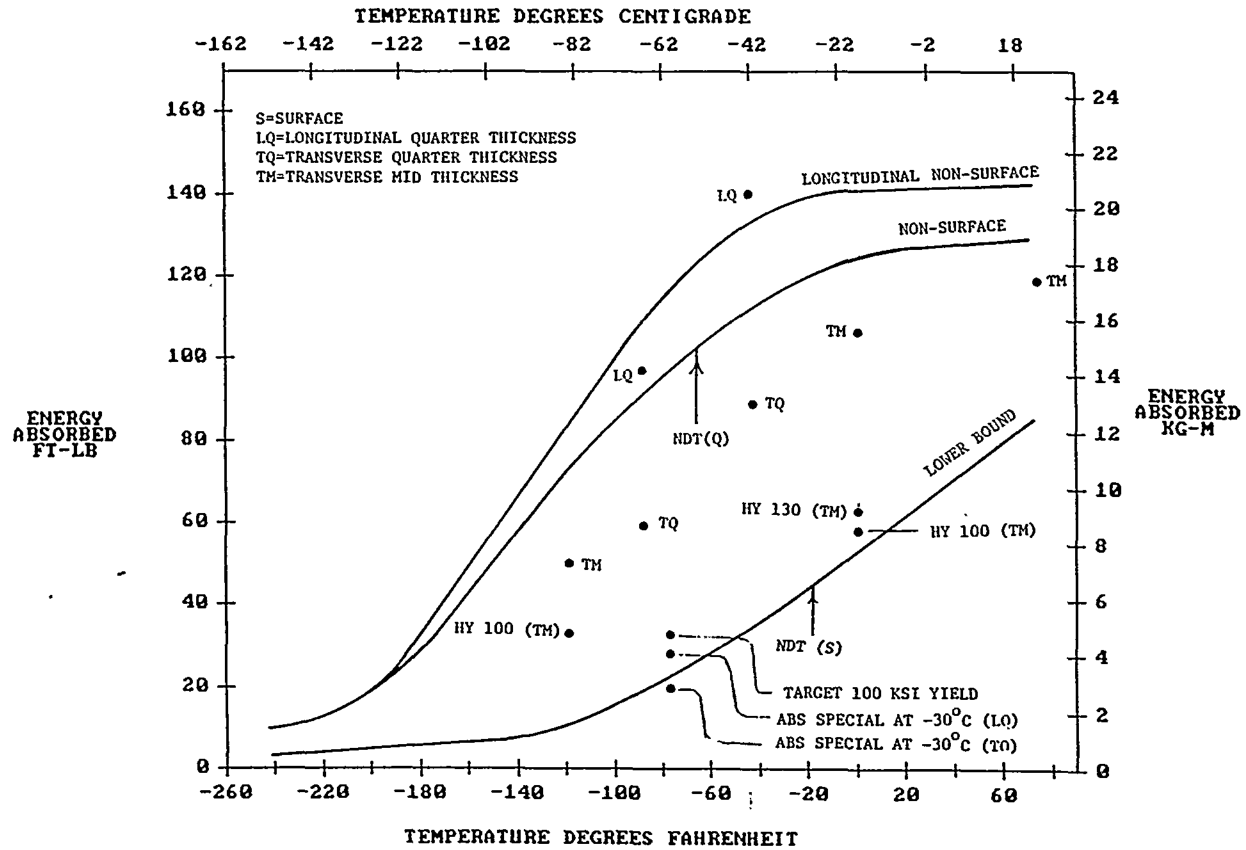

FIGURE SEVEN STEEL D
CHARPY V-NOTCH ABSORBED ENERGY
TEMPERATURE TRANSITION

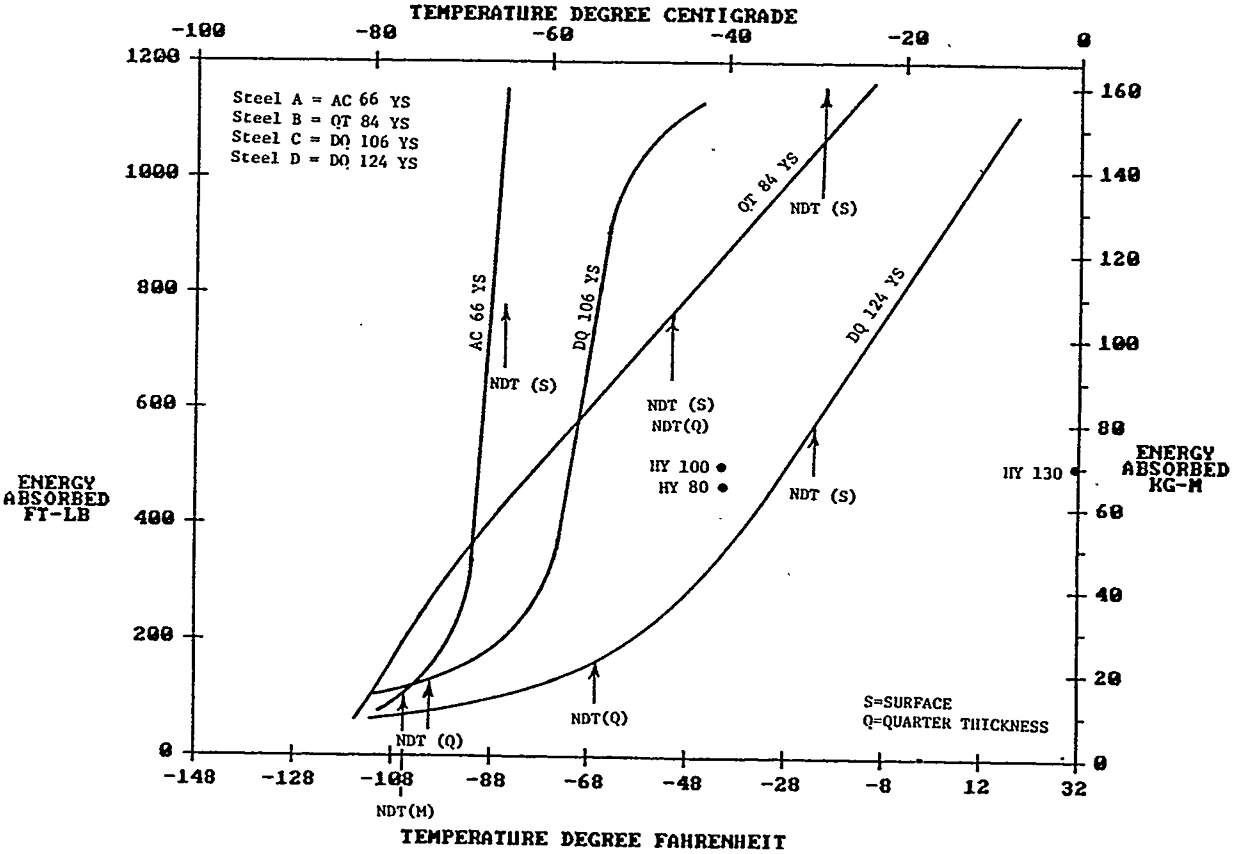

FIGURE EIGHT STEEL A THROUGH D
DYNAMIC TEAR ABSORBED ENERGY
TEMPERATURE TRANSITION

Review of all the Charpy V-Notch impact test results, including absorbed energy, lateral expansion and fracture appearance, indicated that the thermomechanically processed Steels C/D displayed a lower-toughness surface effect while the conventionally processed quenched and tempered Steel (B) did not exhibit this effect.

CONCLUSIONS AND RECOMMENDATIONS

On the basis of this study and the results obtained, the following conclusions are drawn.

1. All steels studied satisfied the base metal toughness requirements for ABS MODU special application service at -30C.

2. Steel B met (dynamic tear test data indicates likely compliance with specification requirements) the small-scale mechanical test requirements for HY80.

3. Steel C met (dynamic tear test data indicates likely compliance with specification requirements) all (except the HY80 upper limit on yield strength) the small scale mechanical test requirements for HY80 and HY100, indicating a potential as a substitute for HY steels.

4. In the 80 ksi to 100 ksi yield strength range, the thermomechanically processed steel exhibited higher toughness than the conventionally processed quenched and tempered steel.

5. Steels B/C/D exhibited greater resistance to HAZ cracking than HY80/100.

6. Steels A/C exhibited good weldability and generally met the ABS MODU requirements for special application service at -30C.

7. The thermomechanically processed steels exhibited a lower toughness associated with the surface in comparison

with other locations. This lower-toughness surface effect was more evident in the direct quenched and tempered steels (C/D).

It is recommended that thermomechanically processed steels of the type evaluated herein can be considered for higher strength applications requiring high toughness and for higher strength applications at lower temperature. This recommendation includes further evaluation encompassing explosion bulge testing, line-heating, cold forming and high heat input welding.

ACKNOWLEDGMENTS

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TABLE ONE
CHEMICAL COMPOSITION, IN PERCENT
IIW CARBON EQUIVALENT

					ABS MODU	CTS TEST CONTROLS		MIL-S-16216J	
ELEMENT	STEEL A	STEEL B	STEEL C	STEEL D	FQ GRADES(1)	HY80	HY100	HY80	HY100
Carbon	0.04	0.10	0.12	0.11	0.18 max	0.16	0.17	0.10-0.20	0.10-0.22
Manganese	1.43	1.84	1.01	0.94	1.60 max	0.35*	0.33*	0.10-0.45	0.10-0.45
Silicon	0.17	0.21	0.27	0.26	0.55 max	0.21*	0.16*	0.12-0.38	0.12-0.38
Phosphorus	0.019	0.012	0.010	0.014	0.025 max	0.14	0.016	0.020 max	0.020 max
Sulfur	0.003	0.005	0.003	0.003	0.025 max	0.017	0.020	0.020 max	0.020 max
Nickel	0.23	0.05	0.78	1.05	(2)	2.67*	2.71*	2.43-3.32	2.67-3.57
Chromium	0.04	0.10	0.45	0.45	(2)	1.61*	1.49*	1.29-1.86	1.29-1.86
Molybdenum	0.01	0.31	0.23	0.33	(2)	0.43*	0.36*	0.27-0.63	0.27-0.63
Copper	0.25	0.10	0.23	0.23	(2)	0.04*	0.10*	0.25 max	0.25 max
Aluminum	0.032	0.046	0.018*	0.049*	—	0.017*	0.005*	NS	NS
Columbium	0.028	0.029	0.005*	0.005*	(2)	0.005*	0.005*	NS	NS
Vanadium	0.005*	0.005*	0.038	0.048	(2)	0.008*	0.005*	0.03 max	0.03 max
Titanium	0.018	0.005*	0.005*	0.005*	—	0.005*	0.005*	0.02 max	0.02 max
Boron	0.0011	0.001*	0.0011	0.0012	(2)	0.001*	0.001*	NS	NS
Nitrogen	0.0026	0.008*	0.005*	0.005*	—	0.003*	0.007*	NS	NS
IIW-CE	0.32	0.50	0.49	0.51		0.81	0.78	1.02 max 0.59 min	1.05 max 0.61 min

$$CE = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15}$$

NS = Not Specified

(1) Alloying and fine-grain elements are to be reported.

(2) Are to be reported, including zirconium.

*By spectrographic analysis

TABLE TWO
AUSTENETIC GRAIN SIZE (1)

SAMPLE	SURFACE	QUARTER THICKNESS	MID THICKNESS
Steel A	8	8	7
Steel B	6	7	8
Steel C	6	6	7
Steel D	6	6	6

(1) A grain size of five or finer (i.e., higher number) fulfills the requirements for "Fine Grain".

TABLE THREE
AVERAGE TENSILE PROPERTIES
LONGITUDINAL (TRANSVERSE)

SAMPLE	TENSILE STRENGTH, IN KSI	YIELD STRENGTH, IN KSI	ELONGATION GL = 4.51 A, IN PERCENT	REDUCTION OF AREA, IN PERCENT
Steel A	91.5 (95.0)	66.0 (70.0)	28 (26)	74 (76)
Steel B	98.0 (97.0)	84.0 (84.0)	25 (24)	76 (72)
Steel C	114 (114)	106 (106)	24 (21)	76 (72)
Steel D	130 (130)	124 (122)	20 (20)	70 (67)

Note: Data for Steels B/C/D (2 inches in thickness) is from quarter thickness. Data for Steel A (1¼ inches in thickness) is from quarter thickness thru mid thickness.

TABLE FOUR
NIL-DUCTILITY TRANSITION TEMPERATURE

SAMPLE	TEST LOCATION	IN DEGREES CENTIGRADE	IN DEGREES FAHRENHEIT
Steel A	Surface	-65*	-85
Steel A	Mid Thickness	-75*	-103
Steel B	Surface	-45*	-49
Steel B	Quarter Thickness	-45*	-49
Steel C	Surface	-29	-20*
Steel C	Quarter Thickness	-75*	-103
Steel D	Surface	-29	-20*
Steel D	Quarter Thickness	-55*	-67

*Temperature scale used in test.

TABLE FIVE
CONTROLLED THERMAL SEVERITY (CTS) TEST HAZ CRACKING RATING

SAMPLE	BITHERMAL TSN = 16	TRITHERMAL TSN = 24
Steel B	0	1
Steel C	½	½
Steel D	0	½
HY80	1	4
HY100	2	1
HY80 (1)	2	3

(1) Data from Stern/Quattrone (Ref. 2).

TABLE SIX
WELDMENT TRANSVERSE TENSILE (1/4 T) DATA

SAMPLE	TENSILE STRENGTH, IN KSI	LOCATION OF FRACTURE
STEEL A	88.0	WELD METAL
	86.0	WELD METAL
STEEL C	114	BASE METAL
	114	BASE METAL

TABLE SEVEN

WELDMENT TRANSVERSE CHARPY V-NOTCH (1/4 T) DATA, IN FOOT-POUNDS AT -75F (-60C)

SAMPLE	FUSION LINE	1mm HAZ	3mm HAZ
STEEL A	10	148	166
	17	144	178
	132	74	149
STEEL C	155	155	120
	60	118	165
	54	114	166

TABLE EIGHT
WELDMENT TRANSVERSE HARDNESS SURVEY (1/4 T) DATA IN VICKERS HARDNESS NUMBER

LOCATION	STEEL A	STEEL C
WELD METAL CENTERLINE	223	250
FUSION LINE	237	265
DISTANCE FROM FUSION LINE, IN mm:		
1	211	239
2	191	226
3	182	256
4	195	248
5	202	243

APPENDIX A

COMMENTARY ON METALLURGICAL PROCESSING

Three of the four steels investigated herein have been produced by thermomechanical processing. Through thermomechanical processing, steel can be produced to levels of toughness and strength usually achieved by a separate heat treatment subsequent to rolling. A leaner chemistry without loss of strength is possible, thus reducing the carbon equivalent with an attendant increase in weldability (A1). Economic benefits are derived from lower alloying costs and omission of heat treatment (A2).

Thermomechanical processing is an extension of the controlled rolling technology, a viable commercial practice for more than fifteen (15) years. The basic change from controlled rolling methodology is the rolling of the steel at lower temperature, specifically around the Ar_3 temperature. Thermomechanical processes are proprietary, and as such, show differences in the number of rolling stages and the reduction ratio of each stage, the temperature regimes of the rolling stages, and the use or omission of accelerated cooling or direct quench and tempering after rolling. The use of accelerated cooling or direct quench and tempering after thermomechanical rolling permits steel chemistries of much lower carbon equivalent without loss of strength properties (A2). In addition, some proprietary processes may include substantial intermediate reheating and continued rolling (A3).

In light of the proprietary differences inherent to the thermomechanical processing of steel, several generalizations as to the process can be made and are listed below:

1. The slab reheat temperature is generally lower than for conventional steel rolling practice: reheat in the range of 950-1200C (1742-2192F) provides a finer initial austenitic grain size at the beginning of rolling than the higher temperature of conventional practice (A4).

2. The subsequent rolling stages consist of high reductions in the austenite recrystallization region to promote a finer austenitic grain size, and high reductions in the austenite non-recrystallization region but above the austenite transformation temperature to promote deformation bands for subsequent fine grain nucleation (A4, A5). In addition to the above rolling stages, rolling may also be conducted just above the Ar_3 and at times below the Ar_3 after which the steel is air cooled (A4, A5, A6, A7).

3. Depending upon the desired properties, the rolled steel is air cooled, accelerated cooled, or direct quenched and tempered. Generally, the cooling rates for accelerated cooling are less than 15C per second, while for direct quenching they are higher (A8, A9, A10).

The cooling practices used for the thermomechanically processed steels tested herein are as follows:

Steel A: Accelerated Cooled
Steel C: Direct Quenched and Tempered at 640C (1184F)
Steel D: Direct Quenched and Tempered at 600C (1112F)

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(A6) "Kobe Steel's 'Kontroll Process' for New Type of Controlled Rolled Steel Plate", January 1980, Kobe Steel Ltd.

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(A10)Tsukada, K., et.al., "Development of YS 36 Kgf/mm^2 Steel with Low Carbon Equivalent Using On-Line Accelerated Cooling (OLAC)", Nippon Kokan Technical Report, <u>Overseas</u> No. 35 (1982).

APPENDIX B - TEST DATA

TABLE B1

BASE METAL LONGITUDINAL TENSILE PROPERTIES

SAMPLE	TENSILE STRENGTH IN KSI	YIELD STRENGTH IN KSI	ELONGATION GL = 4.51 A, IN PERCENT	REDUCTION OF AREA IN PERCENT
Steel A	91.0, 91.5	66.0, 66.0	27, 29	74, 74
Steel B	97.0, 98.0	83.5, 84.5	24, 26	77, 75
Steel C	114, 113	106, 106	23, 24	76, 76
Steel D	130, 131	123, 124	20, 20	72, 69

TABLE B2

BASE METAL TRANSVERSE TENSILE PROPERTIES

SAMPLE	TENSILE STRENGTH IN KSI	YIELD STRENGTH IN KSI	ELONGATION GL = 4.51 A, IN PERCENT	REDUCTION OF AREA IN PERCENT
Steel A	94.5, 95.5	70.0, 69.5	26, 27	76, 75
Steel B	96.5, 97.0	83.0, 84.0	24, 24	73, 71
Steel C	114, 114	106, 106	21, 21	72, 71
Steel D	128, 131	121, 123	20, 20	68, 66

TABLE B3
BASE METAL CHARPY V-NOTCH PROPERTIES
ABSORBED ENERGY, IN FOOT-POUNDS

		LONGITUDINAL ORIENTATION			TRANSVERSE ORIENTATION		
SAMPLE	TEST TEMPERATURE IN DEGREES FAHRENHEIT	SURFACE LOCATION	QUARTER THICKNESS LOCATION	MID THICKNESS LOCATION	SURFACE LOCATION	QUARTER THICKNESS LOCATION	MID THICKNESS LOCATION
Steel A	-40	PB*,238,218	PB*,PB*,PB*	PB*,PB*,PB*	186,166,192	259,233,237	187,173,189
	-90	178,247,PB*	PB*,PB*,PB*	PB*,165,180	180,214,238	198,PB*,PB*	163,PB*,PB*
	-120	168,197,209	149,176,PB*	235,38,142	29,33,69,221.5	144,PB*,203	133,PB*,PB*
	-140	189,170,210	183,187,190	PB*,61.5,18,19	104,187,192	151,13,19	123,17,190
	-160	14.5,17,9.0	51.0,9.0,240	11.0,13.0,9.0	15.5,114,138	23.0,14,13	18.0,9.5,205
Steel B	-40	152,183,196,166	197,192,196,193	209,184,204,177	124,141,132,127	102,113,110,126	120,131,125,147
	-50	152,186,146	147,130,155	197,190,189	113,112,104	113,128,119	128,111,112
	-60	194,188,131	120,143,143	124,143,143	121,110,132	94,113,116	120,109,112
	-90	121.5,114,129	107,135,125	107,141,127	95,100,105	106,82,105	107.5,99,69
	-120	48,110,20,20	30,20,27,126	117,109,12,75	71,71,58	68.5,81,72	80,66,65
	-140	32,60,59	7,39,44	34,52,103	73,42,65	69,65,48	16,59,80
	-160	9.5,15,12	26.5,12,10.5	8.5,29,21	19,13,31	60.5,68,17	21.5,30,12.5
Steel C	68	185,178,174	191,188,188	182,189,185	136,177,178	159,181,178	163,183,180
	0	173,178,174	180,188,188	176,189,185	116,150,122	153,165,151	153,154,154
	-40	156,150,149	176,166,181	183,172,189	105,103,108,111	148,155,144	132,151,136
	-90	127,149,165,134	185,140,152	142,130,135	91.5,75,77	123,101,107	137,111,108
	-120	93.5,94,102	117,125,106	99,123,101	56,18,66	58.5,69,61	67,62,97
	-180	14.5,13.5,11.0	13.5,52,11.0	46.5,57,78	6.5,34,20	47.0,23,18.5	39.5,30,56
	-240	9.5,13.5,12.5	9.0,46,31	18.0,11.5,13.5	4.0,9.0,7.5	6.0,9.0,9.5	4.5,8.5,21
Steel D	68	145,135,147	141,147,141	142,142,167	83.5,92,91	114,110,116	117,114,123
	0	120	135	138	56	100	108
	-20	114,133,120	139,151,140	139,151,143	42,85,70	90,104,104	95.5,90,111
	-40	100,101,132	150,135,145	147,142,147	55,64,64	70,99,112	98,99,113
	-50	83,116,115	118,151,147	103,151,143	39.5,52,56	76,88,89	80.5,94,86
	-90	96.5,87,78.5	112,81,91	130,95,106	44.5,43,40	72.5,50,56	72.5,66,17
	-120	68,8,57	75,76,71	76.5,84,66	8.0,29,28	49,54,55	61,53,42
	-180	27,10,10	46.5,7,21	43,12,25	6.5,12,18.5	33,27,26	33.5,36,26
	-240	3	7	10.5	6	9	12.5,16.5

PB = Partial break

Note: *Maximum test machine capacity 264 ft-lbs.
Data for information only: not valid according to ASTM E23.

TABLE B4
BASE METAL CHARPY V-NOTCH PROPERTIES
LATERAL EXPANSION, IN MILS

SAMPLE	TEST TEMPERATURE IN DEGREES FAHRENHEIT	LONGITUDINAL ORIENTATION			TRANSVERSE ORIENTATION		
		SURFACE LOCATION	QUARTER THICKNESS LOCATION	MID THICKNESS LOCATION	SURFACE LOCATION	QUARTER THICKNESS LOCATION	MID THICKNESS LOCATION
Steel A	-40	PB,95,90	PB,PB,PB	PB,PB,PB	91,89,100	81,94,95	93,98,96
	-90	97,95,PB	PB,PB,PB	PB,96,99	96,96,99	89,PB,PB	96,PB,PB
	-120	86,106,101	86,99,PB	89,32,82	22,26,52,106	82,PB,98	79,PB,PB
	-140	93,108,100	85,97,96	PB,49,14,13	62,94,101	89,10,18	71,16,103
	-160	13,16,11	41,10,98	6,17,9	9,84,PB	14,11,11	11,9,99
Steel B	-40	85,87,96,95	89,95,96,94	80,90,95,95	74,82,94,82	68,80,74,81	78,81,82,89
	-50	88,96,95	86,90,99	90,95,95	73,76,75	80,81,83	88,76,76
	-60	94,96,92	79,44,98	88,92,95	82,77,88	64,75,85	83,69,76
	-90	82,80,91	76,91,90	75,93,90	73,67,69	73,61,77	77,72,50
	-120	30,13,13	18,26,22,96	80,81,16,56	48,50,42	45,61,52	59,46,46
	-140	12,50,42	7,29,32	26,40,72	52,27,44	42,51,36	10,40,60
	-160	2,8,10	15,10,8	3,20,14	10,11,16	39,30,9	15,23,7
Steel C	68	81,92,91	87,97,96	92,100,101	79,90,88	87,94,83	88,93,93
	0	87,92,91	89,97,96	89,100,101	81,91,81	87,94,83	84,97,95
	-40	91,90,85	89,91,92	93,86,98	71,57,68,73	85,86,86	75,86,86
	-90	82,88,77,76	92,83,84	80,83,83	56,50,48	74,65,65	79,70,63
	-120	60,57,67	71,66,67	61,70,60	34,6,39	34,44,42	40,35,60
	-180	8,9,7	8,34,6	24,36,48	0,22,11	29,11,06	23,20,36
	-240	0,6,4	0,29,20	6,4,10	0,4,0	0,3,4	0,2,10
Steel D	68	84,76,82	81,88,82	79,74,88	56,61,63	73,74,71	71,74,80
	0	70	77	80	35	62	65
	-20	68,68,72	80,86,82	60,82,81	27,54,45	57,52,64	70,60,65
	-40	62,63,76	90,81,96	81,85,85	31,34,38	47,50,68	60,56,70
	-50	50,71,72	80,84,88	64,94,85	28,33,36	46,57,62	52,56,58
	-90	55,57,57	66,56,60	77,58,70	27,30,26	41,32,36	41,40,18
	-120	42,9,36	43,47,44	44,55,41	0,19,18	25,32,34	32,32,26
	-180	15,3,4	27,2,7	23,6,11	0,8,14	17,19,14	14,25,18
	-240	2	0	2	0	0	0, 4

PB = Partial break.

TABLE B5
BASE METAL CHARPY V-NOTCH PROPERTIES
FRACTURE APPEARANCE, IN PERCENT SHEAR

		LONGITUDINAL ORIENTATION			TRANSVERSE ORIENTATION		
SAMPLE	TEST TEMPERATURE IN DEGREES FAHRENHEIT	SURFACE LOCATION	QUARTER THICKNESS LOCATION	MID THICKNESS LOCATION	SURFACE LOCATION	QUARTER THICKNESS LOCATION	MID THICKNESS LOCATION
Steel A	-40	PB,PB,PB	PB,PB,PB	PB,PB,PB	100,100,100	100,100,100	100,100,100
	-90	100,100,PB	PB,PB,PB	PB,100,100	100,100,100	100,PB,PB	100,PB,PB
	-120	91,90,90	100,100,PB	100,26,100	27,30,30,100	100,PB,100	100,PB,PB
	-140	90,90,90	90,90,90	PB,14,0,0	100,100,100	51,0,0	100,0,100
	-160	0,0,0	0,0,100	0,6,11	0,50,PB	3,0,0	0,0,69
Steel B	-40	100,100,100,80	100,100,100,100	100,100,100,90	50,100,69,65	77,51,60,65	82,66,65,100
	-50	100,100,100	59,62,80	100,100,100	72,72,70	60,61,56	66,65,76
	-60	100,100,62	62,75,75	70,69,64	63,62,56	59,50,50	70,69,70
	-90	45,45,45	50,51,45	50,57,45	60,60,60	66,40,70	56,56,40
	-120	18,29,0,0	0,0,0,4,2	29,29,0,35	33,27,30	21,27,27	35,20,20
	-140	0,10,10	0,3,10	0,10,33	39,30,39	26,30,26	5,26,35
	-160	0,0,0	0,0,0	0,0,0	0,0,0	3,10,0	0,0,0
Steel C	68	100,100,100	100,100,100	100,100,100	100,100,100	100,100,100	100,100,100
	0	100,100,100	100,100,100	100,100,100	100,100	100,100,100	100,100,100
	-40	100,90,90	100,100,100	100,100,100	100,100,100,100	100,100,100	100,100,100
	-90	75,69,76,70	69,80,84	90,92,100	66,47,55	65,79,71	61,69,68
	-120	36,33,45	50,73,54	43,68,42	27,0,14	30,25,30	33,39,45
	-180	0,0,0	0,16,0	10,20,23	5,5,3	14,3,0	10,3,14
	-240	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0
Steel D	68	100,100,100	100,100,100	100,100,100	100,100,100	100,100,100	100,100,100
	0	100	100	100	100	100	100
	-20	77,100,90	100,100,100	100,100,100	44,73,60	100,100,100	100,100,100
	-40	69,77,100	100,100,100	50,100,100	50,50,59	90,80,100	100,100,100
	-50	66,66,69	69,100,100	67,100,100	47,34,39	56,65,74	66,65,58
	-90	54,55,66	58,63,51	61,55,59	35,27,30	42,39,52	59,62,39
	-120	27,5,30	30,44,34	33,39,39	0,0,10	34,40,39	39,47,30
	-180	3,0,0	10,0,0	6,0,0	0,0,0	0,5,0	0,0,0
	-240	0	0	0	0	0	0

PB = Partial break.

TABLE B6
DROP WEIGHT DYNAMIC TEAR TEST DATA

SAMPLE	TEST TEMPERATURE, IN DEGREES C	ENERGY ABSORBED IN FOOT-POUNDS
STEEL A	-60	PB
	-70	112; PB
	-80	62
STEEL B	-20	PB
	-40	802
	-60	597
	-70	382
	-80	17
STEEL C	-20	PB
	-40	1,107; PB
	-50	PB
	-60	332; 50
	-70	117
	-80	237
STEEL D	0	PB
	-20	557
	-40	404
	-60	72
	-80	42

PB = Partial break

TABLE B7
THROUGH THICKNESS HARDNESS SURVEY

	STEEL A in RB*	STEEL B in RB*	STEEL C in RC*	STEEL D in RC*
SURFACE	95	98,98	21	26
DEPTH BELOW SURFACE, in sixteenths of an inch				
1	98	98,98,100;RC20	22,24	27,28
3	95	98,98,98;RC18	22	28
5	95	96,99	23	28
7	95	96,98	22	28
9	96	97,100	22	29
	CL			
11	94	97,99	22	26
13	95	97,98	22	25
15	94	97,98	20	24
		CL	CL	CL
17	93	97,98	20	24
19	94,96;RC14	97,98	22	26
21	-	97,100	22	27
23	-	96,96,102	21	28,28
25	-	97,102	22	28,28
27	-	98,103	22	28
29	-	100,105	22	28
31	-	99,102;RC26,27	22	28
SURFACE	96	98,98;BHN229	27	25

*in hardness scale noted unless otherwise indicted

R_B = Rockwell B scale

R_C = Rockwell C scale

BHN = Brinell Hardness number

CL = Plate Centerline

APPENDIX C – WELDING PARAMETERS

TABLE C1
WELDING PARAMETERS FOR CTS TEST

Process	Shielded Metal Arc Welding
Filler	AWS A5.5, E11018M
Filler Diameter	5/32"
Position	Flat (1F)
Joint	Fillets
Preheat	None ((RT)
Polarity	Direct Current Reverse Polarity
Current	110-120 Amps
Voltage	22-23 Volts
Technique	Stringer
Bead Sequence	Single Pass
Travel	5-7 inches/minute
Heat Input	21-33 KJ/inch

TABLE C2
WELDING PARAMETERS FOR SMALL SCALE TEST WELDMENT

	STEEL A	STEEL C
Process	SMAW	SMAW
Filler Metal	AWS A5.5, E9018M	AWS A5.5, E11018M
Root Passes Diameter	1/8"	1/8"
Fill Passes Diameter	5/32"	5/32"
Position	Flat (1G)	Flat (1G)
Joint, as per AWS D1.1	B-U5a*	B-U5a*
Preheat	None (RT)	None (RT)
Interpass	200F	200F
Polarity	DCRP	DCRP
Current		
Root Passes	120-130 amps	120-130 amps
Fill Passes	150-160 amps	150-160 amps
Voltage	19-22 volts	19-22 volts
Technique	Stringer Only	Stringer Only
Bead Sequence	Multipass/Split Layer	Multipass/Split Layer
Travel Speed	5-6 in/minute	5-6 in/minute
Heat Input		
Root Passes	23-34 KJ/in.	23-34 KJ/in.
Fill Passes	28-42 KJ/in.	28-42 KJ/in.
Back Gouge	Yes	Yes

*Double Bevel Groove Butt Joint; square side of "K" used for fusion line and HAZ study

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User's Perspective of CAD/CAM Software

No. 22

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ABSTRACT

Great emphasis has been attached to the achievement of productivity and producibility benefits through the application of Computer Aided Design and Computer Aided Manufacturing (CAD/CAM) technologies. To ensure the achievement of these benefits, it is important that the end user have appropriate software and is able to use it to his advantage. The proper procurement, customization, installation, training, and implementation of software can play a significant role in the effectiveness of CAD/CAM.

INTRODUCTION

Ingalls Shipbuilding Division has made major commitments to the use of computer software to assist design and manufacturing functions. A quarter-century of experience has been compiled in the use of batch stand-alone systems to aid the engineer in the computational aspects of his job. The first major integrated manufacturing effort began in 1968 with the acquisition and installation of a system to take in design definition data, perform some of the naval architectural functions, and ultimately produce the numerical control instruction sets needed to programmatically direct the cutting of structural steel plate.

In February 1979, Ingalls took delivery of the first software and hardware specifically intended to assist the designer with the labor intensive drafting activity. Four years later, it was recognized that in order to gain the maximum benefits from this data, product definition would have to be more complete and representation in a three-dimensional coordinate system would have to be accompanied by the attribute data that gives meaning to a model. This is to say, the model members must be identified not only by their dimensional properties, but also by material, specification, source identification and other information that would allow the model data to ultimately be integrated into the downstream design, planning and manufacturing areas.

As a result of these milestones being accomplished, Ingalls presently finds itself with a capability of integrated hardware and software that includes a quadraplex of mainframes, thirteen graphic workstations used exclusively for drafting purposes, and self-contained workstations operating in a ring-network (see Figure 1) being used for the creation of three dimensional (3-D) design models, drawings, and associated manufacturing aids. This gives Ingalls a state-of-the-art design capability.

These achievements were not gained without pain. False starts, misconceptions of abilities (of both man and machine), and overly ambitious plans have been experienced enough times to make them completely unpatentable. The remainder of this paper will share some of our findings in hopes that you will profit from our mistakes and take advantage of our successes.

THE TURNKEY SYSTEM

Many CAD systems are available on the market today and most profess to be turnkey. That is, they present themselves as a ready solution to your problems, which can be immediately implemented and used with neither waiting nor modification required. Beware!

It has been our experience at Ingalls that no system is available today that will do our job completely. Nor will it do it the way we want it done. Therefore, it becomes immediately obvious that certain provisions must be accepted with the selection of any turnkey system.

The system, as selected, will serve as a baseline for future development and expansion. The system will often require software modification to suite existing company methods and procedures. This is preferable to changing the company to suit the software.

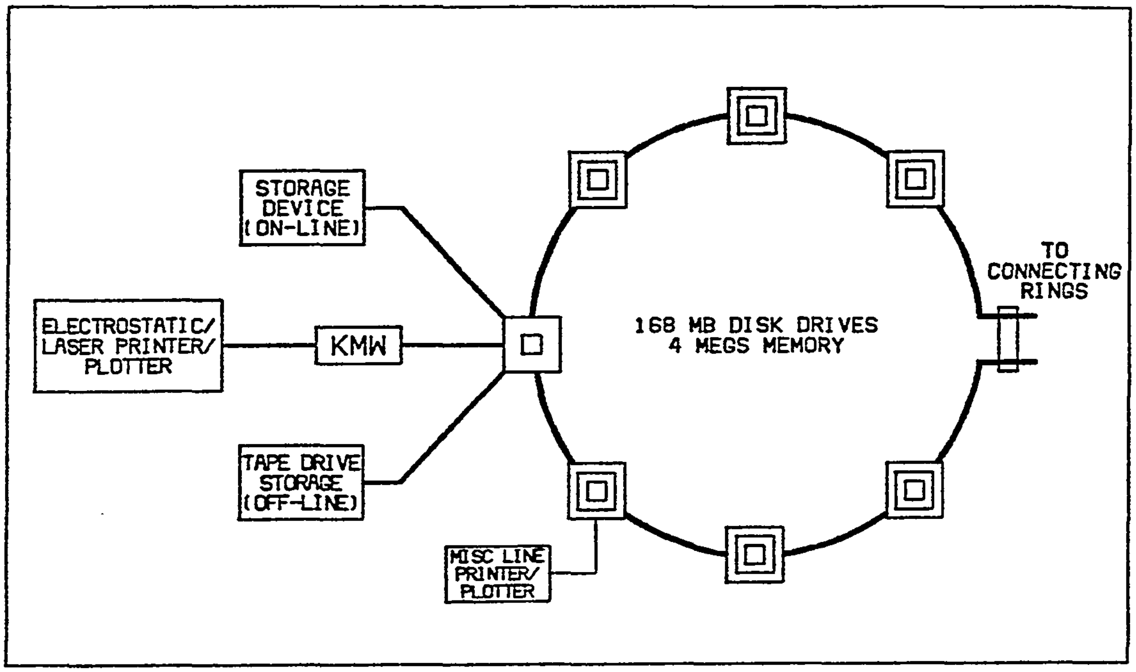

FIGURE 1 - TYPICAL CAD RING/NETWORK CONFIGURATION

No software is ever tested to the extent that it can envision all of the possible uses that creative users can imagine. And when software fails, someone will have to support the shortcoming.

And certainly, a major provision to be made concerns funding. Regardless of whether you intend to provide all software support internally, hire someone to do it, or some combination of the two, it will take time and it will cost money. Support of your schedules and conformance to your priorities should be the major considerations, because it will be done with your money. So much for the turnkey myth.

THE SOFTWARE TREATMENT ALTERNATIVES

In spite of the notes of negativism regarding the infallability and incompleteness of vendor offerings, one should not assume that a system that is not perfect has no value. I submit that a more practical and realistic position is to view the procured system as a software baseline, or foundation if you prefer, rather than the solution to all of your problems. This perspective offers you several alternatives. The application and prioritization of these alternatives may vary or be interchanged as situations and circumstances dictate.

Alternative 1 - Use the System as Procured and Accept Its Limitations. In spite of the system's shortcomings, often you will still be provided tools that are preferable to manual methods. The pressure of schedule and the limitation of time, money, and development resources make this option viable for short term solutions.

Alternative 2 - Enter Into an Agreement With Your Supplier to Provide a Fixed Amount of Development Resources. This agreement will be used to custom tailor his basic software offerings to your specifications. This allows the author of the code to use his expertise, minimizes the programmer learning period, and results in a more capable product. At the same time, the vendor is benefiting by having a more marketable product, an in-use computer base, and a development cost being defrayed by your participation.

Alternative 3 - Hire Outside Independent Software Developers. In spite of the promises these people normally make, they usually face the same basic problems that you do -- learning curves, etc. -- with the added problems of understanding neither your requirements nor the vendor's offerings in any level of detail. There are some companies that specialize in software for selected CAD systems, but this option can usually be dismissed out of hand unless the task is very well defined.

Alternative 4 - Acquire an Internal Development Capability. While this alternative usually appeals to one's basic desire to be an innovator, it must be recognized that the cost involved with training, managing and retaining a qualified staff capable of quality and timely software development of this specialized nature must never be underestimated.

IMPACTS OF ALTERNATIVE SELECTION

As previously mentioned, the use of a system with serious shortcomings may be workable on a temporary basis, but over time one can expect adverse effects. User enthusiasm and commitment to the system's success -- the two most important ingredients required -- will suffer. Software inefficiency and workarounds will also bring about procedural and management problems.

The use of outside software developers takes daily project oversight away from in-house control and tends to retard software integration. And by placing total reliance for support outside your company, you are also forfeiting any opportunity to gain a full and complete understanding of the capability of the system.

As a final word of caution, projects involving software systems of this size are usually very complex and expensive. The specification development becomes the primary tool for performance measurement and requires an inordinate amount of detail in order to assure that the system will satisfy all of your needs.

INGALLS ALTERNATIVES EXPERIENCE

At times, on different software projects, Ingalls has made use of all of the alternatives discussed. However, on the CAD/CAM project, the focus has been on combining the creation of an internal staff with the use of dedicated resources from the system vendor. These arrangements were part of the original procurement negotiations, which assisted in the forming of favorable terms, conditions, and rates. By combining these two techniques, Ingalls has used its vendor's experienced personnel as hands-on trainers and, at the same time, has made the Ingalls technical personnel more familiar with the proven techniques for development and testing that might not have been covered in a classroom environment with instruction by a professional trainer. This has also aided in the solution of continuity-of-personnel problems. With a small staff of people at the two facilities interfacing with each other, there has been less likelihood of an individual becoming the single expert in any field. Therefore, in instances where people have been lost through normal attrition, the impact on schedules and other commitments has been lessened. This approach has been successful at Ingalls, and I would encourage anyone considering entry into the CAD/CAM world to consider it.

TYPES OF SOFTWARE ISSUES

Acquisition and installation of CAD/CAM systems will present opportunities to deal with different types of software issues. One of these is system oriented software. The software's ability to allow orderly installation and testing of changes and/or new releases of operating systems in an orderly fashion is not unlike its counterpart requirement for mainframes in a general data processing shop. Also, one must recognize the need for management system concerns, such as workstation availability, workstation usage, data security, and database management. Let me point out now that no single CAD/CAM vendor, to my knowledge, has satisfactorily developed his offering to the point of adequately satisfying the requirements of the user community for all of these needs. Because of these shortcomings, it has been necessary for Ingalls to direct significant resources toward the development of such tools. This has not changed our view that this most lacking area of software capability is one of the most important.

Communication software, linking workstations to each other and to mainframes, should be considered by any potential user. Only recently have we been able to satisfactorily achieve a reliable communication link between the mainframe processors and all of the ringed workstations located throughout the shipyard. This experience provides an excellent example of dealing with software "futures". While it will always be true that there is a certain amount of risk involved in the acquisition of software, you are cautioned to assure yourself that enough of your mandatory system attributes are clearly specified so that meaningful and cost justified work efforts can take place upon system acceptance while these "futures" are still being developed and tested.

APPLICATION ISSUES

Application software is, without question, the paramount issue involved in the selection of a CAD system. Targets for application software functionality are cited in Figure 2. This is the issue that will produce the product, thereby determining the cost effectiveness of the system's usage. At Ingalls, design areas are specialized by discipline and customized software has been developed for each of them to make the user/software interface as efficient as possible.

These design disciplines are:

1. Structure
2. Heating, Ventilation, and Air Conditioning
3. Electrical

STAGE 1	STAGE 2	STAGE 3
FUNCTIONAL DESIGN	TRANSITION DESIGN	WORKING INSTRUCTIONS
SPECIFICATIONS REVIEW SCANTLING CALCULATIONS & PREPARATIONS LINE FAIRING C & A DEVELOPMENT (PRELIMINARY) KEY SPACE ARRANGEMENT SYSTEM CALCULATIONS & DIAGRAMS FINITE ELEMENT ANALYSIS DISTRIBUTIVE SYSTEMS ROUTING WELDING PLAN & STANDARD DETAILS MACHINERY PACKAGES TECHNICAL & PRELIMINARY DATA ADVANCE BILL OF MATERIALS INTERFERENCE CHECK	GRAND BLOCK/BLOCK MODEL BREAKDOWN MERGE FINAL STRUCTURE DEVELOP CONNECTING STRUCTURE & FOUNDATIONS DEVELOP FINAL EQUIPMENT DEVELOP DISTRIBUTIVE SYSTEMS FINALIZE MACHINERY PACKAGES PENETRATIONS INTERFERENCE CHECK FINALIZE TOTAL DESIGN ADVANCE BILL OF MATERIALS JOS & BACKUP STRUCTURE	DEVELOP STRUCTURAL FABRICATION PACKAGE DEVELOP STRUCTURAL INSTALLATION PACKAGE DEVELOP FINAL FABRICATION PACKAGE DEVELOP FINAL MACHINERY PACKAGE DEVELOP FINAL INSTALLATION PACKAGE

FIGURE 2 - APPLICATION SOFTWARE FUNCTIONS

4. Combat Systems Integration
5. Piping and Machinery

Although the product and the design techniques differ for each of these disciplines, software products for all of them have been developed using a common philosophy. And that is that the primary software product will be the 3-D design model. Figures 3 and 4 are examples of some of these models, and how they appear as created by the designer.

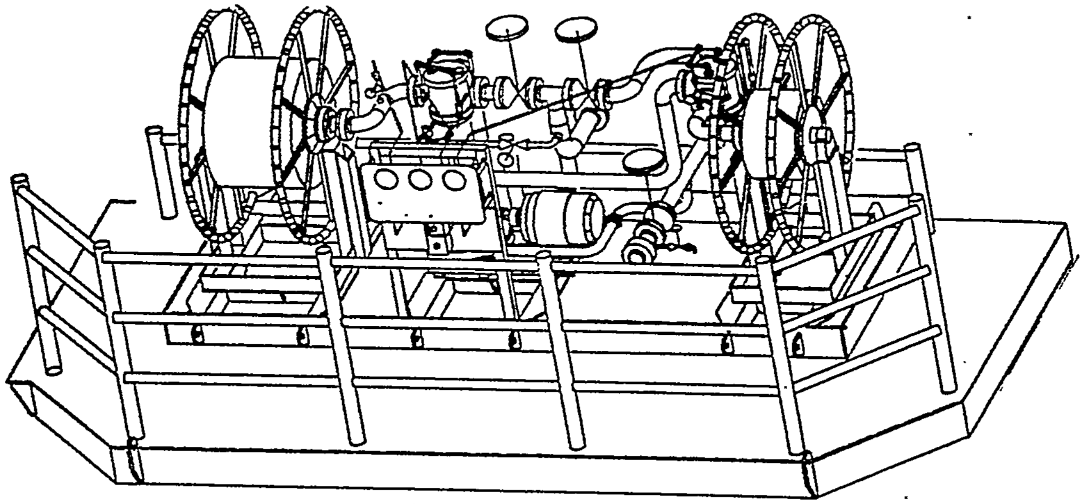

FIGURE 3 - TYPICAL 3-D MODEL

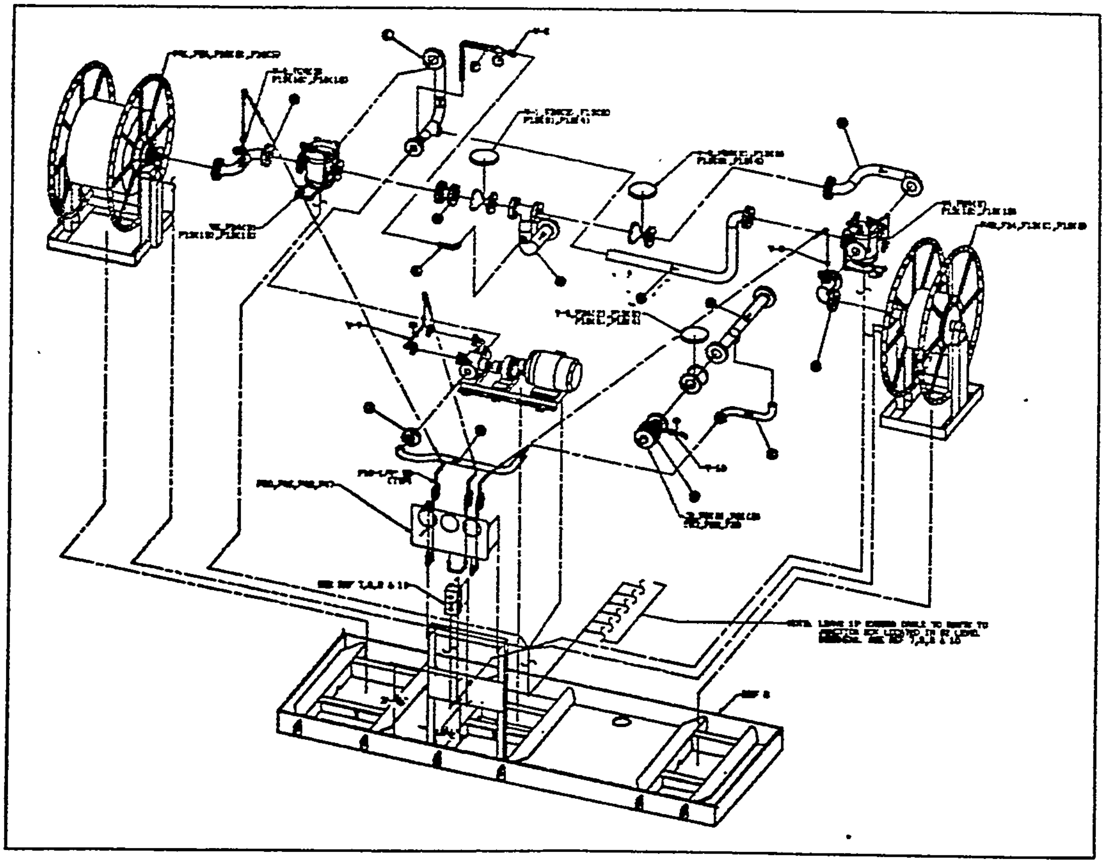

FIGURE 4 - TYPICAL 3-D MODEL (EXPLODED)

The special application software that has been developed for Ingalls has been designed to be totally external to the vendor's base product. The vehicle used for this development has been a language supplied by the vendor and intended exclusively for interfacing with the primary application routines. We have found that the vast majority of CAD systems have been developed to service the electronics industry, for printed circuit board design, or the petrochemical, aerospace, and automobile industries. Some similarities do exist between these industries and shipbuilding, but more often than not, we found that basic shipbuilding practices required capabilities not needed by our friends in the oil refineries. The reasons for these differences are readily understandable when we picture the contrasts in the design environment for space alone. Since much of the piping in the petrochemical industry is very large and located in an open area, general design practices tend to have very long runs of straight pipe and a high usage of standard fittings (usually 90 degrees). The limited space available in the ship's hull is occupied not only by the counterpart piping systems, but by the other design disciplines' products as well. This results in the need for higher incidents of direction changes and increased use of bent pipe as opposed to using fittings. The use of pipe bending not only reduces pipe fitting time and welding, but reduced weight, which is still another environmental difference.

Application software has also been developed to add rules for producibility to the design process. Sample piping product outputs are shown in Figures 5 and 6. Lengths of straight pipe between bends are validated against the pipe bending machine's capabilities, to ensure sufficient clamping room exists. Bend angles are verified against pipe lengths to make certain that the pipe extending from the machine will not contact the shop floor during bending. Other rules are continuing to be added as the need for them is identified, thus pointing out that the software expansion criteria is an ongoing concern.

The modeling concept has given the shipyard new tools which allow functions to be automated to a degree never before practical. Individual discipline models are merged in a master model which is then interference checked to prove that no component exists in the same space as another element. Savings from this

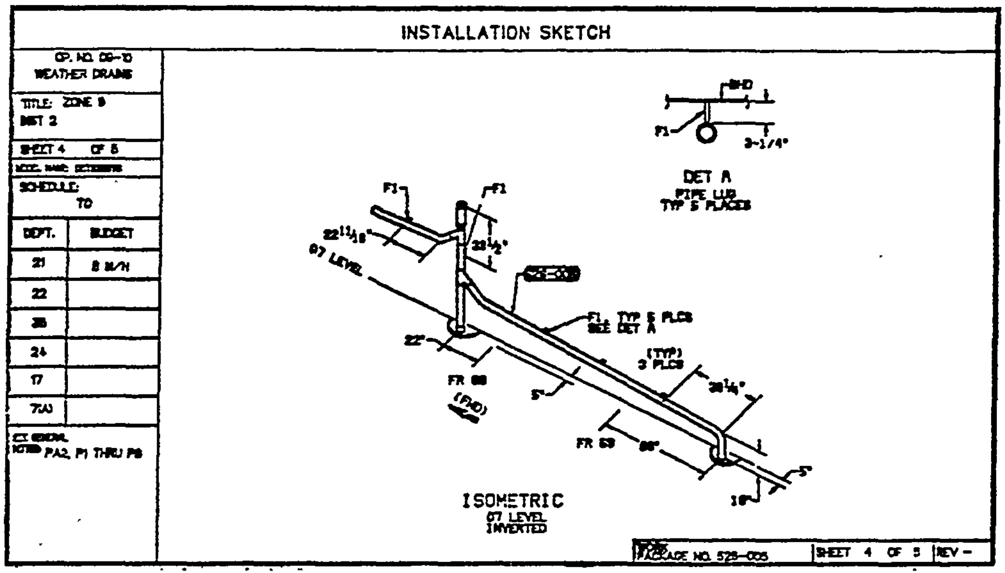

FIGURE 5 - TYPICAL PIPING MANUFACTURING DETAIL

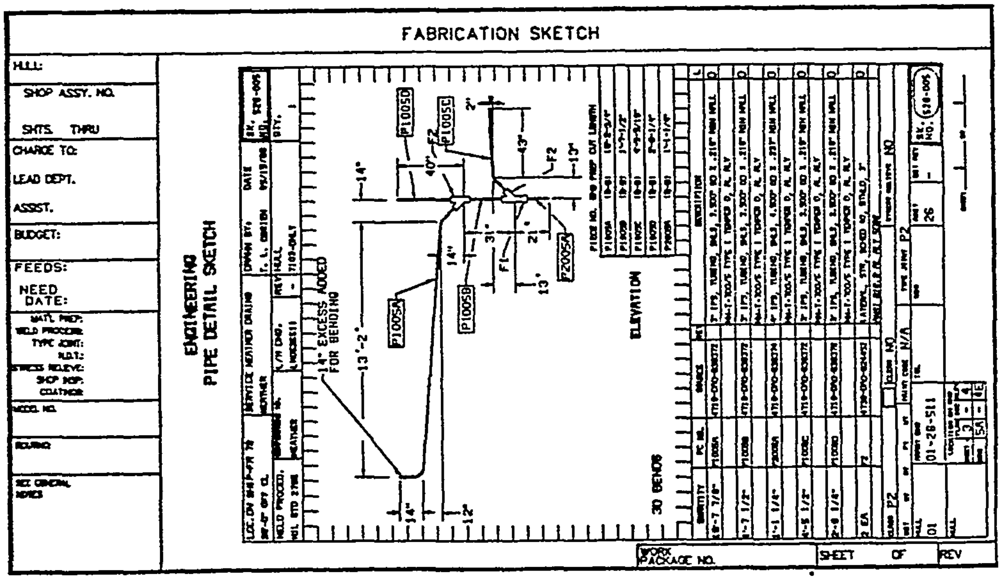

FIGURE 6 - TYPICAL PIPING INSTALLATION DETAIL

process alone may ultimately return the entire original investment when all design data is available in model form.

THE CAM IN CAD/CAM

The term CAD/CAM may be the industry catch phrase, but in most installations, the CAM part of the acronym mysteriously disappears. The main reason for the absence of CAM from most systems is simple; it never existed in the first place. Again, most of the system development in the CAD/CAM industry was pointed at a very narrow market segment. This led to systems that could do any form of manufacturing support you wanted, as long as it was done in APT.

Since only a very small portion of the computer aided manufacturing support at Ingalls involves machines which require APT generated instruction sets, it became incumbent on us to develop interfaces for numerically controlled machines in different manufacturing shops, many of which require different data structures and instruction sets. Pipe, sheet metal, plate steel and aluminum are all produced through the use of numerically controlled equipment. Because of the software facilities available to us, Ingalls has and is continuing to create manufacturing support interfaces that not only interface with data created in the design process, but do it in a fashion that eliminates much of the physical paper communication media which has existed for years.

The state of the integrated software art in CAM is significantly behind its CAD predecessor because of the priorities in software development. This is probably the correct order of precedence since without the data being generated as an integral design function, the cost of acquisition for manufacturing support alone distorts the true cost effectiveness. However, in the shipbuilding industry, CAM is where the money is!

THE SOFTWARE SEQUENCE

The correct sequence of events to assure success is sometimes misunderstood or misapplied. A suggested guide for software inclusions in a CAD/CAM system are included for your information and use.

1. The RFP and Specification - The most important elements in the process. Take the time and spend the effort to insure that the software you buy will do the job -- the way you want it done.

2. Benchmark and Evaluation - This is the first opportunity available to rule out gross shortcomings of capability and to determine the efficiency of the software as well as its functionality. Efficiency should not only include timings of performance, but should consider things such as complexity and ease of use.

3. Installation and Acceptance - These issues are particularly critical because they provide the last major levers at your disposal to get everything you're paying for in the basic system procurement. Once acceptance is established, the next software activity is likely to cost you additional money.

4. Training and Usage - Be certain that your implementation plan not only provides for training for applications software, but for all other types of software as well. The need for system management, system support, and error detection and correction software must be recognized and dealt with as an integral part of installation -- not as an afterthought.

5. Maintenance and Updates - Establish a firm vehicle to communicate with your supplier all forms of problems. Determine not only how to report them, but how to classify them with respect to responsibility for action, priority, and expected resolution time.

Understand the impact of such items as new software releases with regard to ongoing work commitments and the requirement on your part to properly install and test it prior to making it available to the user, who cares less about software, except when it fails.

THE CAD/CAM SOFTWARE FUTURE AT INGALLS

Software development and procurement at Ingalls will proceed at the rate of, and in conjunction with, the quantities and types of ships that comprise our business base. In the event that we are successful in acquiring work requiring a high incidence of design activity, major emphasis will be placed on improving the cost effectiveness of the workstation/user interface in order to gain more correct and more complete data from which downstream functions can gain.

However, if contracts are primarily of a construction nature utilizing designs which have previously been done by Ingalls or by another lead yard, the obvious need is to develop means by which existing data can be more effective in planning and in operational tasks.

Ingalls will continue to place high emphasis on software that deals with database management and communications. We realize that our experience to date is still extremely limited when compared to the task we see before us and data and configuration management features will require much improvement before we can consider them adequate.

We will continue to try to influence vendors, both our primary vendor and the industry in general, to develop software that can be somewhat generic in nature. We will work with the Navy, software suppliers, and the National Bureau of Standards on the future development of the Initial Graphics Exchange Specification (IGES) and its expected successor, Product Data Exchange Specification (PDES).

We hope that this information relates to your problems and plans and that it serves to provide a means to avoid some of the pitfalls inherent in the acquisition of the heart of any CAD/CAM system -- software.

THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
601 Pavonia Avenue, Jersey City, NJ 07306
Paper presented at the NSRP 1987 Ship Production Symposium, Hyatt Regency Hotel, New Orleans, Louisiana, August 26-28, 1987

A Low Toxicity Insulation Material for Shipboard Piping—Non-Halogenated Polyphosphazene Foam

No. 23

O.J. Davis, Visitor, Litton Systems, Inc., Ingalls Shipbuilding Division, Pascagoula, MS

ABSTRACT

A flexible, fire retardant, chlorine-free polymer foam with applications to pipe insulation has been tested for ship producibility. The new material, Non-Halogenated Phosphazene (NHP) foam, is based on Phosphorus-Nitrogen linkages (Phosphazene) with non-halogenated organic groups attached to produce selected engineering properties. The material tested is flexible, fire retardant, and produces less toxic combustion products than conventional plastic pipe insulation material.

Producibility tests have demonstrated the new material to be equivalent in handling characteristics to conventional material which uses PolyVinyl Chloride in its formulation.

The use of the new pipe insulation offers a prospect of removing over 1,400 pounds of elemental Chlorine from some surface ships now in production. Removal of Chlorine is in keeping with the objective of producing ships with improved fire protection and safety.

BACKGROUND - ORIGIN OF NON-HALOGENATED PHOSPHAZENE

The degeneration of Halogenated hydrocarbons such as Vinyl Chloride to toxic and corrosive products when burned makes elimination of Chlorine- and Fluorine-containing elastomers from ships a worthwhile objective. Replacement of such compounds with Non-Halogenated and more flame resistant materials has been recognized as a means of enhancing personnel safety and improving the passive fire protection status of ships.

Research in this area has resulted in technology which provides alternatives to the use of Chlorine to form strong, stable bonds with Carbon, Nitrogen, Oxygen, and Hydrogen in elastomers. From that background, a new family of compounds known as Poly-Phosphazenes, which utilize the Phosphorus=Nitrogen bond (P=N) as an inorganic basis for flexible long chain polymers, has been developed. These compounds exhibit a number of useful properties, including low temperature flexibility, good flex-fatigue, sound dampening, flame resistance, low smoke production, and resistance to oil, in addition to greatly reducing toxic gas emissions.

DEVELOPMENT OF NON-HALOGENATED PHOSPHAZENE (NHP) FOAM AS AN INSULATION MATERIAL

One form of the chemical family, Polyaryloxy Phosphazene, has been demonstrated to be producible as low density, closed cell foam. The product is now in production by at least one U.S. producer as foamed slabs and tubing. It exhibits the properties described above, as well as low thermal conductivity and low toxicity of pyrolysis products. The acronym, NHP, will be used to refer to the Non-Halogenated Polyphosphazene foam used to generate data on which this report is based.

The production of NHP as a foamed elastomer in tubes suitable for pipe insulation and in sheets for general insulation has reinforced shipyard interest in Chlorine-free sound dampeners and insulations because the combinations of low moisture absorption, low smoke, and low fume toxicity offer distinct advantages for both surface ships and submarine applications.

FUME AND TOXICITY TESTING

Flame and fume toxicity testing of Phosphazene compounds has been performed at the University of Pittsburgh, Graduate School of Public Health, and the Department of Metallurgical and Materials Engineering; test results have been published by Lieu, Magill, and Alarie [1]. In that study, the LC50 for laboratory animals was compared with the LC50 of Douglas Fir. The LC50 for the Non-Halogenated foam was 21 grams; for the wood, the value was 37 grams. The LC50 is the sample loading which provides a concentration of thermal degradation products resulting in 50%

mortality of test animals under the test conditions. In practical terms, the toxicity products from the Non-Chlorinated foam were determined to be similar to the irritating effects of the smoke and fumes produced by burning a common specie of wood. Alarie and co-workers estimated that smoke and fumes from Poly-Vinyl Chloride rubber products are approximately ten times more toxic than Poly-Phosphazene [2]. Another study involving human exposure concluded that tolerable levels of respiratory or lachrymal (tears) distress are produced by brief human exposure to Poly-Phosphazene smoke [3]. Reduced to practice in terms of ship safety, this means that significantly longer times may be made available for fire-fighting personnel to gain control of a fire in or adjacent to a compartment which contains Non-Chlorinated Polyphosphazene foam insulation rather than Poly-Vinyl Chloride foam. In contrast, a fire in a compartment with PVC insulation can be expected to emit toxic levels of Chlorine and Chlorinated gasses.

Further indication of tow toxicity of pyrolized Non-Halogenated foam relative to currently used PVC-Nitrile foam is shown in published data and in independent tests.

Comparative tests of NHP and PVC insulation reported show the following typical values:

	Eypel$^{\text{tm}}$ A (NHP)	Typical MIL-P-15280 (PVC)
Acid Gas Generation (mg HydroChlorine Acid/gm per MIL-C-24640)	0	70
Halogen Content, % by weight	< 0.2	> 14

SHIPYARD TESTING OF THERMAL STABILITY, CHLORINE GAS EMISSION AND SMOKE

Under normal conditions, the Chlorine in conventional insulation is securely bonded chemically within the Hydrocarbon molecules; however, when heated, the molecules pyrolize, break down, produce smoke, and release toxic fumes, including Chlorine gasses and potentially corrosive solids as smoke particles and ash. The Chlorine combines readily with moisture in the atmosphere to form Hydrochloric (HCL) acid gas. Laboratory measurements were made to determine the actual temperature at which a sample of conventional PVC/Nitrile insulation material would just start to pyrolize and emit Chlorine and Hydrochloric acid gas without direct flame on the material. To make this measurement, a 6"x6" piece of 1/2" thick aluminum plate was drilled from the edge to receive a laboratory thermometer. A 1"x1"x3/4" piece of insulation was placed on the plate, and to concentrate the fumes, a pyrex funnel was inverted over the sample. A Bunsen flame was placed under the plate and the plate was heated until the sample began to decompose. Flame was prevented from making direct contact with the sample. Emissions from the outlet of the inverted funnel were aspirated into a 2-20 PPM Hitagawa 1095B "Hydrogen Chloride Length-of-Stain Detector Tube". Several repetitions were made to determine that the starting temperature for the emission of HCL acid from the PVC/Nitrile foam was 335 degrees C (635 degrees F). Emission of black smoke, even without impingement of flame, began at the same time that Chlorine was detected.

Chlorine is present at one step of processing of NHP foam, and for that reason, the test was repeated for an equivalent NHP foam sample. A light trace of smoke was observed at 350 degrees C, but no residual Chlorine was detected up to and including 355 degrees C (671 degrees F). The test was stopped at that temperature to prevent damage to the lab equipment. Further efforts to force detectable levels of Chlorine gas out of the Phosphazene foam by direct application of the flame also failed to produce an indication on the Hitagawa Test Tubes.

The presence of a high percentage of Chlorine content in the conventional foam sample and the absence of Chlorine in the Phosphazene was further demonstrated by the classical Bielstein test. A Copper wire was heated in the Bunsen flame. The hot Copper wire was rubbed on the sample to produce and pick-up pyrolysis products. The contaminated Copper wire was then transferred directly into the Bunsen flame. A green fluorescence in the flame would indicate the presence of Chloride. The PVC/Nitrile material produced a bright green color, as expected, since Poly-

Vinyl Chlorine is a major component of the material. On the other hand, the NHP sample did not produce any detectable green color in the flame, indicating very low or no Chlorine present.

FIRE RETARDANCY OF NHP FOAM

Direct flame was then applied to both materials using an Oxygen-rich acetylene flame to make a visual comparison of the flaming, smoke producing, and charring properties of both types of insulation.

Both materials produced observable secondary combustion with yellow flame and black smoke. The PVC/Nitrile sample of conventional insulation flamed much more vigorously and produced much more black smoke than the NHP foam. Both materials were self-quenching when the flame was removed, and both produced charring and black powder residue to about the same extent. Neither sample showed any tendency to melt and drop hot or burning plastic, as would occur with a thermoplastic polymer such as Polyethylene foam.

The relatively greater flaming and flaring of the PVC is clearly seen when a Bunsen burner flame is applied directly to foam samples. The PVC foam reaction is distinctly exothermic, and supports the spread of combustion, whereas the Poly-Phosphazene is slower to flame, and then produces only slight initial exothermic heat, becoming non-contributing to the fire.

Flame retardant properties of Poly-Phosphazene were found to be superior to conventional insulation in the National Bureau of Standards Quarter Scale Test. This test method was developed to test flame and heat propagation characteristics of candidate coatings and insulation for ship compartments. In this test, a steel box is lined with test material and a methane burner is ignited in one corner of the box. Time after ignition to flash-over of combustible emissions from insulation is measured, and smoke generation is observed. In the test performed by Mueller, Arroyane and Associates [3] PVC/Nitrile foam flashed over quickly with a 640 BTU/minute Methane flame [3]. Paper placed on the floor of the box, which was two feet high, ignited from the heat of the chamber and flames flared out of the transom of the "door" of the box.

The Poly-Phosphazene did show initial combustion of some volatile emissions, but stabilized in about one minute, after which time flame did not spread beyond the direct path of the Methane burner in the corner of the box. The NHP foam did not support combustion. After the ten minute duration of the test, the thermocouple mounted on top of the box recorded a maximum temperature of 131 degrees F (55 degrees C) [3]. A video tape of the PVC foam and NHP foam Quarter Scale Test was made, and is available.

HANDLING CHARACTERISTICS AND SHIPYARD PRODUCIBILITY

In order to test for producibility, an eight foot section of the 2" NPS Copper pipe was used in the Ingalls shop as a mock-up of production pipe. Both standard and the new materials were used to insulate the pipe, using standard shipyard processes.

Insulation of a Typical Pipe

One segment of Copper pipe was insulated using standard tubular PVC/Nitrile and two other segments of pipe were insulated with NHP foam. One pipe segment was insulated with tubular NHP material, and the other used 1/2" thick flat sheet formed around the pipe. After wrapping around the pipe, the slitted edges of the insulation were bonded together. The adhesive used for both materials was the standard solvent-based MIL-A-3316 which is normally used for this purpose. The adhesive bonds were verified as acceptable by tensile loading across the bonded seams to failure. In both types of material, the failures always occurred as base material tearing rather than adhesive failure of the bonded joint.

During cutting and trimming of the two types of foam, it was observed that both materials were subject to tearing on the edges if sharp edges on cutting tools were not maintained. The NHP foam was slightly more susceptible to tearing than the PVC foam.

Repairability Test

Repairability was considered an important producibility factor because of the need for occasional partial rip-out for repairs to piping. Because of the relatively low tensile strength of both types of material tested, comparisons of repairability were made by ripping and then patching tears over 3" long in both materials.

The tears were made through the thickness of the material, and patched with the same adhesive used to join sections in production. The adhesive used is quick curing, and repair is performed very quickly. The insulation craftsman reported that there is no difference in repairability of NHP and PVC insulation material.

Typical tensile strength of the NHP appears to be somewhat less than the PVC; however, both materials are subject to tearing. For that reason, it is standard practice to apply a protective lagging of glass cloth over insulation in the way of heavy traffic and in all areas where personnel and hardware are likely to cause damage. For that reason, response of the new material to lagging procedures and materials was also tested.

Installation of Standard Lagging Materials

Subsequent to cutting, fitting, and installing the two types of insulation on the Copper pipe, both test areas were wrapped with the standard lagging materials -- MIL-C-20079 glass cloth, and impregnated with MIL-A-3316 water-based sizing compound. The lagging material is from Vimasco Corporation of Nitro, West Virginia. According to the insulation craftsmen who performed the installation, there was no significant difference in handling characteristics and response of the NHP relative to the lagging materials and application.

No effort was made to fabricate an irregularly shaped covering as would be needed for a valve; however, it can be inferred that the workability of the flat 1/2" thick Poly-Phosphazene foam sheets applied to pipe would be equally applicable to valve bodies or other components, and no producibility problems would be expected.

COMPARISON OF NHP FOAM WITH OTHER INSULATION MATERIAL

Other important physical properties compared indicate that the new Non-Chlorinated foam is equal to or better than the PVC/Nitrile elastomer now generally used for pipe insulation. For example:

Property	NHP Test Result/Comparison
Density	4.5 lbs/ft^3 (density can be controlled by cell size) material
Compression Set	equal to PVC foam
Thermal Conductivity	equal to PVC foam
R Value	equal to PVC foam

The availability of equivalent Non-Halogenated insulation materials other than Phosphazene has been considered. Technically, foamed Polyimide and Silicone compounds could become candidate materials to replace PVC foam for ship piping insulation. However, the available information indicates that Polyimide and Phosphazene are close together in cost, but that Polyimide is an open cell foam which retains water. The NHP has already been produced and tested in both sheet and tubular form. Polyimide foam has not been demonstrated producible in flexible tubular foam for pipe and valve insulation; the Silicone-based material is expected to be more costly than either Polyimide or Poly-Phosphazene.

WATER RETENTION OF INSULATION MATERIALS

Three basic types of material are generally used to insulate piping for cold liquids and gasses in surface combat ships; open cell foam, closed cell foam, and fibrous materials.

When all other factors are equal, closed cell insulation materials for shipboard piping offer the advantage that it will not absorb and retain a significant amount of water. Retention of water adversely affects two important properties -- density and thermal conductivity. Several currently used insulation materials were tested for tendency to absorb, to drain, and to retain water. Four materials were compared: PVC-Nitrile (closed cell), Non-Halogenated Phosphazene (closed cell), Polyimide Foam (open cell), and layered glass fiber batting.

Samples of the tested materials were tare weighted on a lab balance and then subjected to water droplets impinging on cut edges. The droplets were applied at a rate of approximately one per second for thirty minutes. The PVC-Nitrile and the NHP did not produce a significant weight increase. A three cubic inch sample of Polyimide foam increased its weight by 296%; the 4.5 cubic inch glass fiber batt increased its weight by 278%. Note that the dry glass had a density twice that of dry polyimide and absorbed about twice as much water under the similar conditions.

A worst case test of water absorption and retention was performed by immersing the four samples in water for one hour. The samples were hung in air and allowed to drain for 16 hours, then reweighed. As seen in the table below, the PVC-Nitrile and NHP foam retained no water. The glass batt and the polyimide foam retained the equivalent of 7.44 and 14.88 pounds per cubic foot, respectively, even after 16 hours of hanging in the air to drain.

WATER RETENTION TEST OF SEVERAL
COMMONLY USED INSULATION MATERIALS

Material	Sample Size	Tare Weight (gm)	Weight After Immersion (gr)	Weight After 16 Hour Drain (gm)	Wt/ft^3 (Increase)
Glass Fiber Batting	1-1/2"x1-1/2"x 2"	1.4	22.9	18.9	14.8 lbs/ft3
Polyimide Foam	1-1/4"x3-1/4"x 3/4"	0.6	9.4	9.4	7.44 lbs/ft3
PVC-Nitrile	3-1/2"x1-1/2"x 3/4"	4.2	4.4	4.2	0
NHP	6-1/2"x2"x1/2"	8.6	8.9	8.6	0

COST FACTORS

Details of comparative costs of NHP versus conventional pipe insulation are not available at the time of this writing. The producibility exercise described above indicates that labor costs to install would be essentially the same for NHP as for PVC-Nitrile. Initial cost of the NHP material would likely be greater than for PVC-Nitrile and to maintain cost equivalence, innovative methods of reducing labor cost to install are being evaluated. One approach being considered is the use of an easily installed, removable protective outer jacket to replace the manually applied lagging materials. One such material has been tested for resistance to damage from hot welding slag and found to be equal to or better than conventional lagging. The reduction in labor using a locking closure insulation shield would be greater than 50% and would also reduce scrap, since removed insulation could be easily reinstalled after repairs.

QUANTITY OF CHLORINE REMOVAL

An estimate of potential for Chlorine removal is given below. The estimate is based on (1) nominal density, (2) percent by weight of Chlorine in PVC-Nitrile and (3) typical quantities of hot and cold water pipe insulation used in today's surface ships. The density of PVC-Nitrile is over 4 lbs/cu.ft., Chlorine percent by weight is 14%, and today's surface ships typically use over 1,000 pounds of such insulation per thousand tons of displacement. Therefore, for a 10,000 ton ship, a conservative estimate of potential yield of Chlorine from fire is over 1,400 pounds as elemental Chlorine gas. If combined with atmospheric moisture to form $HCl.H_2O$ gas, the quantity of gas is significantly greater than 1,400 pounds by weight.

JUSTIFICATION FOR USE - SHIP SURVIVABILITY

The principal justification for consideration of non-chlorinated insulation for ships is found in the increased effectiveness of active and passive fire protection afforded by the new material. Flame retardancy tests and flashover tests show that PVC foam flashes over in a few minutes, allows much more rapid spread of fire, and produces more smoke than NHP foam.

CONCLUSION

A new, flexible NHP foam insulation material for piping has been tested at Ingalls. The material, Non-Halogenated Phosphazene foam, does not support combustion, produces less smoke, and, unlike PVC/Nitrile insulation, does not emit toxic Chlorine gasses when heated. The material has been shipyard tested and meets insulation requirement of MIL-P-15280H, and producibility requirements for shipyard insulation of water piping systems.

The new material provides a potential for removal of over 1,400 pounds of elemental Chlorine from a 10,000 ton ship and proportional amounts for other ships.

The material is currently being evaluated for use on hot and cold water systems on surface ships.

ACKNOWLEDGEMENT

The late Mr. Michael McGowan is recognized and appreciatd for his contribution to this project. Mr. McGowan initiated the project while a member of the Ingalls Advanced Technology Group under the Independent Research and Development program prior to joining the Alcoa Research and Development Center. He was a productive and dedicated researcher, and was responsible for numerous contributions to improvements in ship safety.

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Overcoating Inorganic Zinc Primers for Underwater Service

No. 25

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ABSTRACT

During ship construction, steel hull plate is normally protected with an inorganic zinc pre-construction primer. For the underwater portion of the hull, conventional practice is to remove the primer by abrasive blasting before final coating of the hull. If the requirement for removing the pre-construction primer could be eliminated, there would be a significant cost savings. As a result, a laboratory study was undertaken to investigate the performance of selected marine coatings when applied over inorganic zinc primers in underwater service. In general, the results of the study suggest that there are inorganic zinc pre-construction primers that can be overcoated for underwater service. The results encourage further tests to investigate the parameters affecting compatibility.

INTRODUCTION

In new ship construction, the structural steel plate used to fabricate the hull is often protected with an inorganic zinc pre-construction primer. The pre-construction primer provides corrosion protection to the steel during fabrication. After fabrication, the general practice in U.S. shipyards has been to remove the pre-construction primer on the underwater portion of the hull before application of any subsequent coats. This is done to eliminate blistering and disbondment of the topcoat which reportedly can occur when inorganic zinc coatings are overcoated in underwater service (1), (2), (3), (4).

Japanese shipyards are overcoating inorganic zinc pre-construction primers on the underwater portion of the hull. Reportedly, the Japanese are able to overcoat without problems because they are using pre-construction primers that have very low zinc levels and are less reactive, with less of a tendency to liberate hydrogen gas when contacted by water. The lower zinc levels do not provide comparable corrosion protection to those traditionally used in U.S. yards. However, the turn-around time for steel plate fabrication in the Japanese yards is supposedly lower then in U.S. yards (2-3 months vs. 6-9 months), and thus it is believed the additional corrosion protection is unnecessary.

Based on the reported practice in the Japanese shipyards, a study was undertaken whose objectives were as follows:

- To determine whether it is necessary, for underwater marine service, to remove inorganic zinc pre-construction primers by abrasive blasting prior to the application of subsequent coatings.
- To compare the propensity of different inorganic zinc primers (pre-construction vs. full-coat) to cause topcoat blistering in underwater service.
- To evaluate the effect of different inorganic zinc primer weathering periods on topcoat blistering susceptibility.
- To determine to what extent cathodic protection will affect the performance of coatings applied over inorganic zinc primers.

EXPERIMENTAL APPROACH

General Test Plan

The general test plan comprised the evaluation of three different epoxy topcoats over each of five inorganic zinc primers. Prepared test panels were exposed to three different test environments: (1) quiescent seawater immersion at a potential of -1.0 volt vs. SCE, (2) quiescent seawater immersion at 150°F, 25 psi, and (3) flowing seawater at 18 knots.

Coatings Selected For Testing

Table I describes each of the five inorganic zinc primers selected for testing. The test matrix included three pre-construction primers and two full-coat systems, among which was a Japanese pre-construction primer.

Table II describes the topcoats included in the test program -- a coal tar epoxy, a MIL-P-23236 epoxy, and a MIL-P-24441 epoxy. The coal-tar epoxy was included as a benchmark because of its wide use on the underwater portion of ship hulls. The MIL-P-23236 coating was selected because it is recommended as a tank coating over inorganic zinc primers. The MIL-P-24441 coating system was included since it is the standard U.S. Navy underwater hull coating.

Test Panel Preparation

The inorganic zinc primers were applied to ASTM A-366 steel panels, white-metal blasted to obtain a surface profile between 1-2 mils. The nominal panel dimensions were 6" x 12" x 1/8" thick for quiescent immersion testing and 5 1/4" x 7 1/2" x 1/2" thick for flow testing.

The inorganic zinc primers were applied by airless spray using an automated application system designed to provide close control of applied film thickness. The system utilized a fixed spray gun with apparatus for moving the test panel by the spray gun nozzle at a controlled speed. After coating, the

Table I

GENERAL DESCRIPTION OF INORGANIC ZINC PRIMERS SELECTED FOR TESTING

Coating No.	Description
1	U.S. manufactured, single component, alkyl silicate type shop primer, 35% zinc in the dry film, recommended dry film thickness = 0.6 - 1.0 mil.
2	U.S. manufactured, 2-component, modified zinc silicate shop primer, 86% zinc in the dry film, recommended dry film thickness = 0.6 - 1.0 mil.
3	Japanese manufactured, 2-component shop primer, 50% zinc in the dry film, recommended dry film thickness = 0.5 - 0.7 mil.
4	U.S. manufactured, 2-component, full-coat primer, 60% zinc in the dry film, recommended dry film thickness = 3.0 mils.
5	U.S. manufactured, 2-component, full-coat primer, 85% zinc in the dry film, recommended dry film thickness = 2.0 mils.

Table II

GENERAL DESCRIPTION OF TOPCOATS SELECTED FOR TESTING

Coating No.	Description
1	Two-component, polyamide-cured high-build coal-tar epoxy, 67% volume solids, recommended application thickness = 5 mils (DFT)/coat.
2	Two-component, polyamide-cured epoxy, 56% volume solids, recommended application thickness = 5 mils (DFT)/coat. Meets MIL-P-23236, Type 1, Class 1.
3	Two-component, polyamide-cured epoxy, recommended application thickness = 2-3 mils (DFT)/coat. Standard U.S. Navy underwater hull coating meeting MIL-P-24441, Type 1.

dry film thickness on all test panels was determined using an Elcometer magnetic thickness gauge. The average dry film coating thicknesses of the respective inorganic zinc primers were as follows:

Primer #1 - 1.0 mil

Primer #2 - 0.7 mil

Primer #3 - 0.8 mil

Primer #4 - 4.2 mils

Primer #5 - 2.1 mils

After application of the zinc primers, all test panels were weathered on the test fences at the Ocean City Research Corporation marine exposure test site. This test site provides a natural marine atmosphere and is located approximately 300 feet from the ocean. In order to evaluate the effect of different weathering times, one-half of the test panels were exposed for 7 days and the other half for a period of 60 days. After weathering, all test panels were lightly sanded with 600 grit silicon carbide paper to remove any zinc corrosion product (white rust).

After sanding, the test panels were topcoated with one of the three epoxy topcoats. The topcoat systems were applied in accordance with manufacturer's directions using hand-controlled airless spray equipment. After coating, all panels were inspected for "holidays" using a wet-sponge, 67.5 volt holiday detector. All holidays were suitably repaired. The panels were allowed to cure for 10 days before being placed into test.

After topcoating, the dry film thickness of all panels was again determined using the same equipment as described previously. The average dry film coating thicknesses of the respective topcoat systems were as follows:

Coal-tar epoxy - 9.6 mils (applied in 2 coats)

MIL-P-23236 - 11.0 mils (applied in 2 coats)

MIL-P-24441 - 9.2 mils (applied in 3 coats)

During application of the topcoats, some blistering problems were encountered. Depending on the particular primer over which the topcoat was being applied, small blisters or pinholes developed almost immediately after topcoating. This problem occurred even with the application, first, of a thin mist coat (0.25 to 0.5 mil) which was allowed to tack up before applying the full coat. The problem was most evident on zinc primers #4 and #5, the two full-coat inorganic zincs included in the program. Little or no blistering was observed over the thinner pre-construction primers. Those test panels where pinholing occurred during topcoating were lightly sanded and then recoated with a thin topcoat to seal the pinholes.

As an experimental benchmark, the respective topcoats were also applied to white-metal blasted steel test panels. No application problems were encountered on these test panels.

Duplicate test panels of each coating system were prepared for each of the seawater immersion exposure tests. For the flow test, single panels were prepared. The total number of test panels prepared for exposure testing was 165.

Performance Testing

Three different types of exposure test were conducted in the study to evaluate the performance of the selected topcoats applied over the different inorganic zinc primers. These tests included: (1) quiescent seawater immersion at a potential of -1.0 volt vs. SCE (2) quiescent seawater immersion at 25 psi, 150°F and (3) seawater flow at 18 knots.

Seawater Flow at 18 Knots. The natural seawater flow channel permits velocity testing under flow conditions that are reasonably representative of the flow conditions that would exist over a major portion of a ship's hull--fully developed parallel, turbulent, high Reynolds Number, seawater flow. The flow channel accommodates test panels large enough to minimize edge and/or boundary effects. The width of the channel cross section varies along the length permitting testing at different flow velocities simultaneously. Figure 1 shows the flow channel while Figure 2 shows the method by which test panels are typically mounted in the flow channel.

Seawater flow through the channel is accomplished using a double-suction centrifugal pump powered by a 100 HP motor. The flow rate exceeds 5,000 gpm and is measured using a calibrated 316 stainless steel orifice plate/differential pressure gauge set-up. The rate of seawater make-up into the channel can be adjusted to control seawater temperature to within ± 4.5°F and is maintained sufficiently high to avoid stagnation or concentration effects.

A single test panel (5 1/4" x 7 1/2" x 1/2" thick) for each weathering/primer/topcoat condition was exposed in

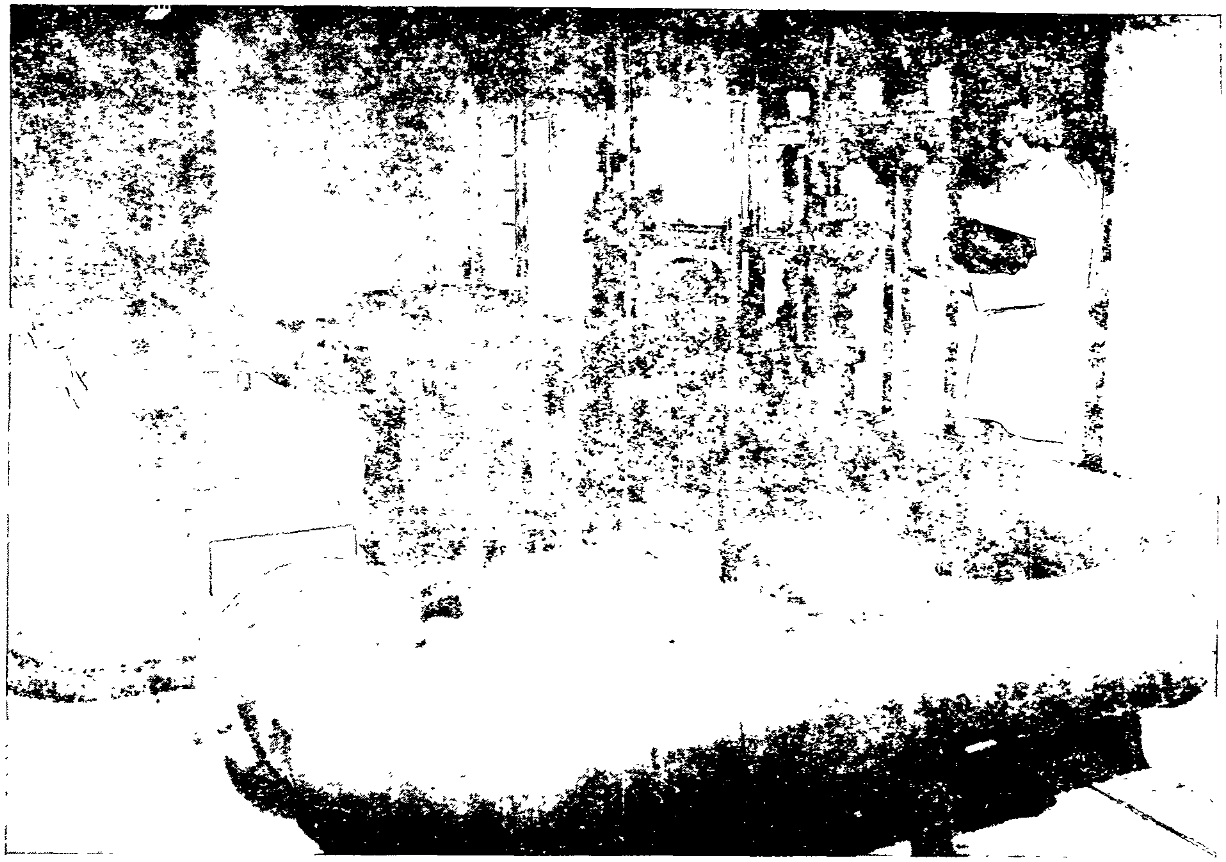

Figure 1 - Flow Channel

a natural seawater flow channel for a period of 60 days at a velocity of 18 knots. Both sides of each panel were scribed at the center (1" vertical scribe) with a razor knife. In this way, each side of the panel represented a duplicate exposure.

After the first 30 days of test, the intentional scribe on those panels not evidencing any significant failure (disbondment area $\leq$ 1 in^2) was modified. The original 1" vertical razor scribe was widened to 1" x 1/4" rectangular holiday. All zinc primer within the holiday area was removed to expose bare steel. Coatings which had disbonded over 1 in^2 were recoated with a MIL-P-24441 epoxy and left in test without a scribe.

Quiescent Seawater Immersion @-1.0 volt. Duplicate test panels (6" x 12" x 1/8" thick) for each weathering/primer/topcoat condition were suspended in 100-gallon plastic tanks filled with fresh seawater. The seawater tanks were continually refreshed at a rate sufficient to effect a complete changeover 3 times a day. The seawater temperature was maintained at 70°F.

A lead wire was attached to each test panel facilitating electrical connection to a zinc anode. Electrical coupling to a zinc anode maintained the test panels at a potential of -1.0 volt versus a saturated calomel electrode. Prior to the start of test, each test panel received a 1/4" radial holiday directly in the center of one side. The test duration was 6 months.

Quiescent Seawater Immersion @ 25 psi, 150°F. Duplicate test panels were immersed in seawater maintained at 25 psi, 150°F. Each test panel had a 1" vertical scribe centered on one side. The panels were mounted in PVC racks. The racks were then inserted into a 12-inch diameter PVC pipe which served as the test chamber. A pump provided seawater make-up while maintaining a positive pressure of 25 psi inside the pipe . The make-up flow was sufficient to effect a complete changeover once a day. The temperature was controlled at 150°F with two thermosensors immersed in the test chamber which were electrically coupled through an appropriate temperature controller to a nichrome heating element wrapped around a titanium tube in the seawater supply line. The seawater was constantly circulated through the heating tube to maintain temperature. The test duration was 6

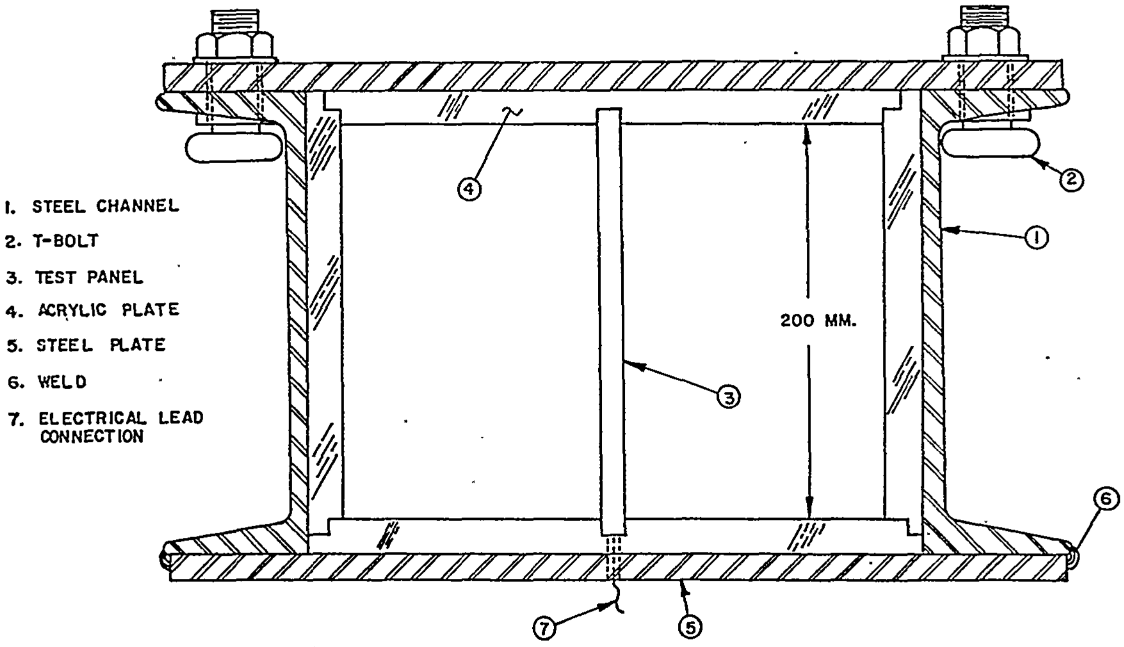

Figure 2 - Typical Test Panel Arrangement in the Flow Channel

months.

Inspection/Evaluation Procedures

During the course of each of the three exposure tests, the test panels were periodically removed, visually inspected, and rated for blistering, disbondment, and/or other forms of deterioration. At the conclusion of each test, the total extent of coating disbondment was determined by lifting all loose or disbonded coating with the point of a knife.

RESULTS AND DISCUSSION

Weathering of Inorganic Zinc Primers Before Topcoating

Visual inspection of the inorganic zinc primed panels after the two different weathering exposures (7 days, 60 days) showed significant differences on only one primer (#1). For system #1, the panels exposed for 60 days exhibited extensive rust-through while those exposed for only 7 days showed no evidence of rust-through. Of the three pre-construction primers, primer #1 had the lowest zinc loading in the dry film based on the manufacturers' specifications.

For the other four inorganic zinc primers, there were only slight, visually detectable differences between the 7-day and 60-day panels, with the 60-day panels exhibiting slightly more corrosion product (white rust).

Seawater Flow Test

There were 16 separate instances where significant disbondment (greater than 1 in^2) occurred during the 60-day test. Of these, 6 occurred within the first 24 hours after start-up and 15 occurred within the first 30 days. Of the 13 test panels that exhibited disbondment failure during the test, failure on both sides occurred on only 3 test panels. Analysis of these results at 30 days raised concern about the seemingly poor replication. It was felt at this time that there might have been differences traceable to the knife-cut scribe initially made at the center on each side of each panel. All disbondment failures had initiated at the scribe. Thus, at this point, the intentional holiday was expanded from a knife-cut scribe to a 1" x 1/4" rectangular window which was felt would provide more uniformity. However, the lack of further failures (excepting the control) during the latter 30 days of the test precluded obtaining any further insight regarding this concern.

Where the topcoats did disbond, there was extensive rusting of the substrate (Figure 3). This observation suggests that the zinc primers tend to sacrifice rapidly once exposed to flowing seawater. Furthermore, it suggests that, at scribes or holidays, topcoats may be prone to underfilm lifting as the zinc coating dissolves. Topcoat disbondment due to dissolution of the zinc primer exposed at a holiday may decrease with time as the zinc corrosion products build up and plug the underfilm paths. The occurrence of such a phenomenon might account for the lack of further disbondment over the latter 30 days of the test.

Table III lists the total area of disbondment which occurred over each inorganic zinc primer. The data in Table III show that the least amount of topcoat disbondment occurred over primer #1 while the most disbondment occurred over primer #4. There was clearly a marked propensity for topcoat disbonding over primer #4 compared to other primers. Primer #4 is a 2-component, full-coat system which was applied at an average thickness of 4.2 mils (the heaviest applied thickness included in the study).

Of special interest was the comparative topcoat performance over primer #3, a Japanese pre-construction primer whose manufacturer suggests can be topcoated (without need of washdown or sandsweep) for underwater service. As is evident, significant disbondment occurred on two of the six test panels within 30 days. On both panels, some degree of disbondment was observed within 24 hours after start of the test.

Comparison of the disbondment results by topcoat shows that topcoat #3, the standard Navy hull coating (MIL-P-24441, Type I), exhibited the least amount of disbondment over 60 days. For this topcoat, disbondment occurred only on those panels primed with primer #4.

For three out of five primers, the total area of topcoat disbondment was greater on the panels weathered for 60 days versus 7 days. This observation is somewhat surprising -- in planning the study it had been felt that aging or weathering of the inorganic zinc primers would tend to reduce their inherent porosity (due to plugging of the pores with corrosion products) thereby reducing the tendency to blister and disbond. Additional data would be required however to establish that this observation is statistically significant.

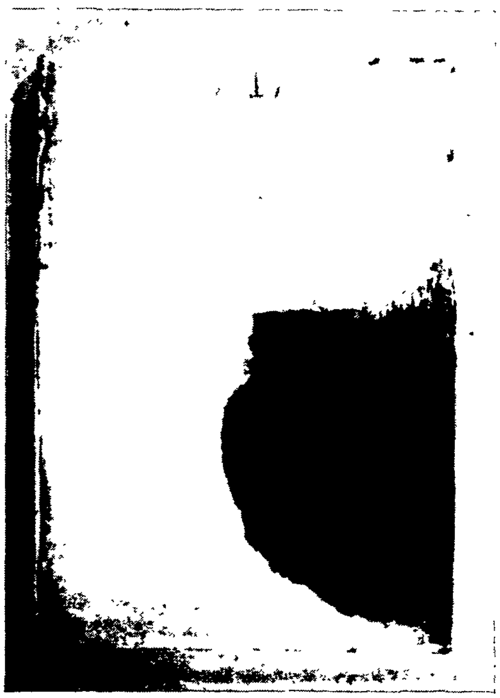

Figure 3 - Topcoat #2 over Primer #4 after 30 Days Exposure to Flowing Seawater at 18 Knots

Comparison of the results for all inorganic zinc primers versus the results obtained for the control panels indicates the only primer for which there is a clear-cut evidence of increased susceptibility to disbondment is primer #4.

Quiescent Seawater Immersion @-1.0 Volt

Of the 66 panels exposed in this phase of the test program, only four test panels exhibited blistering (excluding the area immediately around the holiday). Table IV summarizes the observed blistering after 6 months. The blistering was first detected after 3 months exposure. Figure 4 shows the blistering observed for topcoat #2/ primer #4 after 6 months of testing. The blistering occurred at the zinc/ topcoat interface.

Table V summarizes the blistering observed immediately around the holiday after 6 months exposure. Blister formation at the holidays was first detected as early as one month into test. None of the panels which exhibited blistering at the holiday showed blistering elsewhere on the surface. This observation suggests that blistering outside the holiday area occurs by a different mechanism than that at the holiday.

Table VI summarizes the extent of

disbondment which occurred about the holidays over the 6-month test. There was only one case (topcoat #1/primer #3) where disbondment over an inorganic zinc primed panel was outside the disbondment range exhibited by the control panels. Comparing just the inorganic primers, there appeared to be more of a tendency for cathodic disbondment with primers #1, #2, and #3 than with primers #4 and #5 (the full-coat primers). As in the flow tests, the MIL-P-24441 epoxy topcoat system (topcoat #3) exhibited the least susceptibility to blistering and disbondment.

Quiescent Seawater Immersion @ 25 psi, 150°F

Table VII presents the results of the quiescent seawater immersion tests at 25 psi and 150°F. The data in Table 6 show that topcoats applied over primer #4 were especially susceptible to rapid and extensive blistering. The results appeared to be insensitive to the length of weathering period. Figure 5 shows the appearance of topcoat #3 over primer #4 after a month in test.

Table III

TOTAL AREA OF DISBONDMENT AFTER 60-DAY SEAWATER FLOW TESTS

Inorganic Zinc Primer	Weathering Period	Area of Disbondment, in^2 Topcoat #1	Topcoat #2	Topcoat #3	Total
#1	7-day	0.00	0.59	0.00	0.59
#1	60-day	0.16	0.41	0.22	0.79
#2	7-day	7.62	0.02	1.08	8.72
#2	60-day	0.00	8.59	0.12	8.71
#3	7-day	0.09	21.0	0.08	21.17
#3	60-day	5.00	0.12	0.15	5.27
#4	7-day	8.00	12.13	4.30	24.43
#4	60-day	24.00	1.36	13.69	39.05
#5	7-day	0.91	0.16	0.00	1.07
#5	60-day	0.06	20.00	0.11	20.17
Control	-	50.53	7.34	0.16	58.03
	Total	96.37	71.72	19.91	

Table IV

BLISTERING OBSERVED AFTER 6 MONTH QUIESCENT SEAWATER IMMERSION @ -1.0 VOLT

Inorganic Zinc Primer	Weathering Period	Topcoat	Description
#3	60-Day	#2	Few 1/32" blisters were observed on both of the replicate test panels
#4	7-Day	#2	Medium 1/16"-1/8" blistering on single test panels
#4	60-Day	#2	Medium 1/32"-1/16" blistering on single test panel

Table V

BLISTERING OBSERVED IMMEDIATELY AROUND HOLIDAY AFTER 6 MONTH QUIESCENT SEAWATER IMMERSION @ -1.0 VOLT

Inorganic Zinc Primer	Weathering Period	Topcoat	Description
#1	7-Day	#1	Medium 1/64"-1/32" blistering
#1	7-Day	#2	Medium 1/64"-1/32" blistering
#1	60-Day	#1	Medium 1/64"-1/32" blistering
#1	60-Day	#2	Few 1/64"-1/32" blisters
#1	60-Day	#3	Few 1/32"-1/16" blisters
#2	7-Day	#1	Few 1/16" blisters
#2	7-Day	#2	Few 1/4" blisters
#2	60-Day	#1	Few 1/64"-1/32" blisters
#2	60-Day	#2	Few 1/32" blisters
#3	7-Day	#1	Few 1/64"-1/32" blisters
#3	7-Day	#2	Few 1/64"-1/32" blisters
Control	-	#2	Medium 1/64"-1/32" blistering

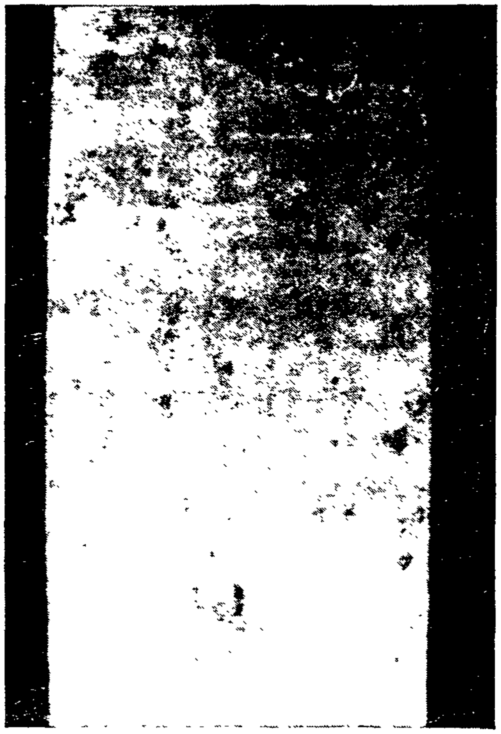

Figure 4 - Topcoat #2 over Primer #4 Weathered for 7 Days after 6 Months Exposure in Quiescent Seawater at -1.0 Volt

Blistering also occurred quickly and extensively over primer #3 but only on those test panels where the primer was weathered for 60 days. A further examination of the data reveals that the topcoats applied on test panels weathered for 60 days were far more likely to blister than those applied on panels weathered for just 7 days. Eighty percent of the test panels weathered for 60 days exhibited blistering of the topcoat compared to forty percent of the panels weathered for 7 days.

Table VIII summarizes the extent of blistering observed within 1 inch of the intentional scribe. These results are consistent with the results for the general surface area. The heaviest topcoat blistering near the scribe was detected on those panels primed with primer #4 (both weathering periods) and primer #3 (60-day weathering period). Again, there was a greater tendency for blistering on those panels weathered for 60 days versus 7 days.

Table IX lists the total area of topcoat disbondment adjacent to the scribe. As with the blistering observations, the worst topcoat disbondment occurred over primer #4 and primer #3 weathered for 60 days. The remainder of the test panels exhibited disbondment that was not significantly differ-

Table VI

AVERAGE AREA OF DISBONDMENT AFTER 6 MONTH QUIESCENT SEAWATER IMMERSION @ – 1.0 VOLT

Inorganic Zinc Primer	Weathering Period	Average Area Of Disbondment, in^2 Topcoat #1	Topcoat #2	Topcoat #3	Total
#1	7-Day	0.47	0.31	0.23	1.01
#1	60-Day	1.05	0.42	0.16	1.63
#2	7-Day	0	1.98	0	1.98
#2	60-Day	0.56	0.34	0.03	0.93
#3	7-Day	0.20	0.74	0	0.94
#3	60-Day	4.82	0.37	0.26	5.45
#4	7-Day	0	0	0	
#4	60-Day	0	0	0	
#5	7-Day	0	0	0	
#5	60-Day	0	0	0	
Control	-	0.53	2.17	0	2.70
	Total	7.63	6.33	0.68	

Table VII

RESULTS OF QUIESCENT SEAWATER IMMERSION TESTING @ 25 psi, 150°F

Primer #	Topcoat #	Weathering Period	Panel #	Comments
#1	#1	7-day	#1	Few 1/4" blisters after 6 months
#1	#1	7-day	#2	Few 1/16"-1/8" blisters after 6 months
#1	#2	7-day	#1	No blistering after 6 months
#1	#2	7-day	#2	No blistering after 6 months
#1	#3	7-day	#1	No blistering after 6 months
#1	#3	7-day	#2	No blistering after 6 months
#1	#1	60-day	#1	Few 1/16" blisters after 6 months
#1	#1	60-day	#2	Few 1/64" blisters after 1 month; few 1/8" blisters after 6 months
#1	#2	60-day	#1	Medium 1/32" blistering after 2 weeks; dense 1/32" blistering after 6 months
#1	#2	60-day	#2	Few 1/64" blisters after 3 months; dense 1/32"-1/16" blistering after 6 months
#1	#3	60-day	#1	Few 1/8" blisters after 6 month
#1	#3	60-day	#2	Few 1/32" blisters after 1 week; few 1/16"-1/8" blisters after 6 months
#2	#1	7-day	#1	Medium dense 1/64" blistering after 4 months; dense 1/64" and few 1/16" blisters after 6 months
#2	#1	7-day	#2	Medium dense 1/64" blistering after 4 months; dense 1/64" and few 1/8" blisters after 6 months
#2	#2	7-day	#1	No blistering after 6 months
#2	#2	7-day	#2	No blistering after 6 months
#2	#3	7-day	#1	Few 1/64"-1/32" blisters after 4 months; medium 1/32"-1/16" blisters after 6 months
#2	#3	7-day	#2	Few 1/64"-1/32" blistering after 1 month; medium dense 1/16" blistering after 6 months

Table VII

RESULTS OF QUIESCENT SEAWATER IMMERSION TESTING @ 25 psi, 150°F

(Continued)

Primer #	Topcoat #	Weathering Period	Panel #	Comments
#2	#1	60-day	#1	Medium dense 1/64" blistering after 3 weeks; dense 1/64"-1/32" blistering after 6 months
#2	#1	60-day	#2	Few 1/64" blisters after 2 months; dense 1/64"-1/32" blistering after 6 months
#2	#2	60-day	#1	No blistering after 6 months
#2	#2	60-day	#2	No blistering after 6 months
#2	#3	60-day	#1	Few 1/32"-1/16" blisters after 4 months; dense 1/32"-1/16" blistering after 6 months
#2	#3	60-day	#2	Few 1/32"-1/16" blisters after 3 weeks; dense 1/32"-1/16" blistering after 6 months
#3	#1	7-day	#1	No blistering after 6 months
#3	#1	7-day	#2	No blistering after 6 months
#3	#2	7-day	#1	No blistering after 6 months
#3	#2	7-day	#2	No blistering after 6 months
#3	#3	7-day	#1	No blistering after 6 months
#3	#3	7-day	#2	No blistering after 6 months
#3	#1	60-day	#1	Medium dense 1/32" blistering after 2 weeks; dense 1/32" blistering after 6 months
#3	#1	60-day	#2	Medium dense 1/64"-1/32" blistering after 3 weeks; dense 1/32" blistering after 6 months
#3	#2	60-day	#1	Medium 1/16" blistering after 1 week; dense 1/16"-1/8" blistering after 6 months
#3	#2	60-day	#2	Medium 1/16" blistering after 1 week; dense 1/16"-1/8" blistering after 6 months
#3	#3	60-day	#1	Medium dense 1/32"-1/16" blistering after 3 weeks; medium 1/16" blistering after 6 months
#3	#3	60-day	#2	Few 1/32"- 1/16" blistering after 2 months; medium 1/16"-1/8" blistering after 6 months
#4	#1	7-day	#1	Coating 20% disbonded after 2 weeks; coating 20% disbonded with few 1/16"-1/8" blisters after 6 months
#4	#1	7-day	#2	Few 1/64"-1/32" blisters after 1 month; few 1/32"-1/16" blisters after 6 months
#4	#2	7-day	#1	Medium 1/8"-1/4" blistering after 1 week; medium 1/4" blistering after 6 months
#4	#2	7-day	#2	Medium 1/8"-1/4" blistering after 1 week; medium 1/4" blistering after 6 months
#4	#3	7-day	#1	Coating 75% disbonded after 1 week; coating 100% disbonded after 6 months
#4	#3	7-day	#2	Coating 40% disbonded after 1 week and 6 months
#4	#1	60-day	#1	Few 1/8" blisters after 2 weeks; few 1/4" blisters after 6 months
#4	#1	60-day	#2	Few 1/8" blisters after 3 months; few 1/8" blisters and medium 1/64" blistering after 6 months
#4	#2	60-day	#1	Few 1/16"-1/8" blisters after 1 week; dense 1/8"-1/4" blistering after 6 months
#4	#2	60-day	#2	Few 1/16"-1/8" blisters after 3 weeks; medium dense 1/16"-1/8" blistering after 6 months
#4	#3	60-day	#1	Few 1/16"-1/8" blisters after 1 week; few 1/8" blisters after 6 months
#4	#3	60-day	#2	Coating 70% disbonded after 1 week; coating 75% disbonded after 6 months

Table VII

RESULTS OF QUIESCENT SEAWATER
IMMERSION TESTING @ 25 psi, 150°F

(Continued)

Primer #	Topcoat #	Weathering Period	Panel #	Comments
#5	#1	7-day	#1	No blistering after 6 months
#5	#1	7-day	#2	No blistering after 6 months
#5	#2	7-day	#1	No blistering after 6 months
#5	#2	7-day	#2	No blistering after 6 months
#5	#3	7-day	#1	No blistering after 6 months
#5	#3	7-day	#2	No blistering after 6 months
#5	#1	60-day	#1	Few 1/32" blisters after 1 and 6 months
#5	#1	60-day	#2	Medium 1/32" blistering after 1 and 6 months
#5	#2	60-day	#1	No blistering after 6 months
#5	#2	60-day	#2	Dense 1/32" blistering after 1 week; dense 1/32"-1/16" blistering after 6 months
#5	#3	60-day	#1	Few 1/64"-1/32" blisters after 1 week; dense 1/32"-1/16" blistering after 6 months
#5	#3	60-day	#2	Few 1/64" blisters after 5 months; few 1/32"-1/16" blisters after 6 months
Control	#1	-	#1	Few 1/16" - 1/8" blisters after 6 months
Control	#1	-	#2	Few 1/8" blisters after 6 months
Control	#2	-	#1	Few 1/36" - 1/16" blisters after 6 months
Control	#2	-	#2	No blistering after 6 months
Control	#3	-	#1	No blistering after 6 months
Control	#3	-	#2	No blistering after 6 months

Figure 5 - Topcoat #3 over Primer #4 Weathered for 60 Days after 1 Month Exposure in Quiescent Seawater at 25 psi, 150°F

ent than that of the control panels. Qualitatively, however, considering the disbonded area due to blistering, the only test panels where the topcoats performed as well as on the control panels were the panels primed with primers #1, #3, and #5 and weathered for 7 days.

All of the blistering/disbondment observed on the test panels originated at the zinc/topcoat interface. This is consistent with the results obtained in the other tests.

CONCLUSIONS

1. The results of the tests suggest that, depending on the degree of weathering prior to topcoating, there may be inorganic zinc pre-construction primers that can be overcoated for underwater service. After a weathering exposure of 7 days, three of the primers tested in this program (primers #1, #2 and #5 in Table 1) did not appear to increase the tendency for topcoat blistering or disbondment when compared to white-metal blasted control panels.
2. The Japanese-manufactured inorganic zinc pre-construction primer tested in the subject program showed a propensity to cause top-

Table VIII

EXTENT OF BLISTERING AT INTENTIONAL SCRIBE AFTER 6 MONTHS QUIESCENT SEAWATER IMMERSION @ 25psi, 150°F

Primer #	Topcoat #	Weathering #1	Panel #	Comments
#1	#1	7-Day	#1	Few 1/8" blisters
#1	#1	7-Day	#2	Few 1/16" - 1/8" blisters
#1	#2	7-Day	#1	Medium dense 1/32" blistering
#1	#2	7-Day	#2	Few 1/8" blisters
#1	#3	7-Day	#1	No blistering
#1	#3	7-Day	#2	No blistering
#1	#1	60-Day	#1	No blistering
#1	#1	60-Day	#2	Medium 1/16" - 1/8" blistering
#1	#2	60-Day	#1	Medium dense 1/32" blistering
#1	#2	60-Day	#2	No blistering
#1	#3	60-Day	#1	Few 1/8" - 1/4" blisters
#1	#3	60-Day	#2	Medium dense 1/8" - 1/4" blistering
#2	#1	7-Day	#1	No blistering
#2	#1	7-Day	#2	No blistering
#2	#2	7-Day	#1	No blistering
#2	#2	7-Day	#2	No blistering
#2	#3	7-Day	#1	Medium 1/8" - 1/4" blistering
#2	#3	7-Day	#2	Medium dense 1/8" blistering
#2	#1	60-Day	#1	Dense 1/32" - 1/16" blistering
#2	#1	60-Day	#2	Medium dense 1/8" blistering
#2	#2	60-Day	#1	No blistering
#2	#2	60-Day	#2	No blistering
#2	#3	60-Day	#1	Few 1/16" - 1/8" blisters
#2	#3	60-Day	#2	Medium dense 1/8" - 1/4" blistering
#3	#1	7-Day	#1	No blistering
#3	#1	7-Day	#2	No blistering
#3	#2	7-Day	#1	Few 1/32" blisters
#3	#2	7-Day	#2	No blistering
#3	#3	7-Day	#1	No blistering
#3	#3	7-Day	#2	No blistering
#3	#1	60-Day	#1	Medium dense 1/32"-1/16" blistering
#3	#1	60-Day	#2	Few 1/16" blisters
#3	#2	60-Day	#1	Dense 1/32" blistering
#3	#2	60-Day	#2	Dense 1/8" - 1/4" blistering
#3	#3	60-Day	#1	Medium 1/16" - 1/8" blistering
#3	#3	60-Day	#2	Few 1/16" - 1/8" blisters
#4	#1	7-Day	#1	Medium dense 1/8"-1/4" blistering
#4	#1	7-Day	#2	Medium dense 1/8"-1/4" blistering
#4	#2	7-Day	#1	Medium 1/4" - 1/2" blistering
#4	#2	7-Day	#2	Few 1/4" - 1/2" blisters
#4	#3	7-Day	#1	Coating disbonded
#4	#3	7-Day	#2	Coating disbonded
#4	#1	60-Day	#1	Dense 1/4" - 1/2" blistering
#4	#1	60-Day	#2	Medium Dense 1/2" blistering
#4	#2	60-Day	#1	No blistering
#4	#2	60-Day	#2	Few 1/4" blisters
#4	#3	60-Day	#1	Coating disbonded
#4	#3	60-Day	#2	Medium Dense 1/4"-1/2" blistering
#5	#1	7-Day	#1	Medium 1/8" - 1/4" blistering
#5	#1	7-Day	#2	Few 1/8" - 1/4" blisters
#5	#2	7-Day	#1	No blistering
#5	#2	7-Day	#2	No blistering
#5	#3	7-Day	#1	Medium 1/4" blistering
#5	#3	7-Day	#2	Medium 1/4" blistering

Table VIII

EXTENT OF BLISTERING AT INTENTIONAL SCRIBE AFTER 6 MONTHS QUIESCENT SEAWATER IMMERSION @ 25psi, 150°F

(Continued)

Primer #	Topcoat #	Weathering #1	Panel #	Comments
#5	#1	60-Day	#1	Few 1/8" - 1/4" blisters
#5	#1	60-Day	#2	Medium 1/8" blistering
#5	#2	60-Day	#1	No blistering
#5	#2	60-Day	#2	No blistering
#5	#3	60-Day	#1	No blistering
#5	#3	60-Day	#2	No blistering
Control	#1	-	#1	Few 1/8" - 1/4" blisters
Control	#1	-	#2	Medium 1/8" blistering
Control	#2	-	#1	No blistering
Control	#2	-	#2	No blistering
Control	#3	-	#1	No blistering
Control	#3	-	#2	No blistering

Table IX

AVERAGE AREA OF DISBONDMENT AT THE INTENTIONAL SCRIBE AFTER 6 MONTHS QUIESCENT SEAWATER IMMERSION @ 25 psi, 150°F

Inorganic Zinc Primer	Weathering Period	Disbonded Area, in^2 Topcoat #1	Topcoat #2	Topcoat #3	Total
#1	7-Day	1.55	0.78	0	2.33
#1	60-Day	0.62	0.78	0.31	1.71
#2	7-Day	0	0.31	0	0.31
#2	60-Day	0.16	0	0	0.16
#3	7-Day	0.16	0.31	0	0.47
#3	60-Day	0.62	36.43	0.31	37.36
#4	7-Day	0.31	0.16	70.68	71.15
#4	60-Day	0	0	35.34	35.34
#5	7-Day	0.31	0	0.31	0.62
#5	60-Day	0.78	0	0.16	0.94
Control	-	2.17	0	1.40	3.57
	Total	6.68	38.77	108.51	

coat blistering. This is contrary to the manufacturer's claims.

3. Of the primers tested, the greatest tendency for topcoat blistering occurred over the 2-component full-coat inorganic zinc primer applied at the heaviest thickness (approximately 4 mils).

4. The results of the tests suggest that a longer weathering period (60 days versus 7 days) increases the susceptibility of the inorganic zinc primers to topcoat disbondment. This is contrary to the generally accepted notion.

5. Of the topcoats included in the test program, the MIL-P-24441 epoxy showed the least tendency toward blistering and disbondment.

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Applications of Digital Transfer of Computer Aided Design Data for Production Usage

No. 26

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ABSTRACT

This paper addresses efforts to provide the capability to transfer data between Computer Aided Design (CAD) systems currently in use on the CG 47 contract. The paper will discuss experience with the use of Initial Graphic Exchange Specification (IGES) and direct translators. The pros and cons of both approaches will be addressed. The issue of transferring data between the two different hull design and lofting systems in use in shipbuilding is explored.

INTRODUCTION

The use of Computer Aided Design (CAD) is having a major impact on shipbuilding. NAVSEA, shipyards and design agents use a variety of CAD systems to develop design data. In this multiple vendor environment, transfer of data between agencies and even within the same agency having different types of CAD systems makes transfer of data difficult at best. This is due to the fact that the CAD vendors store data in unique and proprietary formats. The ability or the lack of ability to transfer data between the different parties has been called by some the greatest problem facing the United States shipbuilding industry today. Ingalls Shipbuilding, under a CG 49/50 technical improvement contract, is entering 1400-plus CG 47 detail design drawings on its CAD systems. This will result in productivity improvements for the program, because of the reduction in time required to incorporate changes and the elimination of change paper. In addition, the quality of the drawing being delivered to the Navy and the follow yard will be vastly improved.

The next logical step is to provide this data in digital form to both the Navy and the follow yard(s). This led to a special engineering study contract under Class Services that addresses the ability to transfer data between the CAD systems in use at Ingalls Shipbuilding and the builders of follow ships.

The use of structural design and numerical control lofting systems offers unique challenges for effective data transfer between lead and follow shipyards. In the case of the CG program, Ingalls Shipbuilding uses Ship Production and Design Engineering System (SPADES) and Bath Iron Works (BIW) uses AUTOKON. To facilitate a totally effective transfer of data, the interface between the structural systems must be addressed. This would include transfer of data between SPADES and AUTOKON and from both to turnkey CAD systems.

INGALLS CG 47 CLASS SERVICE EFFORTS

Ingalls, under the CG special study contract, is pursuing the use of IGES to the maximum extent possible, plus having direct translators developed to transfer data between dissimilar CAD systems. Other CAD-related efforts being performed by Ingalls to assist in transferring and accessing CAD data are:

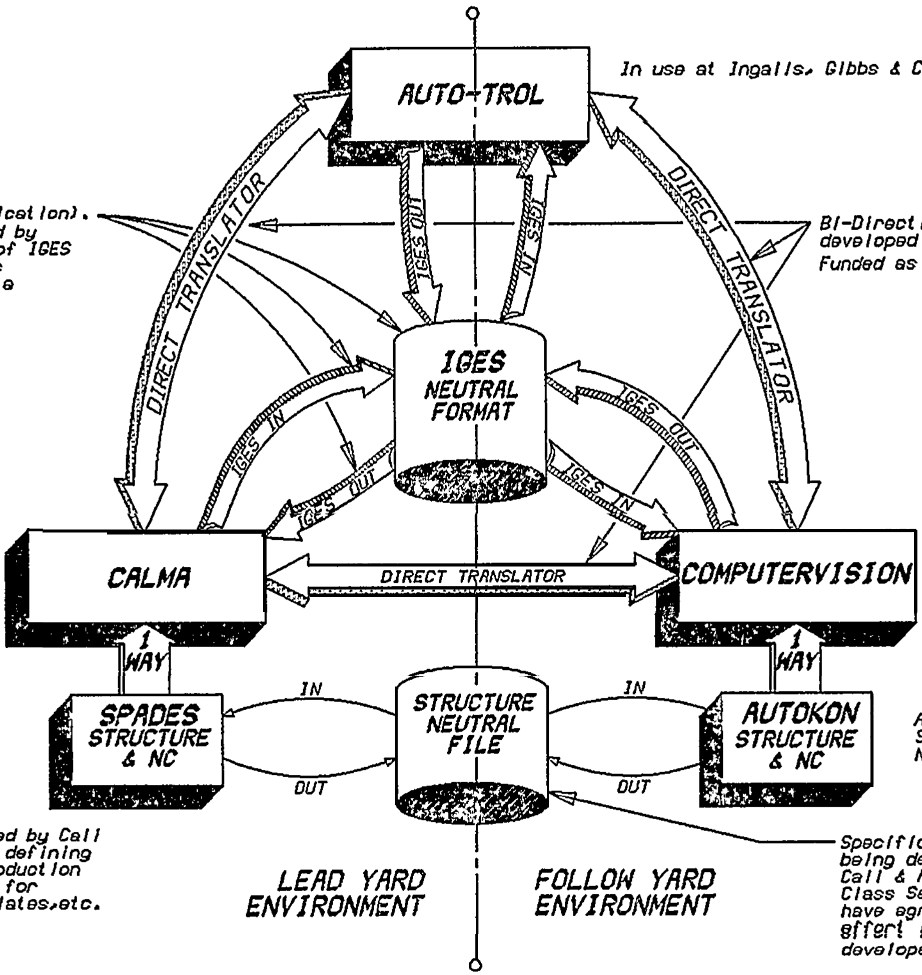
1) Developing a SPADES to Calma translator. This shall provide the gateway from Ingalls structural system to the turnkey CAD systems.

2) Evaluating the use of low-cost stations to view and modify CAD created drawings.

3) Conducting a study and developing detailed specifications on transferring data between SPADES and AUTOKON.

Figure 1 depicts the overall approach and integration of CAD systems in use on the CG 47 Class

CG 47 CLASS SERVICES DIGITAL DATA TRANSFER



In use at Ingalls, Gibbs & Cox, and J.J. McMullen.

I.G.E.S (Initial Graphics Exchange Specification). IGES-In and IGES-out processors maintained by respective turn-key CAD vendors. Testing of IGES is actually a test of how well CAD vendors implement it. This testing is underway as a funded task.

Bi-Directional Direct Translators being developed by Octal, Inc..
Funded as a task under CG 47 Class Services.

In use extensively at Ingells. Limited usege et NRSSCO.

Computervision (CV)-In use extensively
Bath and EB. Limited at CDI Marine, Gibb
& Cox, and Bethlehem Steel.

Autokon- The Functional equivalent of SPADES
Supported from Oslo, Norway. In use at Bath,
Newport News, Bethlehem Steel, and Todd.

SPADES (Ship Production And Design Engineering System)-In use at Ingalls, Avondale, NASSCO, and Lockheed. Supported by Call and Associates in Metarie, LA. Used for defining structural geometry, properties, and production of manufacturing aids such as N/C tapes for cutting of steel plates, sketches, templates,etc.

Specifications for this file are presently being developed by cooperative effort between Call & Associates, Autokon, and Ingalls as a Class Services funded task. Both vendors have agreed to productize and support this effort in the future if software is eventually developed.

OBJECTIVE: TRANSFER 2-D GRAPHICS AND TEXT
PREPARE FOR 3-D CONVERSION

APPROACH: ADDRESSES 3 CAD VENDORS ASSOCIATED WITH CG 47 PROGRAM.
ADDRESSES STRUCTURAL DATA ISSUE.

Service contract. Ingalls is utilizing Calma and Auto-trol for loading the 1400 Class Service drawings. SPADES is utilized for hull design and lofting on major changes. Computervision and AUTOKON are being utilized at Bath. Ingalls is working with the three turnkey CAD vendors (Calma, Auto-trol, and Computervision) on development of usable IGES translators.

In addition, Ingalls has OCTAL, Incorporated developing three bi-directional translators for the turnkey systems. Advantages regarding the two different approaches are addressed later in this paper. Ingalls has developed the SPADES to Calma interface. Bath and Computervision have developed the AUTOKON to Computervision translator. Detail specifications for the SPADES AUTOKON translator have been developed, and if the two vendors are funded, a full function, closed-loop approach to data transfer will be in place for the CG 47 program.

DATA TRANSFER BETWEEN CAD SYSTEMS

This section addresses the subject of two-dimensional (2D) graphics and text data transfer between CAD systems and is restricted to interchanges between Calma, Computervision, and Auto-trol systems. The vendors of these systems are actively participating in the project by reviewing reports regarding difficulties experienced with their software applications of IGES, and by coordinating and forwarding potential solutions to resolve the problems. Figure 2, entitled "IGES Problem Status Report," gives a representative sampling of the types of difficulties encountered in testing and some of the resolutions provided by vendors. It additionally points out that some of the problems are not presently addressable and will not be resolved in the near term.

IGES testing has also shown that even in cases where data is correctly transferred, certain conditions are encountered that may have an adverse impact on users. While the use of standard formats has many benefits, it cannot account for the differences in the ways software may be designed. For this reason, efficiencies in the relationship between software and hardware may suffer in some cases. As an example of this, certain test cases have resulted in the count of instances of element types being increased three to four times as a result of conversions. In other tests, storage requirements have been increased dramatically, thus altering system performance for access times as well as consideration for hardware configuration.

From the outset, the principal emphasis in this project has been placed on the transfer of data through the neutral IGES format. However, in instances where this technique was unable to accomplish complete data transfer, direct translators will be used. Regardless of which procedure will be ultimately employed, it is recognized that significant testing will be required, and that the quality and completeness of the test data will directly affect the quality of the translation.

Early in the project, test cases were created or secured to represent typical cases for the following systems and modes:

- Calma (Calma native format and IGES)
- Auto-trol (Auto-trol native format and IGES)
- Computervision (CV) (CV native format and IGES)

Note: CV test cases were acquired from BIW, NAVSEA, and CDI Marine

The above cases have been further supplemented by IGES data obtained from the National Bureau of Standards. Data originating from an Optigraphic scanner processor used for loading drawings has been successfully tested through IGES transfers to both Calma and Auto-trol. As new releases of IGES are received, problem test cases are being reapplied to ensure that reported solutions actually work. In addition, transfers have been accomplished from Optigraphics to Calma and Auto-trol via direct translators.

In spite of considerable progress with IGES, problems with its implementation still exist to a degree that makes its usefulness questionable in a production environment today.

In order to achieve a rapid and accurate transfer of data between systems by whatever means necessary, ISD has placed an order with Octal, Inc., of Mountain View, CA, to supply direct translators intended to overcome current shortcomings in present IGES implementations. These translators

FIGURE 2 - IGES PROBLEM STATUS REPORT

I/R NUMBER	DATE RPTD	PROBLEM DESCRIPTION AND RESOLUTION
17424	013087	DAL PROGRAM WHICH DOES A NMD AND THEN GIVES A NIL FOR THE IGES FILENAME 0202 SUPPORTING DOCUMENTATION SENT 0219 SOFTWARE PR.RPT #002937 ASSIGNED 0223 VERIFIED FIXED BY INGALLS
17432	020287	IGESOUT ON MODEL VLD110211-GOO2 GENS ERR 0202 SUPPORTING DOCUMENTATION SENT 0219 SOFTWARE PR..RPT #002935 ASSIGNED 0223 VERIFIED FIXIED BY INGALLS
17433	021087	IGESIN CAUSES DATA NOT TO BE DISPLAYED. RDI OR VIEWFIL 0210 SUPPORTING DOCUMENTATION SENT 0219 SOFTWARE PR #002936 ASSIGNED 0223 VERIFIED FIXED BY INGALLS
17609	022587	IC2'S NOT CORRECT AFTER IGES TRANSLATE 0226 SUPPORTING DOCUMENTATION SENT 0318 SOFTWARE PR #003086 ASSIGNED 0318 TESTED BY VENDOR 0506 VERIFIED FIXED BY INGALLS
17610	0225	IGESOUT DOES NOT OUTPUT FRACTIONAL DIM 0226 SUPPORTING DOCUMENTATION SENT 0318 SOFTWARE PR #003087 ASSIGNED 0506 VERIFIED FIXED BY INGALLS

NOTE: The above is a sample of ISD'S Problem Tracking System - Report #U98830R3 will be implemented for use between combinations of systems as follows:

- Auto-trol to Computervision
- Auto-trol to Calma
- Computervision to Calma
- ComputerVision to Auto-trol
- Calma to Computervision
- Calma to Auto-trol

A trip was made to the Octal offices to review progress. Satisfactory results are being achieved by the vendor. In fact, the initial offerings for the Auto-trol to Computervision case has progressed to the point that a transfer of live data between Ingalls and BIW is in the process of being tested.

STRUCTURAL DEFINITION SYSTEMS

This task defined the requirement to develop the specifications for a software interface between the two major structural definition systems in use in the shipbuilding industry: Autokon, a widely used system throughout the world, supported by its authors in Oslo, Norway; and Ship Production and Design Engineering System (SPADES), marketed and supported by Cali and Associates in Metairie, Louisiana. One of these two systems is licensed for use by every major shipbuilder in the United States.

Following Navy approval, representatives from AUTOKON and Cali & Associates began a series of working sessions to define all geometry and data residing in both of the current data bases. Also , known shortcomings, as well as data expansions, were considered in the design of the transfer. A philosophy of using a neutral file was implemented with both parties agreeing to productize their respective pre- and post-processors should the specified software be eventually developed.

The contracted specification has been developed and has been reviewed by ISD. It has also been forwarded to the Navy-Industry Digital Data Exchange Steering Committee working group. While some of the people involved in this activity have stated a preference for the use of IGES rather than the neutral file specified, the consensus is that the document is presently the most complete picture of structure data element definitions for shipbuilding available todav, and it will be adopted as the basis for future structural work by the Navy-Industry group. There is also an admission that while the IGES preference does exist, it is not presently known that IGES will successfully handle all of the data types required. Most of the shipbuilders surveyed readily agree that development of the software is a worthwhile endeavor and will benefit many U. S. shipbuilders regardless of the neutral file used.

LOW ORDER CAD DEVELOPMENT PROJECT

In recognition of the fact that the uses of CAD extend past those of initial design data creation, ISD has taken steps to investigate the uses and vendors of systems we refer to as Low Order CAD. Low Order CAD is a term intended to connote a less capable design software tool available on a less expensive hardware platform that may address requirements of a less complex nature. In other words, you pay less, you get less, but you need less! Ingalls has formed a team of experienced CAD personnel to fully evaluate the cost-effectiveness of applying Low Order CAD to disciplines that support lead-to-follow yard functions with such products as sketch generation, proposed change configurations, evaluations of graphic alternatives, and preparation of technical illustrations and manuals. Written requirements have been developed and furnished to prospective vendors, describing functionality mandatory in their offerings. Among these requirements is the ability to communicate with the system on which the data is originally defined.

Ingalls has already evaluated numerous software packages on several hardware platforms and is convinced of the potential to apply this type of technology to reduce costs.

SPADES TO CALMA TRANSLATOR

The SPADES to Calma translator has been developed to address the common shortcoming of all present CAD vendors: the ability to efficiently define the common shipbuilding structural characteristics into a database to be used as the basis for distributed systems design. Ingalls has developed this software for the two systems in question and has demonstrated the value of defining data only once and being able to use it for multiple purposes, i.e, design and the creation of numerically controlled. instructions for manufacturing.

The Ingalls process involves the extraction of data from the IBM mainframe that processes the SPADES software and formats it for use in the Apollo ring network that services the Calma workstations. Figure 3, SPADES to Calma Process Flow, depicts the functions involved in the transfer process and defines the environments in which they take place. The entire process may be performed by an operator at an Apollo workstation. The basic activity is the extraction of data from the IBM-housed data base, which is processed through a protocol converter to take care of dissimilarities in communications features. The data is then moved via telephone line to a program running on an Apollo, which converts SPADES surface data and associates material data and other intelligence with appropriate structural members. The data is then organized and stored in an Apollo directory. It can then be accessed for construction of a structural product model format for use in system design. Figures 4 and 5 are examples of data cases which have been successfully transferred by the processes shown in Figure 3.

THREE DIMENSIONAL TRANSFER SPECIFICATIONS

The efforts documented in the SPADES to Calma translator and in the specifications for the hi-directional translator between SPADES and AUTOKON give detailed requirements at a data element level for a three-dimensional transfer for shipbuilding hull structure. This structural data comprises the vast majority of data available in digital form in the majority of today’s ship design and shipbuilding programs. While much work is being done by other industries with similar problems to those of shipbuilding for disciplines such as piping, electrical, and ventilation design, Ingalls intends to actively pursue the transfer issues for design data, so that when such data does exist on a significant scale, means may exist to beneficially exchange it as needed.

CONCLUSIONS

It is technically feasible with current technology to transfer data between dissimilar CAD systems. Currently the most effective approach is through the use of direct translators. This should not detract from efforts to force the CAD vendors into developing cost effective, reliable IGES and in the future Product Definition Exchange Specifications (PDES) translators. IGES and PDES should be pursued to the maximum, and the Ingalls and PMS400 efforts have greatly assisted in this task. Low cost workstations have a place in a network of high performance CAD workstations and can perform low level drafting functions and serve as “view only” terminals.

It is technically feasible to develop an interface between two structural design and lofting systems (SPADES and AUTOKON). This development effort should commence as soon as funding can be obtained.

ACKNOWLEDGMENTS

R. V. Shields III
W. A. Solitario

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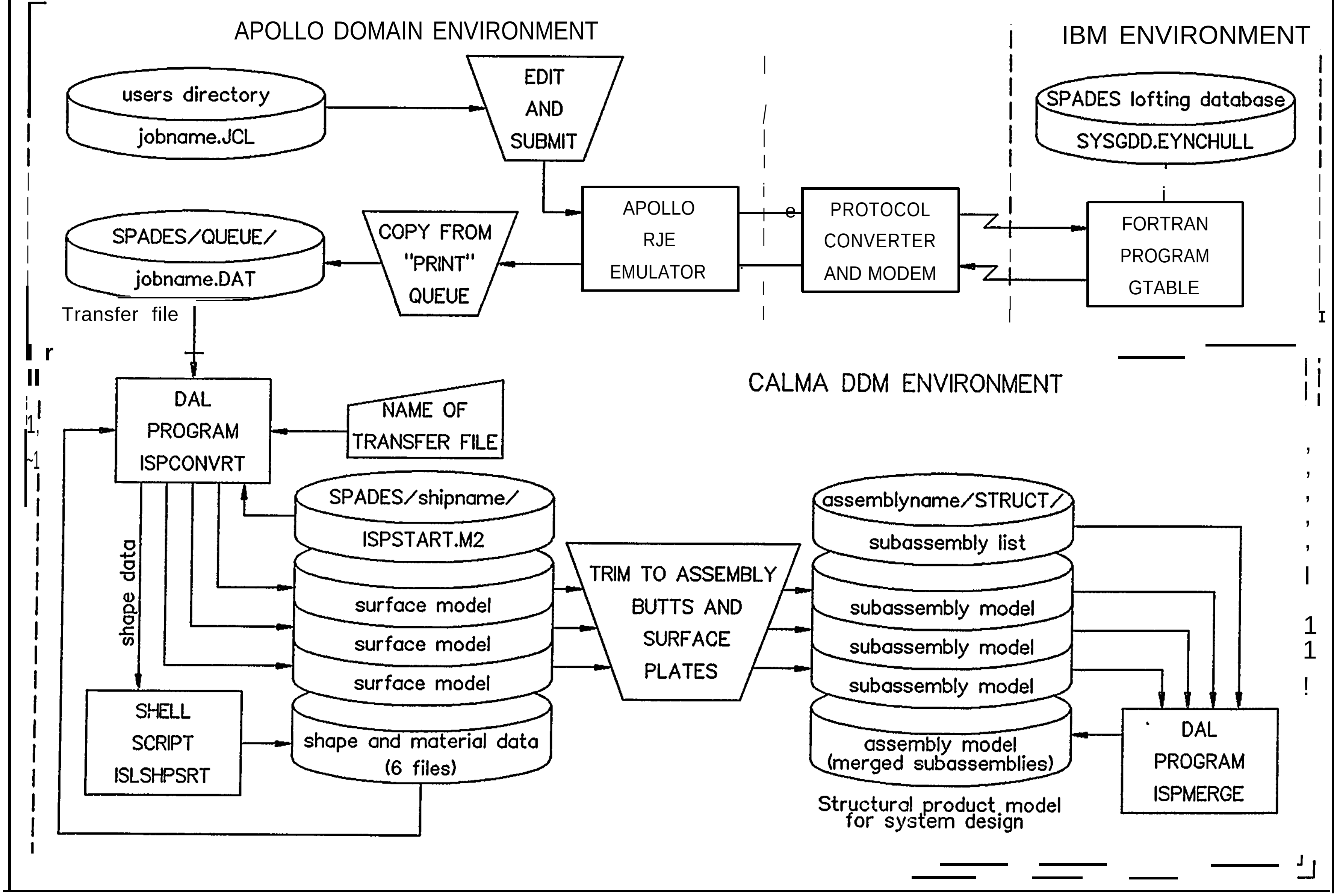
FIG. 3: SPADES – CALMA PROCESS FLOW



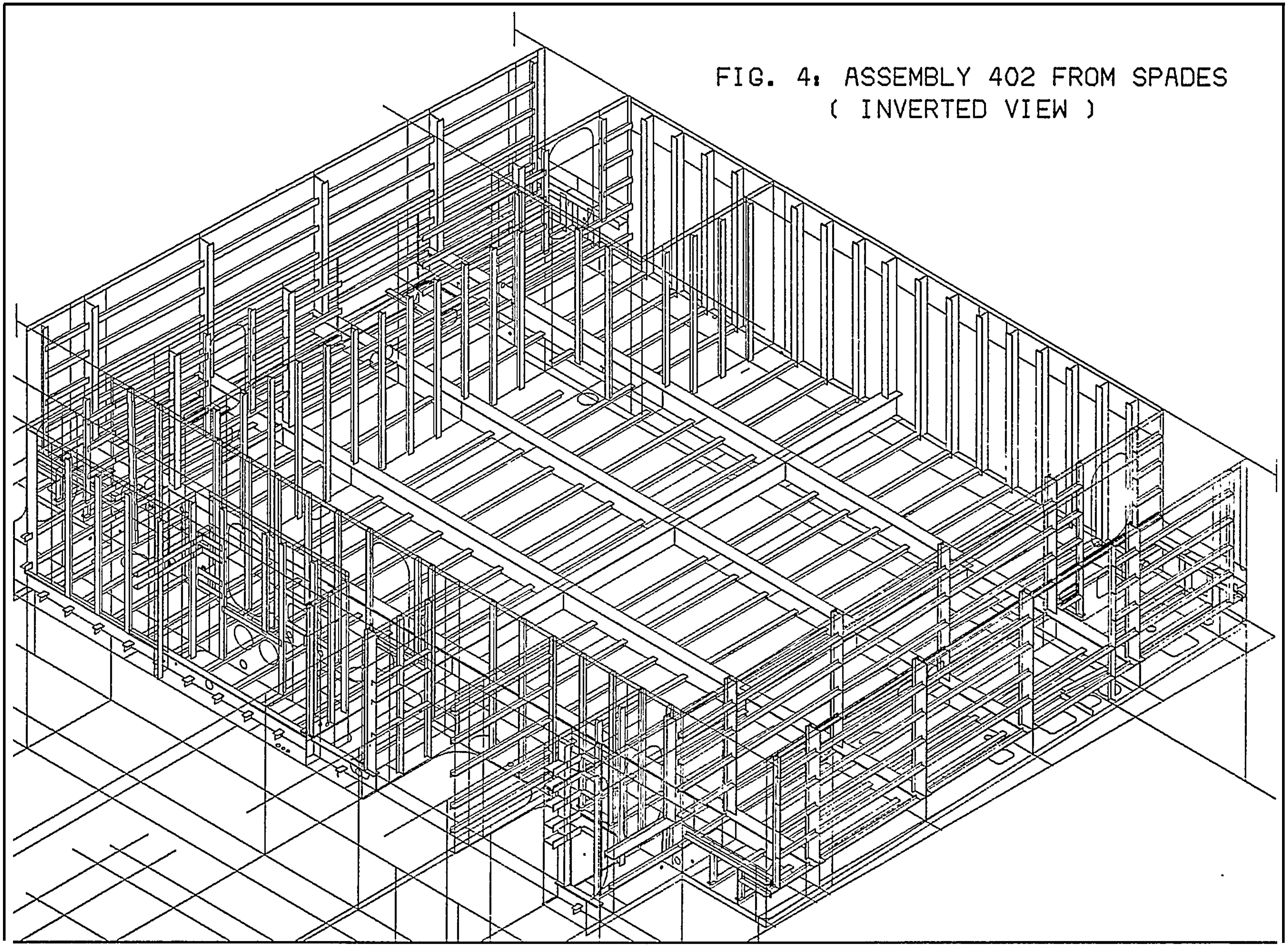


FIG. 4: ASSEMBLY 402 FROM SPADES
(INVERTED VIEW)

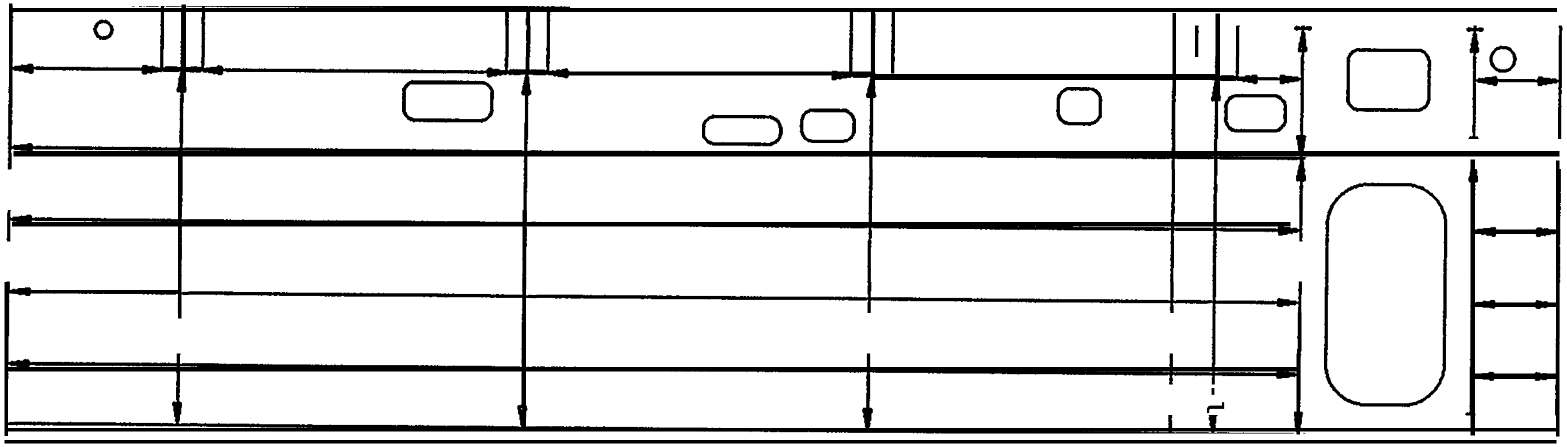


FIG. 5: SPADES LBHD B2 P PROCESSED BY ISPVFE, ISPTRADET, AND ISPSHPSCH

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THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
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Shop and Zone Administration and Management: The Transitions to Zone Outfitting in Repair and Overhaul at Puget Sound Naval Shipyard

No. 27

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ABSTRACT

This paper discusses Puget Sound Naval Shipyard's implementation of Zone Outfitting in Repair and Overhaul (ZORO). Four problems are responsible for past poor performance: funding by system, planning using key-operations which are too broad, scheduling by event, and inflating cost by inaccurate historical expenditure records. These problems are discussed and addressed.

To solve the interactive problems. a new product management structure is being examined. The system is based on a Project team called an Outfit planning Group. Using composites. facilitated by a CAD model, this team of people is responsible for packaging and sequencing the work. The result is a sequenced work package that is scheduled in an incremental time line to support work to be accomplished.

The Work Packages are composed of Unit Work Procedures -- stand-alone information packages. The Unit Work Procedure facilitates schedule enhancement, manhour estimating and manning. and aids in palletization, inventory, and delivery of materials to work centers. Four standard groups of unit work procedures have been established: (1) fabrication, (2) assembly, (3) installation and (4) repair.

The present system-oriented Management Information System (MIS) is unable to process information that crosses Ship Work List Item Numbers (SWLINS) and key-operations. a necessity in zone planning. Suggested changes in the MIS will allow funding, packaging, sequencing, and scheduling to be accomplished independently of one another.

Several preliminary studies have also been released which show significant gains as a result of ZORO. A study of manhour comparisons between identical work, prior to the use of work packaging and after, shows a decrease of thirty percent. Comparison of the manhours required for planning versus manhours saved shows a savings of fifty-four percent. Although these results are very preliminary, they indicate an extensive potential for improvement in both efficiency of production and effectiveness of work packaging.

THE PROBLEM

Over the last ten years, there has been a consistent effort by our maritime industrial base, through the National Shipbuilding Research Program (NSRP), to identify positive applications to resolve the problems which have caused the U.S. shipbuilding industry to fall so far behind in the international marketplace. A few U.S. shipyards have incorporated these studies and have successfully turned the corner. Naval shipyards, as a whole, are seeing a large challenge to change their methods of conducting life cycle support and to implement these progressive applications in order to lower their costs.

The solution to increasing the Naval shipyards' effectiveness begins with understanding the basic problems inherent in the present system. The very heart of the Naval shipyards' problem is an annual budgeting system.

Every year a specific dollar allotment is given to the U.S. Navy for maintenance of the fleet. In turn. based on the amount of work in each of the eight Naval shipyards, the budget is proportionately divided to cover the estimated expenditures. Money not expended or not anticipated to be spent during a fiscal year is returned. The returned funds are then redistributed to cover underestimated expenditures in other Naval shipyards. Any money which is unspent dissolves at the end of the fiscal year. On the surface this may seem to be an efficient distribution of the budget. This is not the case.

The system establishes the rule: what you don't spend, you don't get. Thus, the system discourages anyone from saving money. Private industry turns saved money into profit for shareholders, research, and equipment investment. No such incentive exists within the government structure. Without profits to fund investment, the shipyards are encouraged to continue overexpenditures. while the production facilities become antiquated, both in equipment and method (Figure 1).

Within the Naval shipyards' system there is a strong desire to become competitive: to change the numerous internal problems which result from government regulation [1]: and to modernize facilities, equipment, and methods. Based on published documentation of the National Shipbuilding Research Program [2]. Puget Sound Naval Shipyard is implementing Zone Outfitting in Repair and Overhaul (ZORO) [3].

To effectively implement any program, a feedback loop is necessary in order to identify problems and judge improvements. The shipyard MIS, the cost tracking program presently used in the Naval shipyards to provide feedback, cannot do this at this time [4]. The present way work is planned and scheduled indicates a need to adjust the MIS system to more effectively and flexibly provide information for management.

The assignment of work is given to the shipyard under a SWLIN, which indicates work on a system, either the repair of old equipment or the installation of new. The work within a SWLIN is then divided into job orders, which are further divided into key operations or key-ops. The job orders are phased depending on the work in the key-op. (This is tied to the ship work breakdown structure, SWBS.)

The key-op is the document which defines and funds the work. It contains a number of tasks which vary from a few manhours of work to thousands of manhours. The key-op document gives brief descriptions of tasks: references other drawings, specifications instructions. and/or publications that need to be accomplished: and identifies which shop (work centers) would be performing the tasks.

The. MIS is used to track cost accumulations of key-ops and to store the costs to estimate similar work on another vessel. The key-op is vulnerable to mischarging. and when inaccurate charging is entered into the MIS, future work estimations will be incorrect. The key-op is vulnerable for a number of reasons. First, it is multi-tasked, usually containing thousands of manhours of work [5]. The key-op cannot close until all of the tasks are complete. and often remains open for an extended period. Research time is not part of the allotment of manhours given to a key-op, but larger jobs require research and the key-op's funds are used to pay the mechanic while he performs the necessary research. Several jobs are worked by the mechanic daily. He may spend only portions of an hour on one or two and the rest of the day on a third. It is inconvenient to report small portions of work and commonly one job order would be reported. On occasion, work is not available for all the mechanics on a shift. Two choices are open to the foreman: he can call around to see if another job is short of mechanics. or he can double up on some of the work. A third option exists -- to pay the extra mechanics on shop overhead. but this action reflects badly on the managerial ability of the foreman, and is perceived to be frowned upon by management. Because the shipyard maintains a constant manning force, the situation can arise often. Therefore, job orders which could be closed are left open to ensure that the foreman has a reserve to pay his people. These practices are necessary for a foreman to successfully pay his work force and maintain a good record. It also ensures that almost every job order uses all the funds it has been budgeted.

The system encourages mischarging by creating a key-op which is too broad. and which remains open to be charged against. The inability of the foreman to control the size of his work force or his accessibility to his assigned tasks causes him, on occasion, to mischarge in order to pay his people. Research time is a significant portion of work which is not accounted for, but iS appropriately mischarged to the job which is being researched. The MIS easily hides much of this mischarging. It keeps a record of who charged against that key-op and the total amount spent at a work center. On a large job it may be unclear who has worked it and who has not. Many different tasks are performed at some work centers (especially inside the shop), so it is uncertain who mischarged and by how much. The key-ops are now on record as having been estimated correctly when job orders are closed with no funds remaining. and underestimated for key-ops which have overexpended their allotted budget.

New key-ops are written against this historical data to estimate the time required to do the work. In the case above, both jobs appear to reflect a correct record of the cost of a -Op : that same amount of time is again allotted, plus a margin to allow for unexpected growth. In a continuous cycle, the time required continues to inflate. This trend has been documented (Figure 2).

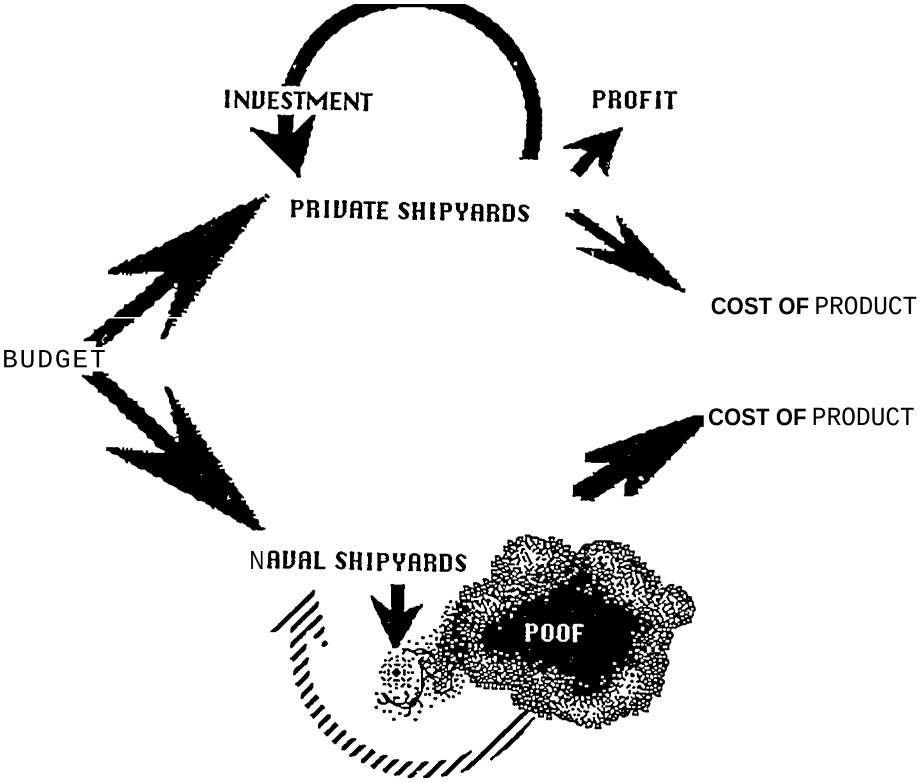


FIGURE 1

Naval Shipyards would benefit from a reinvestment loop (dotted arrow) which Would allow the shipyards to modernize their facilities and encourage savings.

REAL WORK AS PERCENTAGE
OF EXPENDITURE
(HYPOTHETICAL EXAMPLE)

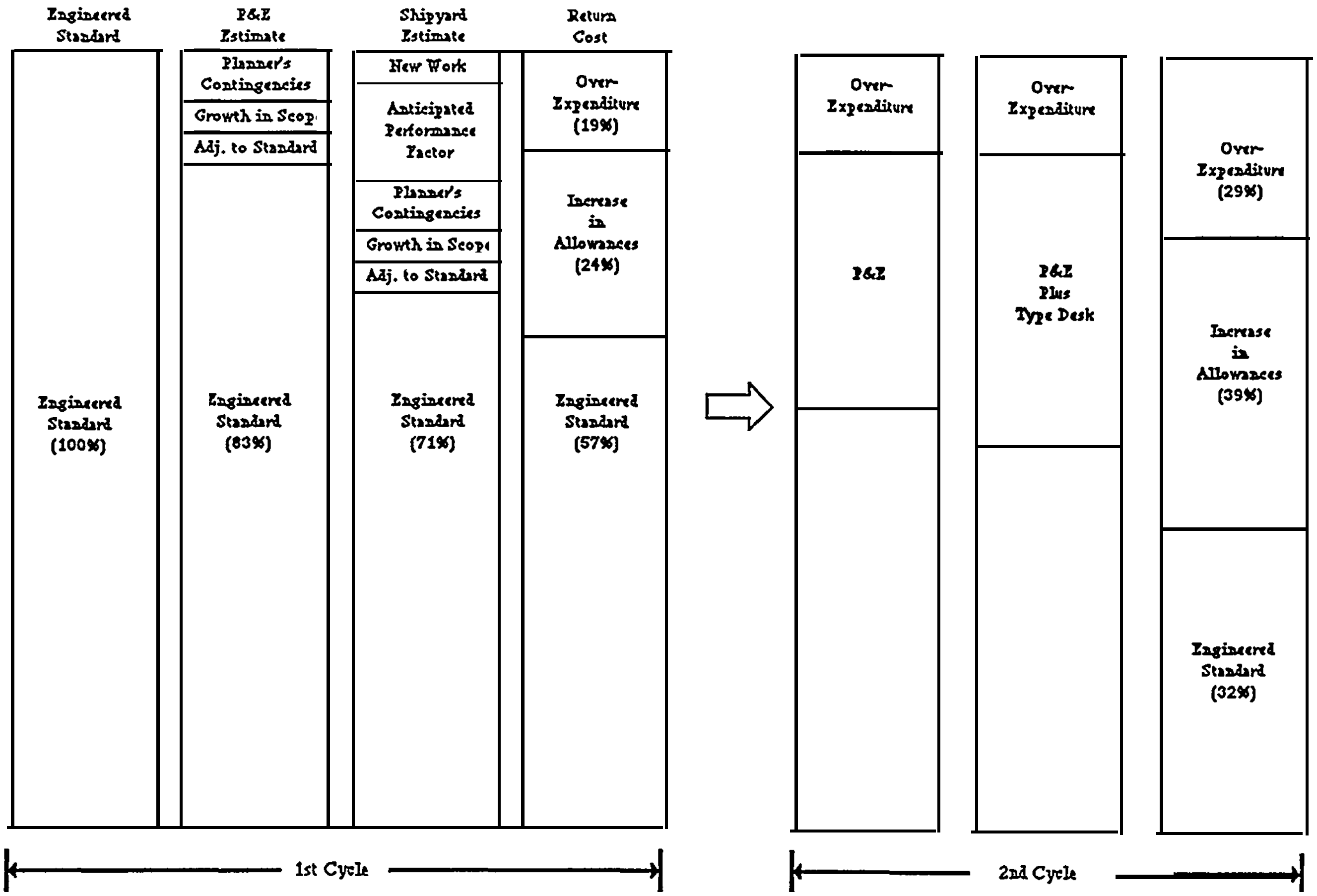


FIGURE 2

In Cooper and Lybrand's Report on the Naval ShipyordS the continual inflation of the key-op was documanted. The multi-tasked key-op remnains open for an extended period which subjects it to rnischanging.

The system of scheduling the keY-op produces problems which can delay Production work. Once a job order is divided into multi-tasked key-ops and phased, a schedule is developed, tying key-ops to key events. A key event is a group of key-ops in the overhaul which must be accomplished by a certain completion date to continue subsequent work. All key-ops in an event have the same completion date. Often work which must precede other work is given the same completion date. Work on one system often interferes with work on another. Drawings, developed by system. are not easily checked for interferences. Systems are often close together, preventing more then one system from being worked at a time. Mechanics are left with the responsibility of identifying interferences and working out a schedule among themselves.

If one system interferes with another and each has a different completion date, the interference can cause the system with the earlier completion date to finish behind schedule. No means in the system, beyond the memory of the scheduler, can anticipate these problems.

Problems in planning and sequencing are usually handled when they are discovered by the mechanic on the ship. The mechanic is burdened with gathering the numerous references (and references on the references) within the key-op before he can establish what he has to do. Planned correctly, the research data should be provided to the mechanic.

This leaves us with five interactive problems. The first is that funding establishes a system prone to waste. This problem is not within the bounds of the shipyards' control: however, it can be significantly reduced by correcting the remaining four. The four remaining problems are: the interactive traps of funding by system, planning using key-ops which are too broad, scheduling by event, and inflating cost by inaccurate historical expenditure records. All four of these problems must be tackled together for any solution to be effective.

CRITERIA FOR A SOLUTION

To construct a solution, certain criteria have been established that will better direct and evaluate progress.

1. Communication between Production, Engineering, Planning and Estimating, Scheduling. and Supply will support a product work breakdown structure.
2. A method of planning and scheduling should be established to facilitate build strategy development and work sequence, developed by zone/ stage rather than system to account for impacts within a work parameter [6].
3. Information delivered to the mechanic should contain all the information required to accomplish the work, enabling him to quickly understand the scope of the work and begin.
4. The MIS must be adjusted to enable analysis of work by relating manhours expended to physical characteristics of material, e.g. length of gas-cutting during ripout, weight of pipe pieces assembled on board. lengths *of* electric cable pulled in place. etc. Work so classified by problem category (area) and such description of how work is normally being performed permits the employment of statistical control methods and realistic manhour budgeting and scheduling. This implies redefining the tasks, processes (manufacturing. ripout , assembly, installation, etc.) and work centers.

These criteria will be used to judge the ZORO program currently underway at Puget Sound Naval Shipyard.

THE OUTFIT PLANNING GROUP (OPG)

The present Naval Shipyard planning system is dominated by a system-oriented approach. This approach stems directly from work assigned on the budgeting level by system; work receives funding through system drawings and key-ops. Unfortunately, this has resulted in planning, production, and design being divided into separate entities concerned with their own responsibilities and having limited interface between these organizations.

To support a product-oriented approach, a team of people collectively knowledgeable in all the tasks involved was perceived as the best means to plan the work. The OPG was the result.

The OPG, in effect an ad -hoc product team, is a medium for communication to produce and schedule a strategy which melds production, planning. and design engineering. Using the zone/stage concept, an OPG is responsible for the development, planning, and execution of a Project leading to a specific product, e.g., outfitted and painted block. overhauled submarine ballast tank. etc.

The OPG's are overseen by a steering committee. The steering committee is responsible for analyzing and evaluating current and future ZORO projects. It also directs and coordinates the ongoing ZORO program, dealing with resource use. equipment acquisition. the distribution of ideas, and recommendations to management to adjust personnel requirements. The steering committee is composed of management facilitators from both the Production Department and the Design Division.

Each OPG is co-chaired by one representative from design and one representative from production. The design chairman is in charge of preparing composite drawings that reflect the build strategy mutually conceived with the production chairman. The production chairman is responsible for manufacturing components and assembly work per the built strategy. Both share responsibilities for breaking the project into sequenced stages, and, for their respective areas, are responsible for budgeting manhours and for scheduling. The co-chairmen are selected by management. based on their expertise, commensurate with the problems posed by a specific product assigned.

Titles given to the design and production representatives are Chairman and Zone Manager, respectively, as they have major responsibilities in accomplishing work associated with the product assigned. The OPG itself is composed of two groups, the core group and a support group.

Typically, the core group is composed of the Chairman representing engineering, the Zone Manager representing the lead production shop, as well as representatives from other important production shops, critical support shops (such as testing), scheduling, supply, planning and estimating. Mechanics, experts on the strengths and limitations of production, now have direct input into how work is accomplished.

A support group is also chosen from those who have a limited role in the completion of the project. Together, this team of people is responsible for packaging and sequencing the work (Figure 3).

PACKAGING AND SEQUENCING

The projects to be planned generally comprise a piece of the ship. These large regions are referred to as grand zones. To facilitate the completion of the project, the OPG reduces the grand zone into individual zones. These zones are then extracted from a CAD model in the form of three dimensional (3-D) graphics, to be used as an aid in planning and sequencing the work. These isometrics are a composite of various systems and ship-alts found within the zone.

To assemble the model at this time is the most expensive portion of the ZORO process. It involves an intense amount of CAD computer and operator time. The structural loft is presently the major modeling unit. with representatives from the sheet metal, electrical/electronics, and pipe shops also participating. In the future, modeling will be accomplished by engineering or a trained contractor. Future alterations to the vessels can be designed on the model and the stored data transferred to the production facility to be planned in detail for production (Figure 4).

In constructing the computer model, several steps are followed to allow easy access to the model and ease of expansion at a later time. The first step is to enter the frames and external structures. Next, the model is filled with existing structure, deck modifications, and new foundations (Figure 5). Also entered are piping. electrical. and ventilation systems. Each model entity is “built” by the respective production shop which usually handles the respective installation. The shops are organized around a layering scheme. Using this layering scheme, the model entities are stored as a unit and can be viewed separately, or combined with other systems from the other shops. Once this is done, the entire model is assembled and a checking process has begun. As the layering is by types of work, it represents inclusion of production planning before the design is issued to the mechanic. This is a singular difference. Traditionally, planning is accomplished after the fact, and problems are solved onboard using costly amounts of time and rework.

The model is examined to find any interferences between planned and existing structure or fixtures. The model is updated based on ship check information, and advance notice of drawing changes. The mistakes that surface are studied, and solution proposals are developed and discussed with the planning organization — usually the Expanded Planning Yard (EPY) [7]. Any problems encountered are illustrated with graphics from the CAD and are then forwarded to the EPY to officially incorporate the changes.

In the past, these shipboard configuration problems did not surface until the installation phase was being accomplished onboard the ship. Each problem found required 5 to 15 days to resolve, delaying work considerably.

Drawing changes result in more serious problems, but with zone-oriented logic, which features planning before the fact. changes are greatly minimized.

In the traditional system-by-system approach, even when CAD is employed. problems often occur because drawings issued to the waterfront are already several revisions behind. Drawings, once updated by the EPY, take one to two months to reach the waterfront of the overhaul yard. This time period is often enough for the overhaul yard to complete the work which has been changed on a revision. When the new revision arrives. P&E funds “rework” to correct the designed-in work (in other words. they do the job right twice). Advanced Notice of Drawing Changes (ANDC) are issued much faster than the drawings themselves, often arriving a month or more ahead of the drawing. The ANDC contains the change which will be made to the drawing [8]. By correcting the model, and the work graphics created from it, the rework can be reduced to minimum levels.

Every piece in the model is given intelligence. It is connected to a database containing information about that part. At present, the information stored is reflected by the output shown (Figure 6). This information is presently used to create material lists giving an upfront view of material to the shop plannermen, regardless of job order or key-op. The plannermen use these material lists to accomplish material ordering and assembly instructions. and to provide a material checklist for the mechanics. In the future, material staging and ordering will be supported by the model piece database.

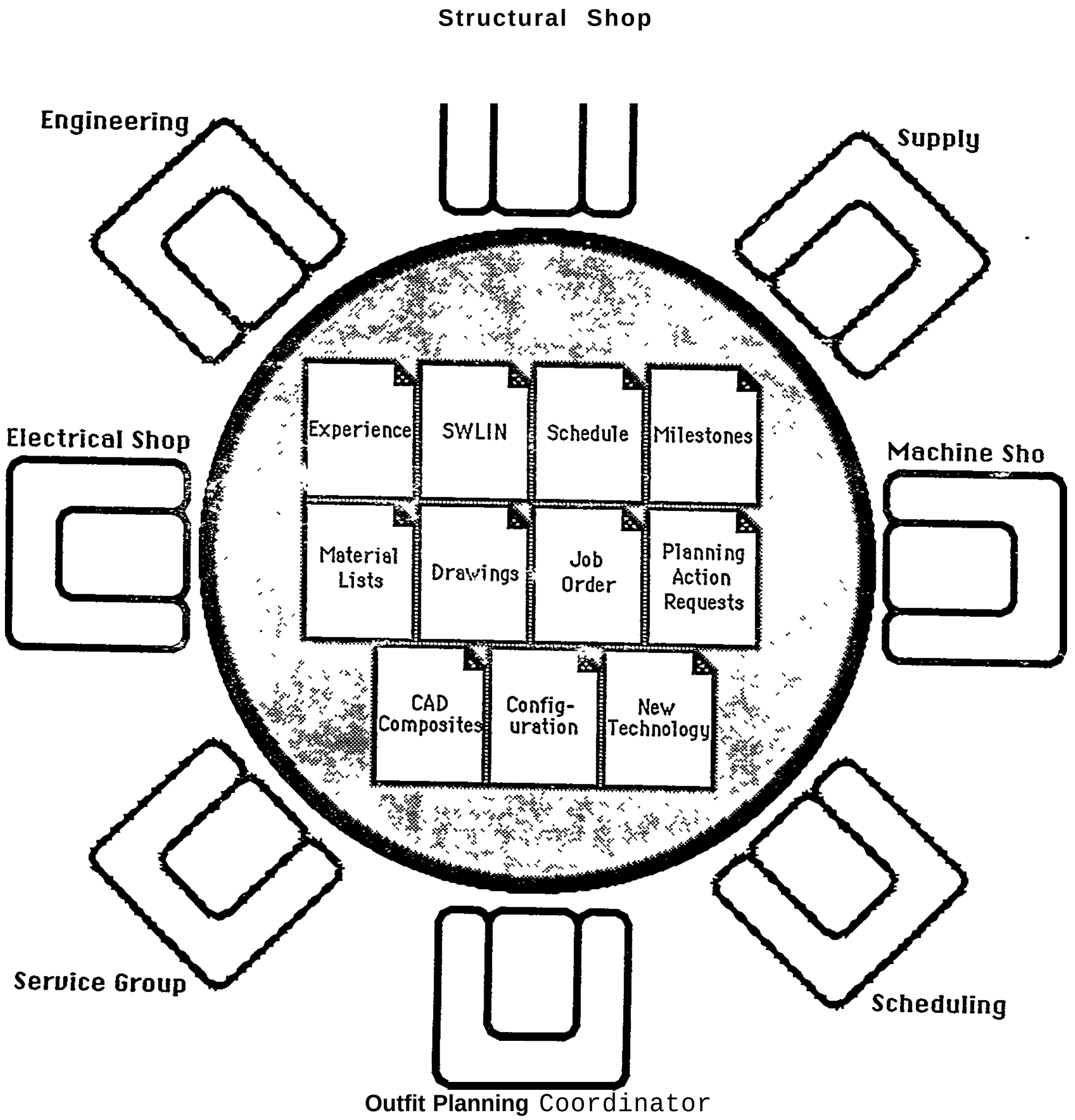


Figure 3.

The Outfit Planning Group provides the opportunely for the collective experience of the members and all the information available to package and sequence the work. New methods, technologies, and innovations can readily be considered and introduced into shipyard procedures.

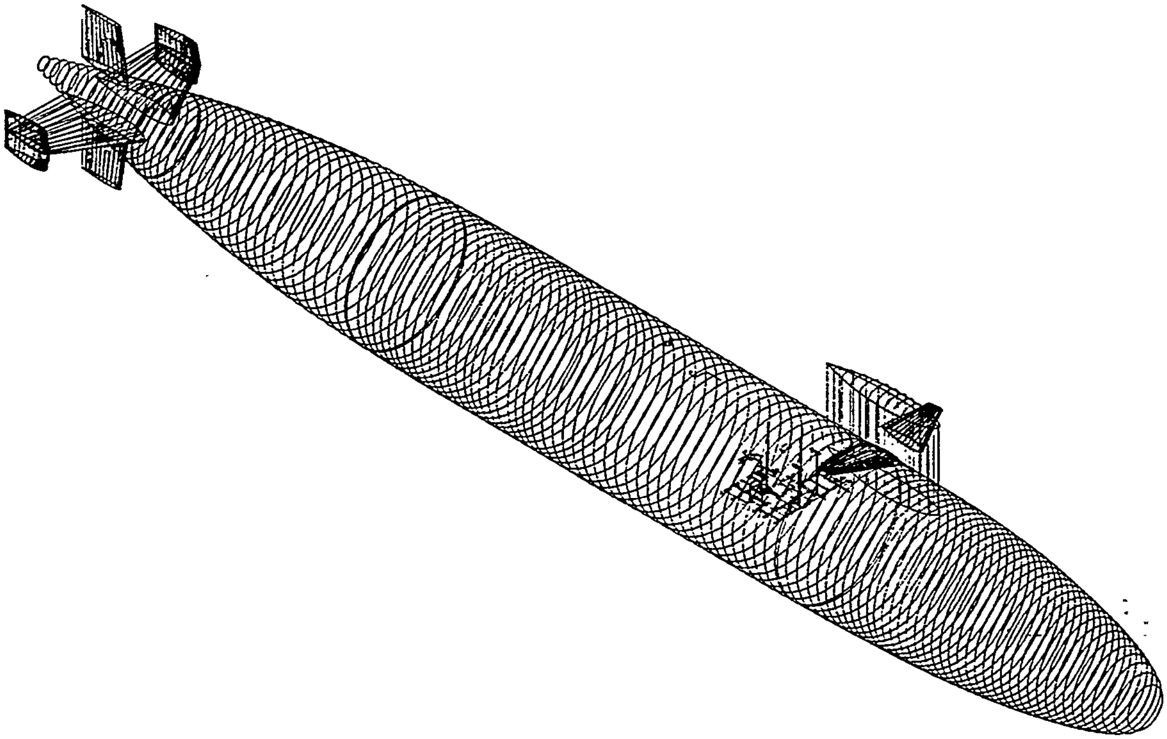


FIGURE 4

The hull of the model is defined and then the structure is inserted followed by foundations, piping, and venting. Above is shown a zone inside the hull frame.

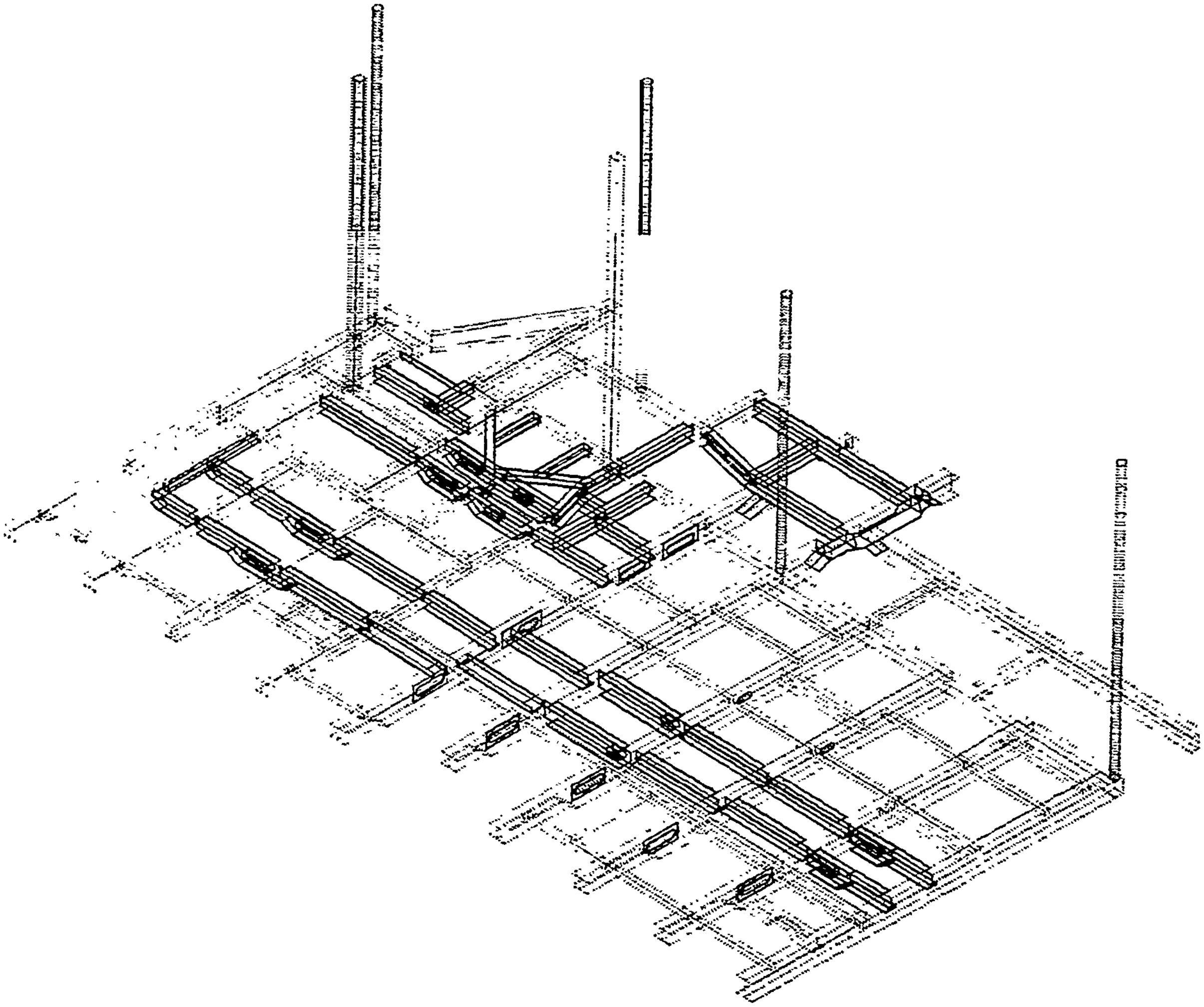
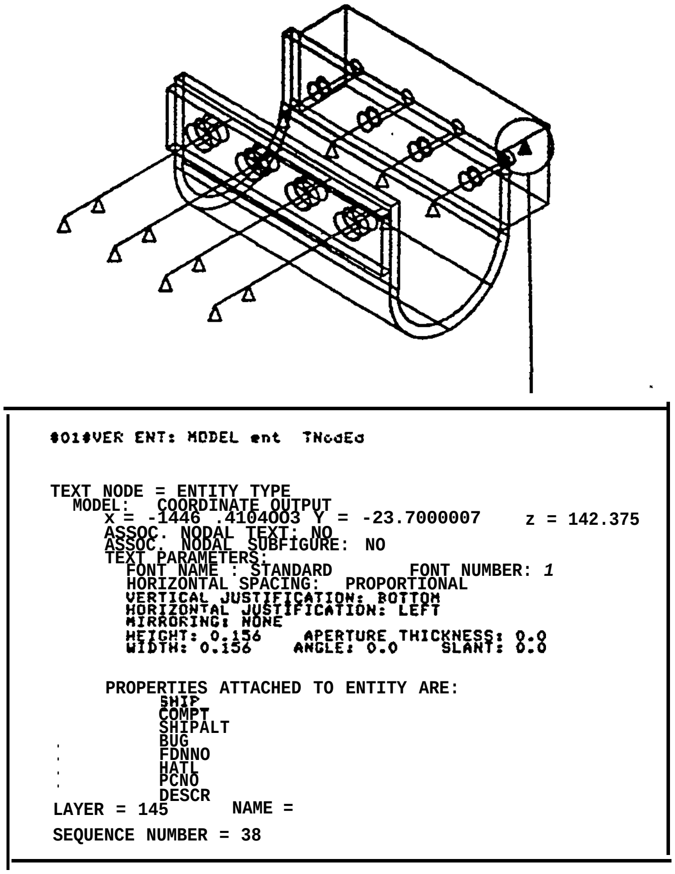


FIGURE 5

The existing structure is faded to avoid confusion in examining the composite. The figure above is the deck ripout in a zone. The ripout composite is a combination of ripout and installation drawings from a number of different ship alterations. In the past it was up to the mechanic to assemble what needed to be ripped out.



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     ASSOC. NODAL TEXT: NO
     ASSOC.  NODAL  SUBFIGURE:  NO
     TEXT PARAMETERS:
       FONT NAME : STANDARD        FONT NUMBER: 1
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       VERTICAL JUSTIFICATION: BOTTOM
       HORIZONTAL JUSTIFICATION: LEFT
       MIRRORING: NONE
       HEIGHT: 0.156    APERTURE THICKNESS: 0.0
       WIDTH: 0.156    ANGLE: 0.0    SLANT: 0.0


     PROPERTIES ATTACHED TO ENTITY ARE:
          SHIP
          COMPT
          SHIPALT
          BUG
          FDNNO
          HATL
          PCNO
          DESCR
LAYER = 145      NAME =

SEQUENCE NUMBER = 38
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FIGURE 6

Each piece is tied to a material database which contains specific information about that piece. This database is used to order material, create assembly instructions, and as a check list for the mechanic on the boat.

Material paybacks alone will justify extensive modeling of ships.

The model is used to generate graphics of each zone (Figure 7). These isometric views are used by the OPG to develop the build strategy. Unlike the system drawings, the views offer several important advantages.

The isometric clearly illustrates how work on one unit will impact another. The flow of work becomes much clearer with all units shown together. The isometric also allows like processes to be identified and grouped together. The most interesting effect, however, has been the new ideas generated by looking at these foundations together as a unit. This has led to combining foundations, reducing weight and volume, and to performing more assembly work in shops .

Once the OPG has discussed the work, the group divides the work into work units (groups of foundations, piping, etc.). The work throughout the zone is then considered in terms of work package phases (Figure 8) and sequenced accordingly. The result is a sequenced work package that is scheduled in an incremental time line to support work to be accomplished. This significantly reduces rework caused by interference with unknown work on another system, and speeds up work, streamlining the production process. It identifies the manning requirements, thereby avoiding two jobs being assigned in the same space at the same time or not having support trades to accomplish assigned work. Further. work so modularized and classified by problem area, per group technology logic, clearly identifies work circumstances that are sufficiently predictable to be controlled by statistical methods.

The Zone Manager and Zone Chairman then take the proposed schedule and assign unit work procedure numbers (Figure 9). These numbers indicate the location task, and sequence of the work unit. The CAD group then begins the production of the Zone Work Packages and Unit Work Procedures.

UNIT WORK PROCEDURES (UWP)

The Unit Work Procedure [9] is a stand-alone information document. containing graphics and text, material requirements, and listing any special tools required to accomplish the task. The UWP is a permanent record of work to be completed -- tied to funding and to schedule. Work progress and cost can be tracked directly from the UWP. The UWP relieves the mechanic of the task of researching and interpreting the key-OP's references and work descriptions. Johny Risko, a mechanic commenting in the installer’s notes at the end of the UWP , wrote, “These unit work procedures are a real time saver, and make the job go faster with more ease. I spent no time having to run down drawings that were not at hand. Everything was at my fingertips. I LIKE THIS IDEA!” In general, the UWP has been enthusiastically received by the mechanics. Four standard groups of UWP have been established: (1) fabrication. (2) assembly. (3) installation, and (4) repair.

The fabrication UWP are divided into subgroups depending on the fabrication process: cuts and forms for structural, cut and bend for piping, and cut and brake for venting and electrical cable lengths. The UWP within a subgroup support a particular type and size of material within a single zone. Staging direction is also included to direct the pieces for assembly by zone.

Movement of each piece is tracked in the pipe shop by a bar coding system. The bar code of each piece is entered as it arrives and when it departs from a work station. At any time. the progress of any piece can be checked by seeing where it is within the shop. Programs to sort and analyze this information can report problem pieces or inform the next work station that it has all the pieces necessary to continue work. The bar coding system has proven effective in tracking work in the pipe shop and will be expanded to other shops. At this time, the yard intends to premanufacture all pieces and assemblies prior to a ship’s arrival. As material receiving and tracking improve, a just-in-time system is anticipated to facilitate better use of staging areas and smooth in-shop work load [10]. Manufacturing or overhauling components in shops long before they are needed is not generally understood to seriously detract from productivity. But even if they did understand, traditional system-by-system planners do not give shops adequate knowledge of when components such as manufactured pipe pieces or overhauled valves are needed for assembly work. The schedule for zone/stage work packages and their material lists solves this problem.

The assembly UWP provides text and graphics to assemble the pieces into a unit. The bar code system will allow easy assessment of the material to confirm whether all the pieces are present. The graphics will include a 3-D isometric of the completed unit. This will give the mechanic a good idea of what the unit will look like, reducing errors that result from misinterpreting a drawing. Assemblies may include more than one shop’s work. A foundation may be assembled. drilled and tapped: a component set in place: and piping and

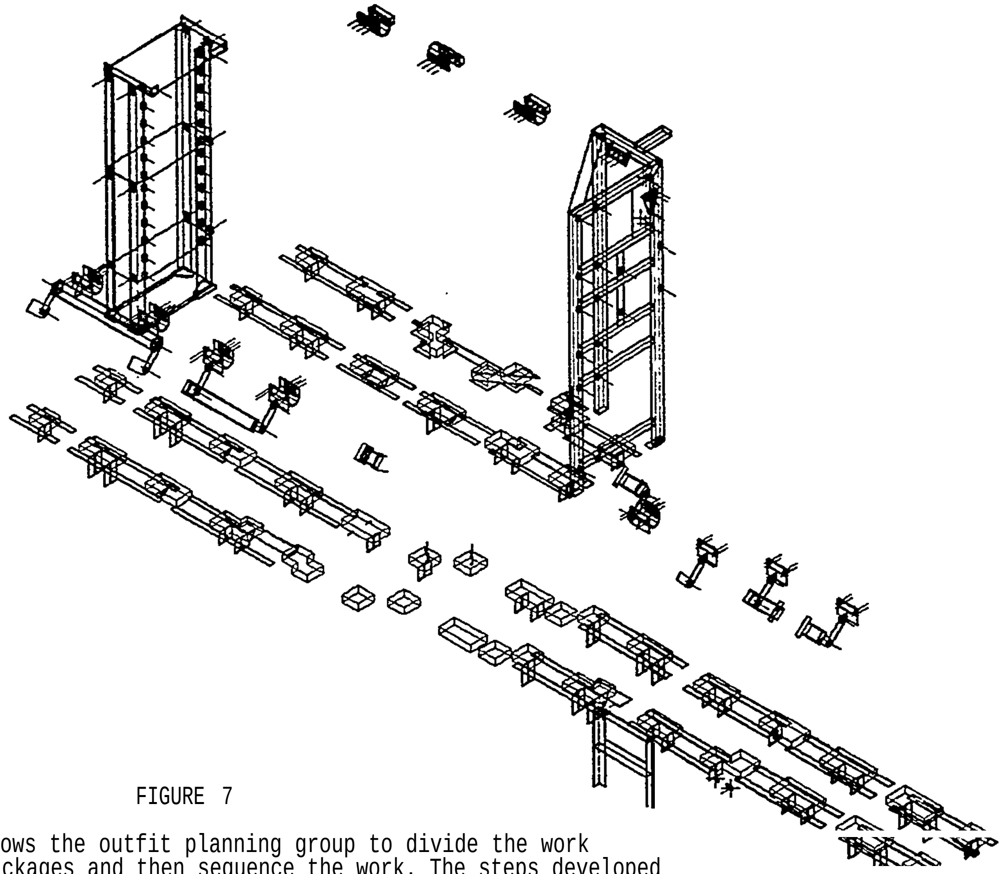

FIGURE 7

The composite allows the outfit planning group to divide the work in a zone into packages and then sequence the work. The steps developed are then assembled into unit work guides.

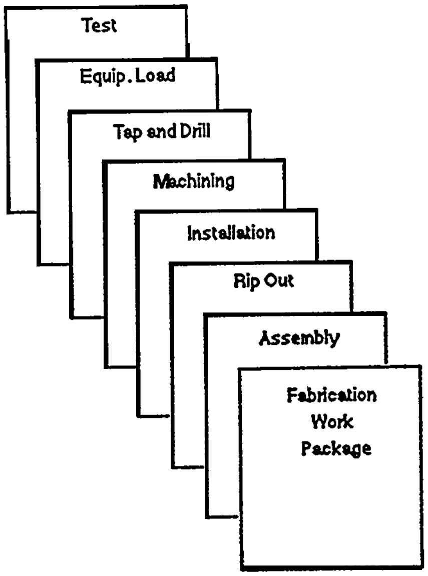

FIGURE 8

Work Packages contain Work for all trades in a single zone. The Work package iscomposed of unit. work guides, sequenced toaccomplish the phase of the work package with maximum efficiency.

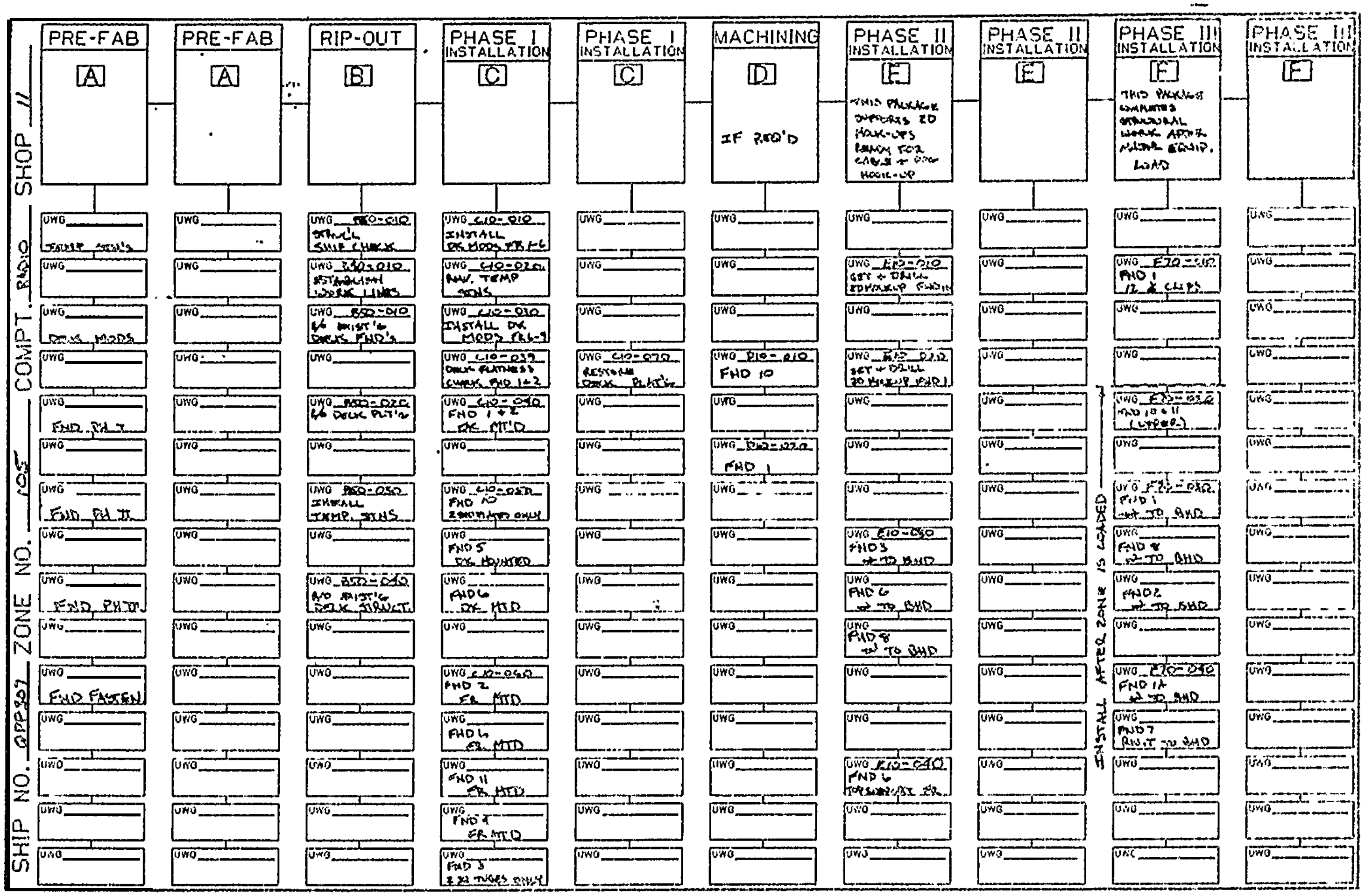

FIGURE 9 - A work package schedule sheet.

wiring connected to match. The assembly is, itself, bar coded and staged to support zone installation when the vessel arrives. By increasing the use of assemblies, more work is accomplished indoors where the working environment is dry, well lighted, and ventilated. Tools and materials are also much closer, and working conditions are safer [11]. Also, manhours, including those for painting, are more evenly distributed over an entire overhauling period.

The installation UWP are sequenced inside of work packages. Each work package covers a phase: shoring, rip-out, deck modification, installation prior to equipment onload, machining, installation after equipment onload, deck refurbishment, and test. Each work package contains installation work for every trade in its phase. The UWP are sequenced to ensure that work in the zone progresses smoothly. Some UWP can be worked in parallel, and this is noted on the schedule included in the work package [12]. The UWP themselves consist of a key isometric showing the area to be worked, sketches showing the work in detail, a cover sheet containing written information, and a list of loose pieces and assemblies. Also included are any procedures or documents necessary to complete the work. A sheet is included for comments by the installing mechanic, to provide feedback on the work accomplished.

The repair UWP contains prerequisites to be accomplished before work on a unit can begin, the paperwork necessary to document work performed (completed as much as possible before work begins), and a list of special tools and materials, coupled with graphics and text. The repair packages are supported by a loose sequence to support reinstallation and test. This flexible schedule helps to determine priorities of work, but still allows for flexibility. Growth is a certainty in repair work: often the complete scope of work cannot be known until the overhaul has begun. The OPG, knowing the scope of the work, can deliver a priority list to both the ship and the shop. The ship can then turn over systems in support of work which needs to begin first, and shops can work in the order necessary to support closing the job efficiently.

The most important advantage of UWP is that experience that formerly was vested only in individuals becomes corporate experience, also. Normal performance of each specific problem classification is published for all to consider. Dissemination of such information, supplemented by training the workforce in simple analysis techniques, e.g. ,Use of cause and effect and Pareto diagrams, makes for a constantly self-improving overhaul system through people working smarter, not harder [13].

Individual UWP are prepared by the shop completing the work in conjunction with Engineering. The sequence into which the UWP fits is developed by the OPG as a whole.

Each UWP is put together in a work package. The work packages contain the entire breakdown of work by everyone accomplishing work in that package. The work packages for each phase of the work comprise the sum of all work to be accomplished from inception to completion. Thus, all work is planned, sequenced, materially supported, and discretely available.

The work package also acts as a unique management tool. It provides a clear plan of work which must be accomplished, and the resources necessary to support that work. It is a unique progress tool, showing the amount of work complete. This ends the need for the foreman to look at the job, scratch his head, and guess a percent complete in discrete units of work. The work package also serves as a record of how work progressed, retaining mistakes and incorporating suggestions through both the zone manager's input and the installer's notes at the end of each work package and UWP, respectively.

The work package supports many process flow techniques. By combining similar work, statistical control methods can be used to monitor, control, and continuously improve shipbuilding design details and work methods so as to maximize production" [14]. This will be applicable not only to shop work; improved premanufacturing techniques and products will result in easy installation in the vessel, further increasing savings and quality.

Currently, tracking of the UWP is by manual batch (the mechanic affixing the time it took to accomplish the task right on the UWP). Certain adjustments to the MIS will be necessary to support the transition to ZORO.

MANAGEMENT INFORMATION SYSTEM ADJUSTMENTS

Presently, the MIS is used to accomplish three operations that need to be reevaluated. The MIS is used: (1) to record key-ops, which are written to represent phases of work, (2) to get back cost accumulation of charges, and (3) to aid in scheduling the key-op to an event.

The present phasing of work by key-op predetermines the work execution process (namely, how and what work is done and in what place), but accomplishes this with minimal transfer of information to the mechanic. The key-op is planned and scheduled using a narrow scope, a particular system. (The mechanic cannot know how one key-op affects other work in the Phase. The mix of work, related or unrelated, has an impact: how can it be considered?) The OPG plans for the entire scope of the work. The work, however, must still be funded. Certainly, estimating will still be required to accomplish this task. Thus, a system is needed that will be flexible enough to estimate by system (at least for the near term} and support work execution by zone (product work breakdown structure).

Flexibility can only be achieved by enabling the internal elements of work (tasks) to be scheduled to an event. To do this, work must be broken down into functional steps. The use of functional steps will allow funding, packaging, sequencing, and scheduling to be accomplished independently of one another.

At present, daily expenditure reports are generated which show an accumulation of charges. What actua'ly needs to be known is <u>who</u> spent the money: “who” being what portion of work or which task within the key-op. The present output of the daily key-op expenditure reports is the total which has been spent so far on any particular job order. To demonstrate how the system is giving inappropriate information, take the following example: within a fabrication key-op, a number of foundations are called out to be constructed. The planner accounts for 10 hours of drilling *on* each, giving the key-op (including cutting, layout, and assembly) a total of 400 hours. About the time 300 hours is spent. the foreman begins to get money conscious. Recognizing that he has reached that number of hours on his daily report for the key-op, he checks on the progress of the foundations. He finds that all have had their drilling completed, but half have yet to be assembled. He knows he does not have enough money left on the key-op to complete the foundations. He does not know who spent the money. Did cutting the pieces take longer than anticipated? Was the key-op inappropriately charged against to cover for extra manning? How could he tell? Further, the fact that 10 hours was estimated to drill each foundation is not recorded anywhere. The drillers may think they have 20 or 100.

To support future ZORO goals, the system must be revised to account for work at the task level, and this level be reflected accordingly in planning, scheduling and funding. The planner accounts for time for each task, each functional step. If that time is recorded, then through feedback the accuracy of that estimate can be determined. The actuaI time required can then be compared to what is normal for a particular work classification. If the time required is below three standard deviations, then the classification of the work or the way it was performed is suspect. Investigate on would have to proceed accordingly. Identifying the functional step, and tracking cost by it, will give the foreman the management tool he needs to audit charging and determine percentage complete and work load.

Under the present system. when a key-op is scheduled, it is grouped with others to a key event which supports a completion date. The key-ops are phased when they are estimated and therefore are already scheduled -- ignoring the internal scheduling of the work within and between those key-ops. Alternatively, by allowing the OPG'S to develop work packages, sequences, and schedules (recognizing their internal interactions), work flow will speed up and cost expenditures will be reduced dramatically. To accomplish this, the funding of work must be made separate from packaging. sequencing. and scheduling work.

Problems seem to develop because the systems funding agent forces all work to be considered in terms of system alone. That funding agent describes the work inadequately. leaving the mechanics to develop a sequence. The funding agent influences the scheduling of the work, and because it is system-oriented. does not consider how work *on one* system impacts another. Funding by functional steps, using work packaging to sequence the work and scheduling to support them. minimizes these problems. Presently, changes are being considered to increase the recording and reporting capabilities of the MIS to support the functional step approach.

The recommended solution to adjusting the MIS is to begin by adding a few numbers to the already lengthy set. This change would not affect the processing time of data. To deliver the flexibility that is necessary, a redefinition of phases and work centers must occur (Figure 10).

The MIS would then estimate and fund the work, allowing the OPG to plan and sequence the details of the varied work of each trade, track the UWP (eliminating research time by the mechanic), record and report both method and cost by zone or system, and ensure accountability from the mechanic upward.

Ongoing projects currently receive funding and work assignment by key-op. They re-breakdown the work assigned using the work package concept. Once the work is accomplished, the feedback information generated from the UWFS and work packages is assembled and recorded.

ACCOUNTING SYSTEM

Work Category
Availability #
SWBS
SWBS Serial #
Key-Op { Presently Phased By Work Center*
Shop Identifier (Organization)
Shop Work Center**
Subtask identifier***
Supervisor Code
Badge #of Mechanic

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*Change accounting number to represent something portion of the ship/ components in an hierchical structured manner.
**Change to task identity, phased and standardized across shops, functional steps. Add the ability to plan multiple simiiiar work tasks for work execution and get return costs at that level.
***Add the ability to have shops indicate detailed planning by subdividing tasks, allowing the return of cost/ schedule data.

FIGURE 10

The incorporation of the proposed MIS system adjustments, both changes and additions(underlined), will create the ability to establish a relationship of tasks within a funding accounting number to a technical requirements file, indicating all the support, material, software, or resulting actions pending to accomplish the task.

To enable cost accounting, the time and material expenditures are reported back to the MIS in terms of the original key-op division. In the future,it is hoped that work wi11 be developed by a product Work breakdown structure and assigned directly by zone.

To begin to integrate these new methods, several projects have been funded by Puget Sound Naval Shipyard. Already the program-s early indicators point to dramatic cost savings in the future.

PROJECT INDICATORS

Several ZORO projects are occurring concurrently at Puget Sound Naval Shipyard. In conjunction with Coopers and Lybrand (C&L), a series of studies are being conducted to help both PSNS and the Naval Industrial Fund Improvement effort evaluate the effectiveness of the outfit planning group, UWP, and zone planning.

The first of these studies is an evaluation of six completed ship alteration ripout packages from the biggest project [15]. A comparison was made of the charges for ripout on the present project using outfit planning and previous work on similar vessels before outfit planning was applied. “The manhours expended by the mechanic were accounted for. The preplanning involved a shipcheck, a revision to ripout drawings, sequencing of ripout work and the issue of revisions to drawings to the mechanic. The manhours charged to the project for the preplanning and ripout of foundation work indicates a savings of 295 manhours over the average 999 manhours charged previously” [16]. This significant savings in manhours. while an early indicator, “may not be a true indicator because it is a small portion of the work and CAD was not used" [17].

A second study was conducted to estimate the cost of a UWP. The work package chosen for study was the shoring package of the project studied above. Modeling costs were determined and broken down by ship. The earliest ship required all the initial hull and frame definition and most of the structural work: thus , it was much more expensive.

The database was then modified for the next two ships due in for deck mounted and hull mounted foundations. The total cost of completing the package, composed of five UWP, was $18.900. For the seven ships which will be overhauled at PSNS in this class. the cost of a UWP is $540

COST ESTIMATE

MODELING:

VESSEL	#OPERATORS	#MAN-HOURS(MH)	COST($35/MH)
ship 1	5	2,800	98,000
ship 2	3	600	21,000
Ship 3	3	480	16,000
Total		3,880	135,800

SHORING PACKAGE COST:

% of Model Cost:	5/60^ *X* (2,800+ 600)	= 284 ($35) = $9,920
Planning Cost	2 X (32MH)^^	= 64 ($35) = $2,240
CAD Time	160^^^	= 160 ($35) = $5,600
Eng. Support:	20% X 160	= 32 ($35) = $1,120
Total		540 MH $18,900*

*Spreading the cost over the series of seven ships the price becomes $2700 per package, $540 dollars per unit work procedure.

^Sixty unit work guides are expected to be completed to support Ship 2 foundation installation. Five unit work guides were needed to support the shoring package.

^^Four days ofplanning by ***two*** people were necessary to prepare the shoring work package.

^^^The CAD operator took 20 days to complete the shoring package. Twenty percent of that time was also accompanied by engineering support,

TABLE 1

The cost of preparing the first work package, a shoring package which will be used on seven ships in series, cost approximately $2700. It is anticipated to eliminate over 2,000 MH of rework which was required on the previous overhaul due to problems caused by warping from insufficient shoring.

(Table 1). A C&L project developed a task specific, system-oriented work instruction which did *not* cross key-ops or SWLIN'S. The estimated cost for a single work instruction was between $4,000-$5,000.

Several other as-yet undocumented savings also serve *to* illustrate the dramatic impact that ZORO can have on construction methods. The best example to date is a foundation which required a five week installation started 28 weeks into the overhaul. The foundation contained work from two ship-alts, and required approximately 40 holes drilled and tapped, as well as machining on board. The foundation sits along the hull behind one stantion and was located close to a major hull cut. The foundation was assembled and machined to tolerance in the structural shop, painted, and transported to the drydock. The riggers began loading the foundation at 9:30, the first tack welds were struck shortly before 11:30. The foundation was completed and welded to the deck in two shifts. For the next ship, the outboard holes will be drilled in shop to further expedite its completion.

This evolution is a direct result of the OPG studying composite drawings of the zone, interacting, and developing a work package for fabrication and installation.

Deck-mounted foundations often have very fine flatness tolerances. In the past, PSNS has machined all such foundations to ensure flatness. However, using controlled welding, the jobs can be completed much faster and do not require the restoration that is required with a mill. One set of three foundations was chosen to experiment with controlled welding to achieve a 0.015" tolerance for each and 0.030" tolerance between each other. Using a machinist level and declivity bars, the foundations were tacked to within 0.002" tolerance and welded to 0.007" tolerance of each other. The welding required more time than the usual quick weld procedure, in anticipation of machining.

As a result of the success of the controlled welding project, similar foundation pads are being examined to take advantage of this faster and less costly procedure. One ship-alt onboard involves the installation of fifty 2x2 pads. Currently, a Liaison Action Request is being prepared for the EPY to allow for the installation of four bedplates as an alternative to the pads. If approved and successful, the time required to complete the ship-alt may be reduced as much as two months.

Machining is not funded until the lead shop requests the funding when the foundation is in place. Since no machining was actually funded, what is shown on the MIS is a greater expenditure of manhours for the shipfitter, even though the cost of placing the mill onboard and the 2-3 days for the men to machine would have occurred. Still, the job closed underexpended, but a significant savings is left unrecorded in the official record.

Finally, the drawings from which all work is performed are in a constant state of flux as corrections are made, mistakes discovered, and updates of changes for numerous reasons cause additions and deletions. By creating 3-D models and constantly updating the database from ANDC'S and new revisions, most designed-in errors are being caught before any fabrication is begun. Over 60 corrections, both minor and major, have been discovered for the current projects' class of ships. This does not include numerous clarifications which were necessary to interpret correctly what was required for completion of the ship-alts.

More extensive results will not be available for several months due to the length of key-ops remaining open and the difficulty of translating MIS information into statistical evaluations of zoned and packaged work.

CONCLUSIONS AND RECOMMENDATIONS

Zone Outfitting in Repair and Overhaul is a powerful planning system that, as the project indicators show, has potential for dramatic impact to meet the criteria detailed in this paper, and accomplished the tasks given to C&L by the Navy. The Outfit Planning Group uses the experience of both production and design to improve production techniques and methods and facilitates their development and integration. Packaging work by zone optimizes production fabrication and installation, while minimizing rework. Sequencing optimizes installation time and manning to accomplish work. The unit work procedure eliminates the need for the mechanic to plan his work from scratch and coordinate haphazardly the integration of his work with other mechanics.

Adjustments to the Management Information System will allow the implementation of a flexible management system where funding, packaging, sequencing, and scheduling can be accomplished independently, allowing Plannermen to more effectively plan and accomplish work and foremen and upper level managers to progress and facilitate the jobs for which they are responsible. In addition, accurate cost accounting, accuracy control programs, manning visibility and requirements, and corporate memory are supported by these changes.

The Philadelphia Naval Shipyard has already completed a significant planning effort for hull expansion of tanks and voids and an auxiliary machinery room in the aircraft carrier KITTYHAWK in accordance with the same zone/stage approach featured by ZORO.

There are several influences which could help the ZORO program develop faster (thus saving more money. more quickly). The first is the support of management. Although the number of supporters at PSNS has steadily grown, further support is necessary. ZORO requires increased up-front money to plan the work *in* detail. It is important for managers to realize that once the initial investment is made, savings will continue for the life of the ship. The Navy needs to encourage that this investment be made, and the database that will develop must be distributed freely through the Naval shipyards.

The present CAD system is a serious deterrent to the speed in which models can be created and work graphics generated. Graphics created and stored on the system are not portable to more modern, much faster systems. It is strongly recommended that another CAD system be integrated into the Naval shipyards. Numerous studies indicate the significant increase in productivity with small increments of computer response time. The CAD system's response time is presently measured in minutes, while comparable operations on other systems are in seconds or fractions thereof. This has impact *on* productivity. efficiency of personnel use, and seriously affects the morale of the operators.

Continued cooperation between all the Naval shipyards, NAVSEA, and C&L and increased involvement by Naval shipyards in the NSRP are essential to effectively coordinate and objectively evaluate progress and future direction.

This approach to planning and packaging work for mechanics drives Engineering to design for producibility through the coordination and experience gained by committing themselves to group technology. In this way Engineering designs a producible product that is efficiently and effectively constructed by Production. The UWP facilitates the integration of ZORO. Their use will cause real and virtual work flows to emerge for most work so as to eliminate much of the greatest single loss in any individual enterprise, people waiting for work. Once implemented, hundreds of millions of government dollars can be saved.

Moreover, the time required to accomplish an overhaul will be reduced. This is a military requirement. This is accomplished by consolidating planning work with CAD and eliminating repetition. With careful sequencing, rework is eliminated and production manhour expenditures minimized. The system provides for feedback which will quickly integrate improvements. ZORO will allow PSNS to once again become a modern. highly efficient Naval facility.

ACKNOWLEDGMENTS

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FOOTNOTES

[1] Government regulation includes the use of material bid, constant planning policy, and management and labor of short term naval officers and ship's force.

[2] *OutfitPlanning*, Maritime Administration. National Shipbuilding Research Program. Seattle. c. 1979. *Product Work Breakdown Structure*. Maritime Administration. National Shipbuilding Research Program. Seattle, C. 1980 (Rev. 1982). *Design for Zone outfitting*. Maritime Administration, National Shipbuilding Research Program, Seattle, C. 1983.

[3] Moen, Dennis, "Application of Zone Logic and Outfit Planning Concepts to Modernization and Repair of U.S. Navy Ships". *Journal of Ship Pro uction* Vol. 1, November 1985, p. 245.
Kjerulf, Shel, "Unit Work Guide for Zone Outfitting in Repair and Overhaul", Draft, February 1986.

[4] Coopers and Lybrand, *Management Analysis of the Navy Industrial Fund Program.* Shipyard Review Report Draft, August 1985.

[5] Ernie EllsWorth of Portsmouth Naval Shipyard reported the distribution of key-ops (work packages) by their size as released by Planning and Estimating for the overhaul of the SSN 690. The majority of 5,432 key-ops. 61%, each contained more than 1,000 manhours. 23% contained between 10,000 and 52,000 manhours. In contrast, most of IHI work packages were about 160 manhours 10 years ago. They are almost down to 40 manhours in size. Toyota is now down to 4 manhours.

[6] *Product Work Breakdown Structure*, Maritime Administration, National Shipbuilding Research Program. Seattle. c. 1980 (rev. 1982). *Flexible Production Scheduling System*. Maritime Administration. National Shipbuilding Research Program, Seattle, c. 1986.

[7] The Expanded Planning Yard is a NAVSEA program which has assigned particular classes of ships to a central organization, one single shipyard. That shipyard is responsible for incorporating any new design changes into classes of vessels, updating drawings for the class, and having an onsite production representative in the overhaul yard to expedite any engineering resolutions required.

[8] At this time, ANDC do not always refect the actual change on the revision, but steps are being taken to bring the percentage to a higher level.

[9] Kjerulf, Shel. "Unit Work Guide for Zone Outfitting in Repair and Overhaul", Draft, February 1986.

[10] *Pipe Piece Family Manufacturing*. Maritime Administration, National Shipbuilding Research Program, Seattle, c. 1982.

[11] *Product Oriented Safety and Health Management*. Maritime Administra- National Shipbuilding Research Program, Seattle, c. 1986.

[12] Quality Assurance (QA) checks can also be carried out at the completion of any phase of work. QA checks could be supported by the same UWG graphics, simplifying verification and problem reporting. This method of checking by zone in stages is being incorporated into the tank inspection and repair project at PSNS, specifically for defining the scope of work, sequencing repair and painting -- to minimize rework.

[13] *Analytical Quality Circles*. National Shipbuilding Research Program,. September 1986.

[14] Storch, Richard, "Accuracy Control Variation-Merging Equations: A Case Study of Their Applications in U.S. Shipyards". *Journal Of Ship Production*, vol. 1. May 1985. pp. 135-144.

[15] Preliminary Study of cost Effectiveness and Schedule Enhancement of Work Packaging (Unit work Guide) C.M. Murphy, Puget Sound Naval Shipyard. Code 383.13. 21 August 1986.

[16] Memorandum Serial 383/1147-86 on the subject of cost-benefit analysis of outfit planning.

[17] Ibid.

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Maritime Administration, NSRP. Outfit Planning, Seattle, c. 1979.

Maritime Administration, NSRP, pipe piece Family manufacturing. Seattle, c. 1982.

Maritime Administration, NSRP, Product Oriented safety and Health Management. Seattle. c. 1986.

Maritime Administration, NSRP, Process Analysis via Accuracy control. Seattle, c. 1982.

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Naval Shipyard Industrial Process Improvement No. 29

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ABSTRACT

In the March 1988 policy letter on Industrial Engineering in Naval Shipyards [1], RADM Roger B. Horne, Jr. (SEA 07) wrote "an effective industrial process control system . . . is an essential ingredient for management control and productivity improvement." This paper describes the prirciples, applications, and initiatives of the management control system for industrial processes in the naval shipyards. It is based on the continuing efforts of the Naval Sea Systems Command Industrial Engineering and Planning Division (SEA 070) and the Naval Shipyards to develop and implement the system, which in turn is based largely on the application and integration of principles and techniques of Industrial Engineering (lE).

The three (3) fundamental aspects of shipyard operations -- planning, performance, and improvement -- and their individual functional elements are highly related. Their common denominator is the industrial processes or methods applied to accomplish jobs included in a ship repair work package. The baseline and systematic relationships between industrial processes and major functional elements of planning (e.g., cost estimating), performance (e.g., production control), and improvement (e.g., capital investment) are examined within this paper. The dependency of shipyard resource effectiveness on industrial process selection and control will be demonstrated. Consider, for example, how the manhours, equipment, and materials would vary if the industrial process applied to perform the job of hull cleaning was hand sanding versus grit blasting versus laser burniag. The key is, of course, to select the "best" industrial process to get the job done in terms of cost, schedule, and quality; this is not always as clear cut as the above simple example might suggest.

The neval shipyard industrial process control system is designed to apply the IE disciplines of methods engineering and work measurement and further, to integrate the resultant information/data in shipyard work planning, control, and improvement systems. The focus of the system is on identifying and implementing the most efficient and effective industrial processes for performing ship overhaul/repair work. This is accomplished with the conduct of IE methods improvement studies and analyses. Representative methods improvement initiatives of the naval shipyard system are outlined herein. In addition, related efforts to optimize industrial process efficiency and effectiveness are briefly discussed.

INTRODUCTION

There are many facets to running an efficient and effective business. whether it's a shipyard, auto assembly plant, or bank. The ability to be product ductive and competitive is affected by an infinite number of internal and external variables, ranging from employee attitudes to technology applied to market conditions. Competitiveness is largely dependent on the effective use of resources (i.e., productivity) and is ultimately measured in dollars reflective of product/service cost. quality, and schedule to customers. There are three (3) fundamental aspects of internal business operations which influence productivity and competitiveness -- planning, performance, and improvement. Planning functions, such as cost estimating, serve as the basis for securing work in a competitive market and optimizing ability to perform. Performing to plan and meeting ccstomer needs will help ensure continued market share. Improvement of operations is essential for cost reduction and business growth.

Planning, performance, and improvement are individually complex and collectively interwoven. For example, prcductive, competitive performance requires efficient and affective planning, though proper planning is not necessarily a guarantee for optimum perfrmance.

The Functional elements of these there fundamentals are highly related and interdependent. The elements of planning, performance, and improvement must be seen as a system which in turn **must be properly integrated. This includes definition and understanding of the inputs, outputs, and relationships for all system elements. The elements include:**

TABLE I

planning	Performance	improvement
* work definition	* work authorization	* strategic business plan
* cost estimating	* cost control	* performance measurement
* workforce strategy	* labor effectiveness	* improved processas
* capital investment	* quality assurance	* new technology/automa-tion
* training	* schedula adherence	* incentives
* material needs	* corporate culture	* management innovation
* workload fcrecasts	* matarial control	* research & development
* scheduling	*organization	* employae involvement
* work packaging	* prcduction control	* systems integration
* industrial process selection/development		

The common denominator of shipyard planning, performance, and improvement is the industrial Processes or production methods applied to accomplish work (i.e.. jobs or tasks) included in a given ship ovarhaul/repair work package. Each and all of these elemants must be systematically driven by information and data reflecting the work to be done, or, mora importantly, how work will be done.

INDUSTRIAL PROCESSES OVERVIEW

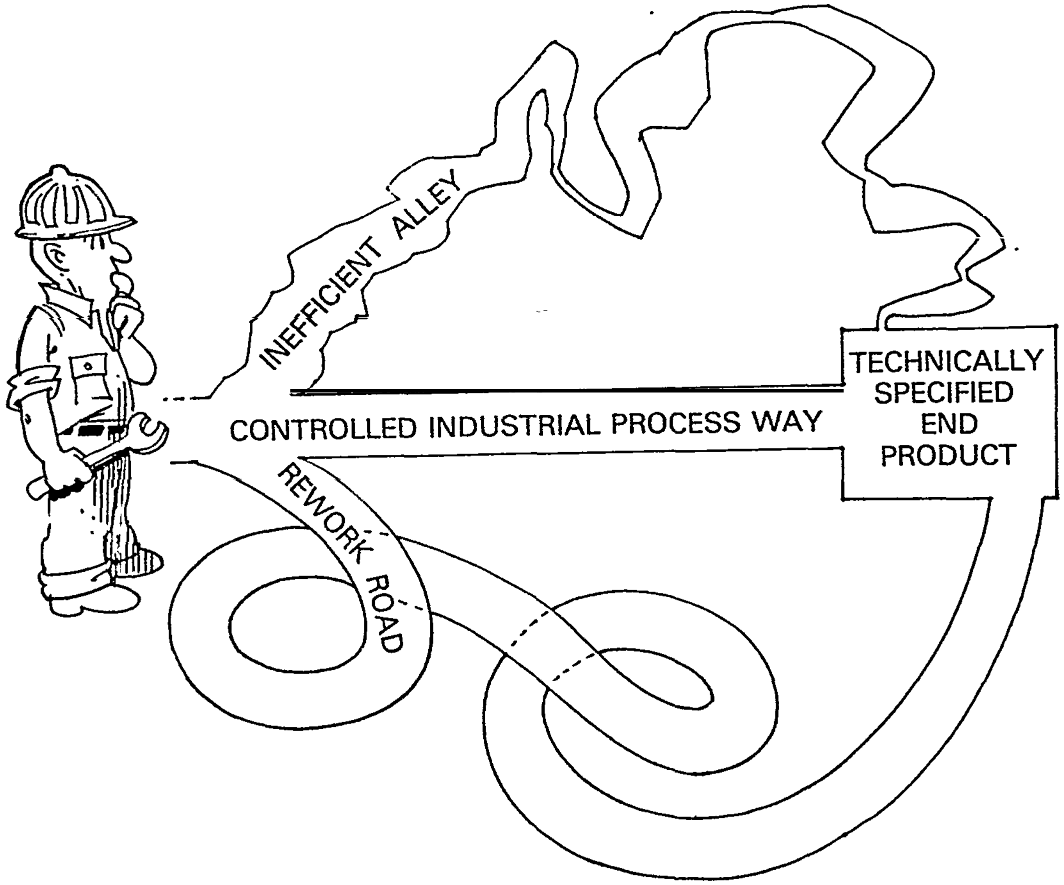
The primary mission of the naval shipyards is to perform ovarhaul/repair surface ships and submarines of the U.S Navy. Fulfilling this mission entails execution of ship work packages assigned or competitively awarded to the shipyard. Each work package consits of jobs which require the pefrformance of work on ship systems/components to achieve the technically specified products. Work is performed by the application of industrial processes. The industrial process is the "means to the end" or "how to" for each job to be perforned.

A more scientific definition of industrial process would be; an integrated set of the information, data, and resources selected and applied to perform a specified unit of work. The components of an industrial process (i.e., the info/data/ resources) include the technical specifications, method. facilities/equipment, materials, quality control/assurance procedures, occupational safety and health (OSH) and environmental protection (EP) requirements, and quantity and skills of labor. All of these components must be identified and integrated to form an industrial process. Technical specifications are normally predeterminad and are therefore the primary independent variable; however, the technical specifications are always subject to modification and streamlining when this will not adversely affect product quality.

As illustrated by Figure 1. there is almost always mere than one "means to the end" or industrial process that can be applied to perform a given job and achieve the required technical configuration and performance specifications. For example, the technical specs for a typical ship overhaul job, such as hull cleaning, might be attainable by a number of methods, such as hand sanding. abrasive blasting, water blasting, roto-peeninig, or lasar burning. Each of thess methcds will have its own associated industrial process: that is, the equipment, manpower. OSH/EP requirements, etc. will vary across each. Furthermore, each of these methods may, in fact, have multiple associated industrial processes. For example, there are several different types of abrasivas which can be used for the abrasive blasting method of hull cleaning: blasting can be done manually or with an automated machine the abrasive may or may not be recycled. and so cm.

The selected method for performing the job is then the focal point or secondary independent variable of the industrial process, and is often described or represented by the equipment or technology employed.

The industrial process or methods selected and applied by the shipyard dictate the required types and amounts of the four {4] basic shipyard resources



HOW DO YOU GET THERE FROM HERE?!

FIGURE 1

of manpower, time, materials, and capital assets. That is, resource requirements are based on how the work will be done. It follows then that the selected/applied industrial processes are key determinants of shipyard resource efficiency and effectiveness (i.e., productivity and competitiveness). Since there are alternative ways to "get there from here". it is vital to the performance and competitiveness of the ,shipyard that the best industrial processes be applied in terms of Cost schedule, and quality. This requires on-going systematic efforts to improve and innovate production methods and/or industrial processes.

The fundamentals of industrial process analysis. selection. design. and improvement are inherent in the IE disciplines of methods engineering and work measurement. Properly applied. these techniques can provide information on which to base cost estimates, workforce strategy, capital investment, schedules, resource requirements, training, and performance measurement/ improvement. A study completed by the Institute of Industrial Engineers (IIE) for Panel SP-8 [2] validates that methods engineering and work measurement techniques provids data for (1) preparingq bids, (2) improving methods to increase productivity and lower costs, and (3) monitoring and controlling production operations.

IIE rated the payoff from implementing these techniques as very high. MIL-STD-1567A [3] identifies the following benefits of these techniques: improving the budgeting process and providing a basis for price estimating; acting as a basis for planning manpower. equipment. and capital requirements; improving production control activities; focusing continual attention on cost control and reduction; and obtaining lower unit cost at all levels because production is more efficient. A Study of Work measurement systems recently completed by the Inspector General of the Department of Defense [4] did not find a single example of a system not being cost effective. The DODIG report did find that commercial contractors use these systems to reduce costs and found similarities in the use of system data for estimating and pricing, manpower and capacity planning, and identification of areas for cost reduction. Furthermore, the DODIG study team found "overwhelming data" in Support of their conclusion that work measurement data should be expanded in shipbuilding and that the shipyard exemption should be deleted from 1567A. At one shipyard visited, the team found data to show the significant amount of cost reduction achieved. Their report also cited the efforts of the National Shipbuilding Research Program (Panel SP-3) in this area as well as those of international shipyards.

INDUSTRIAL PROCESSES: THE COMMON DENOMINATOR

Industrial processes are the common denominator of the functional elements of planning, performance and improvement listed in Table 1. Each of these functions requires input information/data which in turn must be based on the attributes of the selected/applied industrial processes.

To further clarify this relationship, each of the functional elements can be defined in terms of industrial Processes, as illustrated by the following examples:

- Training - providing the workforce with the knowledge, skills, and ability to apply the selected industrial processes.
- Capital investment - obtaining the facilities and equipment required to apply the selected industrial processes.
- Scheduling - Calendar timing and sequencing of the industrial processes to be applied.
- OSH/EP - protecting people and the environment from potentially adverse side effects of the applied industrial processes.
- QA/QC - assuring that the application of the industrial process is performed correctly and resulting in the technically specified product (e.g.. statistical <u>process</u> control).
- Production - performing work by applying selected industrial processes.
- Technical specs - identifying the product configuration and operating requirements which the applied industrial process must result in.
- Workforce planning - determining the quantitY, types, and strategy of human resources required to apply the industrial processes.
- cost estimating - calculating the resources required to apply the industrial *processes* and converting that to a dollar amount.
- Material handling - moving resources or products from one industrial process to another.
- Productivity Improvement - among other things. selecting and applying more efficient and effective industrial processes.

The technical methodology and steps for performing each planning, performance, and improvement function may be the same regardless of the selected industrial process, following the established techniques and practices for the individual discipline. However. a clear understanding of the relationship between industrial processes and each functional element listed in Table 1 is required for an integrated, efficient and effective planning, performance, and improvement <u>system</u>. This relationship is illustrated by the above references and examples. While not necessarily within the scope of the naval shipyard industrial process control system or this paper, it is clear that, given the common denominator relationship of industrial processes with shipyard <u>functions</u> this same relationship can be extrapolated to shipyard <u>organizations</u> and management information systems.

INDUSTRIAL PROCESSES MANAGEMENT CONTROL MODEL

Figure 2 illustrates an IE oriented shipyard management and control system model, showing the foundation of industrial processes and how they integrate with representative planning. performance, and improvement system elements.

The model begins with a job to be performed from the ship overhaul/repair Work package, such as underwater hull cleaning. Selecting the basic industrial process that the shipyard will apply to get the job done is the first

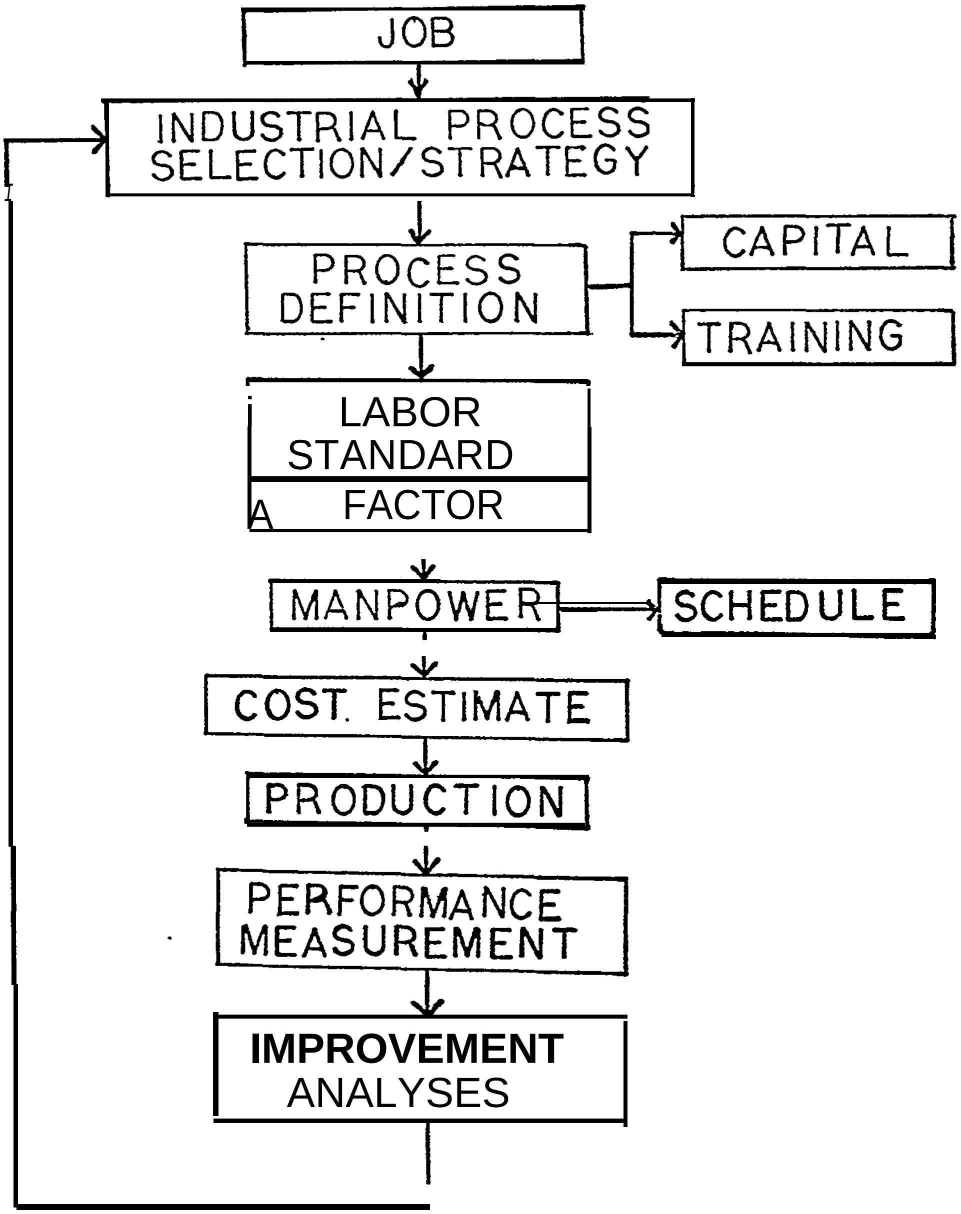


FIGURE 2

and most important step, for this will affect all other factors in the system, as discussed above and as depicted in Figure 2. The objective is to select the most efficient and effective industrial process for performing the job and meeting the required technical specifications. In conjunction with this effort, the way in which this process will be performed and integrated with other jobs as part of the same work package must be determined in overhaul strategy and planning evolutions. This strategy/planning phase can significantly influence the true effectiveness of the industrial process. This phase is concerned with considerations such as zone versus system, application of group technology principles. use of functional work teams, shipboard versus in-shop, make versus buy, and so on.

Next, the method and system parameters for the selected process must be defined based on the techniques of methods engineering. This step involves identifying and integrating the applicable technical specifications, the detailed steps of the method, the equipment and material required. OSH and QA requirements, trade cognizance, and any special considerations. The results of this evolution are often documented, such as in a shipyard Industrial process Instruction (IPI) or Unit Work Guide [5] This documentation provides a record of the information, data, and resources required for process planning, performance, control, and improvement.

Industrial process selection and development provide a clear picture of capital investment, material, and skills/training needs. That is, the shipyard needs the facilities, equipment, materials, and trained employees required for the selected industrial process.

The next key step is to develop a labor standard using techniques of work measurement in order to identify how long the job should take. There are several different types of labor standards with varying development methods and degrees of accuracy, such as engineered. The labor standard then serves as the basis for realistic manpower requirements, estimates/allowances, and performance measurement towards on-going control and improvement. Use of labor standards for these purposes requires application of a factor which accurately reflects variables such as management/production inefficiencies, learning curve, risk assessment, and unique job conditions.

Factors Affecting Application of the Model

Needless to say, the business of shipyard industrial planning and control is not as simple as the model portrays, nor is it as straightforward and Standardized as auto assembly plant planning. However, if the unique aspects and complexities of naval shipyards (e.g.. job shop nature) are recognized and addressed, the model system can be effectively applied to shipyards within prescribed guidelines.

The biggest issue in applying the model is in determining the level of planning effort required for a given job: that is, how much effort should be expended towards selecting the best industrial process. For example, is a comprehensive methods improvement analysis desirable; is an engineered labor standard warranted; are special personnel qualifications appropriate; is capital investment justified; is thorough cost/schedule control needed? The extent of industrial process planning and control required for efficient/effective peformance reaches a point of diminishing returns -- the key is to determine the level of effort required to optimize performance. and to allocate scarce IE and planning resources *to those jobs where* the benefit will be greatest.

There are several factors which affect the appropriate level on a case basis. The different levels of jobs/industrial processes performed in the naval shipyards, ranging from the very simple to the very complex and critical, are depicted in Figure 3. Where a particular job falls within this spectrum is a key indicator of the level of planning effort required. Simple, routine jobs ordinarily require minimum planning, while complex new work may require extremely detailed industrial process planning.

There are many factors which assist in determining where in the spectrum *a* given job or industrial process lies, several of which are difficult, to objectively quantify. The difficulty in determining the optimum level is compounded by the fact that multiple factors often apply to a given job end must be considered simultaneously.

One of the most important considerations is whether the given job is “start-up” or “routine” (with respect to planning). That is, once the planning process has been gone through for a given job as part of a given work package, significantly less effort is required for future applications (unless, of course, one or more of the ten factors indicate a need for action!). Therefore, the initial consideration is what type(s) of planning process output is already in place for the job. such as a trained workforce, advanced technology, industrial process documentation, or labor standard.

Other factors to consider to identify the process level include:

(a) The cost of the job, including labor and material. The greater the cost, the greater the potential benefit from in-depth planning, control, and industrial process improvement.

(b.) The number of times and frequency which the job will be performed. The more a job will be done, the greater the need may be for in-depth planning (start-up) and industrial process development. However, a highly complex/critical job which will be done only once may require extensive planning.

(c) The ship’s system or component to which the industrial process is applied. Certain systems are mission essential or are vital to ship’s force safety/health, and applicable jobs warrant thorough planning and process analysis.

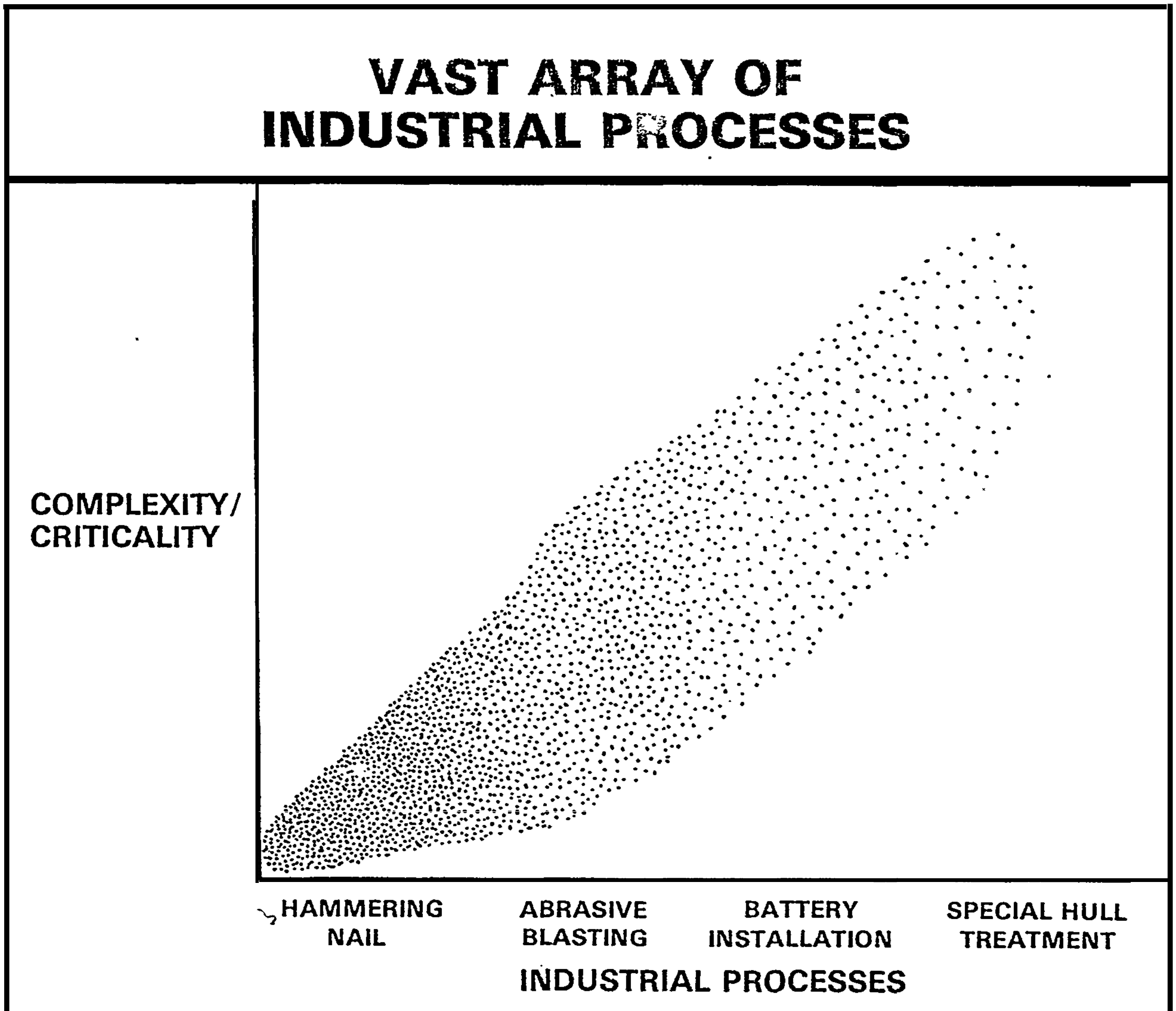


FIGURE 3

(d) The level of occupational safety and health hazards associated with the job. Extremely dangerous jobs warrant significant planning consideration and detailed indastrial process specifications. Similarly, for environmental hazards.

(e) The potential impact of failure. If a process or product failure will result in a threat to ship's mission or ship's force health, or in a significant rework cost, or in an unacceptable schedule delay, detailed planning is almost certainly in order.

(f) Historical failure rates. If a given activity has experienced an excessive amount of failures on a given job, this may indicate a need for improved planning and industrial processes.

(g) The number of trades and/or workers involved. A job which requires a myriad of trades and large quantity of personnel may deserve more planning and control than a single trade/mechanic job.

(h) Schedule critical events. Those jobs which are part of the critical path of the availability should be given more detailed consideration.

(i) New technology. When an industrial process involves use of new technologies or processes where prior guidance and experience are limited, planning must be thorough.

(j) The type(s) of skills required. A job which requires skills which are basic or those which are reasonably expected to be part of a trained journeyman mechanic's skills typically require less planning than a job which needs highly specialized skills.

Different levels of jobs require different levels of planning and control in terms of allocating resources for industrial process selection or improvement. The ten (10) factors listed above help determine job levels to meaningfully correlate with planning/control levels. That is, based on evaluation of the above factors, a job category can be assigned to a given job which reflects the optimum level of planning/control. To provide a hierarchical structure for effective planning and control, the naval shipyard system employs four categories, Each job/process category has associated attributes for planning, control, and improvement variables.

NAVAL SHIPYARD INITIATIVES

The preceding sections of this paper addressed the principles and rationale for the Management Control System for Industrial Processes in the Naval Shipyards. The remaining section is devoted to briefly outlining initiatives of the system.

Industrial Process Improvements

The primary objective of the naval shipyard system is to identify and implement industrial process improvements which will result in optimum resource efficiency and effectiveness. Following are some representative examples of industrial process improvements.

(1) Sewage System Tank Cleaning. Collection, holding and transfer (CHT) tanks collect human and other shipboard wastes and require cleaning during overhaul. Traditional tank cleaning methods were labor intensive, hazardous, and demoralizing. Naval shipyards now use an enzyme/bacteria cultures ("the bugs") process for surface ship CHT tank cleaning. Simplistically, the "bugs" are mixed with water. dumped in the tank, allowed to break down the wastes into solution, and drained into the local sanitary sewer system.

This innovative process is a major improvement, because: minimizes the need for people to enter the tank and the associated hazards/precautions minimizes the need for using hazardous materials and generation of hazardous waste: appreciably reduces the cleaning cycle time: cleans more efficiently and effectively: and, as a result, reduces the cost of tank cleaning by an average of 90%.

(2) Pipe Connection. The use of swaged marine fittings (SMF) is being significantly expanded. SMF are a type of pipe connection which use hydraulic pressure to swage the fitting in place. The SMF is crimped onto the pipe to provide a metal-to-metal and o-ring seal. SBF provide considerable cost savings over traditional welding/silver brazing methods due to advantages, including: does not create heat and fumes which interfere with other work: is not affected by "hot work" constraints: assist trade requirements are minimal. including elimination of firewatch: tooling is portable and service lines are eliminated; the absence of flux, slag, or oxides reduces the need to flush piping: and, smaller radial clearances can be tolerated, thus reducing interference removal.

(3) Special Hull Treatment (SHT) Installation. SHT installation is extraordinary in its scope, complexity, and technical controls, and is extremely labor intensive. Initial production SHT installations were performed in FY'86. Considerable resources were expended in the pre-installation industrial planning phase to develop an integrated installation industrial process. The initial installations were subject to a comprehensive IE methods engineering analysis, which produced cost reductions in excess of $600.000 per installation at one shipyard.

(4) Organotin Paint Application. Organotin is an anti-fouling paint which when applied to hulls, significantly improves ship performance and reduces fuel consumption and costs. It is not, in fact. necessarily an improved ship overhaul/repair process. However. Le-

cause of the hazardous and controversial nature of organotin application, a thorough, detailed industrial planning effort was required to design an efficient, effective, and safe industrial process.

(5) Other process improvement initiatives currently in developmert include hydraulic boiler tube stub removal, thermal spray for corrosion control and machinery restoration. hard chrone plating, heat recoverable couplings, hull circularity measurement, shipboard cleaning of HP flasks. and waterjet SHT removal.

Other Initiatives

Simply selecting the best industrial process is not enough to optimize resource effectiveness. The processes must be properly implemented, managed, planned, and controlled. Following is a brief description of other NAVSEA/Naval Shipyard initiatives consistent with the principles and sbjectives of the subject system.

(1) Work Sampling studies. The time of a shipyard production worker on the job can be in one of three categories: productive (i.e., "turning the wrench"): ancillary (e.g.. training, reviewing documentation, workplace clean-up, personal time); and, non-productive (a.k.a. non-process time and "lost time"). The key of course, is to maximize the productive, optimize the ancillary, and minimize the non-productive. The latter includes time spent on rework; waiting for assist trade, job assignment, material, equipment/tools, or paperwork; performing work which is not authorized or is in excess of the selected industrial process; and, those delays which are in tha direct control of the worker. Minimization of non-productive time requires accurately measuring it. identifying and quantifying the true causes, implementing cost effective improvement actions, and measuring their effect. An ideal technique for accomplishing this is with the performances of results oriented is Work sampling studies. Therefore, naval Shipyards have implemented a disciplined program for work sampling Studies designed to maximize productive time.

(2) Hazardous Waste Reduction. Costs,liability liabilities, and public ***concern*** with hazardous waste (HW) are escalating. Environmental regulations and HW disposal altarnatives are growing ever tighter. As with any problem, HW must be attacked at the source -- the industrial processes where it is generated. Therefore, the naval shipyard IE community has launched a major program to minimize HW genaration, while maintaining emphasis on personnel protection and regulatory compliance. Those processes which generate HW are being studied with consideration to procass modification, Material substitution, product radesign, recycling or reclamation, and improved controls.

(3) NSRP Involvement. The NSRP is a proven source of ship repair planning, performance, and improvement enhancemants, including industrial process improvemants, NAVSEA and Naval Shipyard support and participation in the NSRP are increasing, from Panel membership to project implement ation. Puget Sound Naval Shipyard actions to implement zone by stage concepts and techniques are wal1 recognized, NAVSEA and the NSRP Ship Production Committee. along with MARAD and the Shipbuilder's Council, jointly sponsored the 1987 National Shipbuilding and Repair Industry Productivity Improvement Campaign; efforts for the 1988 Campaign are underway.

Similarly, NAVSEA and the shipyards are conducting Visits to a variety of private sector companies with outstanding reputations for productivity management and improvement, and are a working with other Navy/DoD/Government agencies and ths Institute of Industrial Engineers.

(4) Gainsharing. Gainsharing plans are a proven successful tool for motivating and recognizing employee involvement and productivity improvement. Productivity gainsharing plans are currently being designed and implemented in naval shipyards.

(5) Labor Standards. Because of the pivotal role of labor standards in accurate and reliable planning. control and

improvement functions. NAVSEA and the shipyards are placing increased emphasis on standards development, application, and maintenance. For example, the traditional shipyard jargon of "should cost" has been replaced with "standard cost" to better reflect these principles. NAVSEA and shipyard IE managers, including RADM Horne, visited Peterson Builders, Incorporated to see and learn a successfully implemented Panel SP-8 project on labor standard development and application.

(5) Other current initiatives include implementation of zone principles and techniques, use of project management and functional work teams, improvement of work instructions, quality improvement programs, recyclable packages and rotable pools, and the Model Installations Program.

SUMMARY

Productive and competitive shipyard operations require efficient and effective planning, performance/ control, and improvement. There are a myriad of principles, techniques, tools, and variables which affect these three fundamentals and their individual functional elements. All must be systematically considered and intograted. This paper has demonstrated that the industrial processes selected and applied to perform the workload are the common denominator. Furthermore. these processes are critical determinants of test and resource effectiveness. Industrial process management. central, and improvement are therefore vital to shipyard productivity and competitiveness. It is most difficult to manage that which cannot be measured. It is Gqually difficult to measure that Which is not defined. The industrial engineering techniques of methods engineering and work measurement facilitate accurate, reliable definition and measurement of the information, data, and resources (i.e.. industrial processes) required for shipyard operations, The resultant information/data can then be integrated with shipyard planning, performance, and improvement systems such as cost estimating, Scheduling, training, capital investment, and workforce planning, Naval Sea Systems Commands and the Naval Shipyards are implementing a system and variety of iniatives based on the principles discussed herein.

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Study Circles Applied to Shipyards

No. 30

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ABSTRACT

STUDY CIRCLES ARE A SCANDINAVIAN CONCEPT, IT IS ESTIMATED IN THESE COUNTRIES, EVERY INDIVIDUAL JOINS A STUDY CIRCLE EVERY YEAR, STUDY CIRCLES ARE VOLUNTARY, SELF-FACILITATING GROUPS INTERESTED IN A PARTICULAR SUBJECT, THE RANGE OF THESE SUBJECTS MAY BE FROM LEARNING BASIC PHOTOGRAPHY TO REFERENDUM ISSUES ON NUCLEAR POWER, BACKGROUND MATERIAL IN THE AREA OF THE SUBJECT OF THE STUDY CIRCLE IS PROVIDED BY THE GOVERNMENT, THIS PAPER WILL EXAMINE A METHOD OF TRANSPLANTING THE STUDY CIRCLE CONCEPT TO A LARGE, HEAVY-INDUSTRY, FACILITY OF THE FEDERAL GOVERNMENT - A SHIPYARD- TO SOLVE PROBLEMS BEYOND THE SCOPE OF TRADITIONAL QUALITY CIRCLES.

STUDY CIRCLES

The program of a Scandinavian concept transplanted in a large, heavy-industry, facility of the Federal government solving problems beyond the scope of traditional quality circles. This paper will compare the study circle concept with two common forms of problem-solving groups - the task force and the quality circle. In making the comparison, the three groups - the task force, the quality circle, and the study circle - will be examined using the following six attributes: participant selection, participant involvement, training, participant representation, skill level, and goal selection. The task force and the quality circle are developed in parallel below to aid in discerning similarities and differences.

TASK FORCE

The traditional management approach to problem-solving is the task force. One definition of the task force is a temporary grouping of selected individuals under one leader for purpose of accomplishing a definite objective. A typical shipyard application of a task force would be to summon a group of individuals to solve a problem. In summoning the group, management would identify individuals with specific education, experience or skills, and assign these individuals to work as a group solving a predetermined problem. In this application the problem might be leaking hull valves after reinstallation during an overhaul. After the problem solution was presented to management, the task force would disband with these individuals returning to their parent departments.

The task force will be examined employing the following six attributes: participant selection, participant involvement, training,

QUALITY CIRCLE

Quality circle is a generic term used to identify a participatory management approach to problem-solving. One definition of the quality circle is a small group of employees and their supervisor, with same work area interests, who voluntarily form a team, receive training in group problem-solving techniques, regularly meet to identify work-related problems, recommend solutions to their management for approval, and monitor effectiveness of these solutions. This definition of quality circles is espoused by the International Association of Quality Circles. Unions generally perceive quality circles ranging from just another management tool (in favorable light) to Union-busting (at the other extreme). Management generally perceive quality circles ranging from another management tool (in favorable light) to contemptible (at the other extreme). A typical shipyard application of a quality circle would be a supervisor leading a group of participant representation, skill level, and goal selection.

Participant Selection - individuals are usually assigned to the task force due to being subject-matter experts (example - the "cracker-jack" mechanical engineer from fluid systems).

Participant Involvement - usually involuntary, individuals are assigned to the task force as a representatives of higher authority (example - as cognizant functional areas are identified, someone is delegated from the functional area - the engineer from fluids).

Training - since the individual was assigned due to being a demonstrated subject-matter expert, the individual is usually presumed to be trained in sufficient group problem-solving techniques (example - intuitively obvious; otherwise, the individual would not be a "cracker-jack" engineer).

Participant Representation - in generating the task force, determinations are made to assure representation covering all involved functional areas.

Skill Level - as participants are subject-matter experts from various functional areas, skill levels are advanced in subject/function.

Goal Selection - usually predetermined as definite objective of the task force.

In comparing the task force with the other two problem-solving groups - the quality circle and the study circle, the first three attributes: participant selection, participant involvement and training, may be perceived as limiting effectiveness of the task force. Management selecting an individual to be a member of the task force does not assure the selected individual believes there is a problem. Unless involvement of the selected individual is voluntary, there is no ownership in the group goal. Being the subject-matter expert does not assure training in group problem-solving techniques. The last three attributes: paraticipant representation, skill and goal selection, may be perceived as enhancing effectiveness of the task force as a problem. solving tool.

employees under this supervisor to solve a problem in their immediate work area. In this application the problem of the quality circle might be new sewing machines for the sail loft.

The quality circle will be examined employing the following six attri. butes: participant selection, participant involvement, training, participant representation, skill level, and goal selection.

Participant Selection - in using the above definition, voluntary; the participant is usually expert at the immediate function,

Participant Involvement - by using the above definition, voluntary; also by using the above definition, the participant has same work area interests as rest of the group.

Training - by definition, the participants receive training in group problem-solving techniques.

Participant Representation - all involved functional areas may not be represented as group is voluntary, and have the same work area interests, (example - the group may need an industrial engineer to determine methods/standards for the new equipment).

Skill Level - as participants only are experts at their immediate functions as compared with subject-matter, skill levels vary in the group (example - supervisor, mechanic, helper, temporary, clerk, and so on).

Goal Selection - any random goal is appropriate grist for the group (example - relocation/type of consumables carried in vending machines, Pepsi v Coke).

In comparing the quality circle with the other two problem-solving groups, the task force and the study circle, the first three attributes: participant selection, participant involvement, and training, may be perceived as enhancing effectiveness of the group. The last three attributes: participant representation, skill level, and goal selection may be perceived as limiting effectiveness of the group. Lack of representation transforms the work group into the “haves” and the “have-nots.' The skill level of the group is diverse as the spectrum, for most members are not subject-matter experts. The godl of the group may not Parse with organizational goals, and may even oppose organizational goals.

STUDY CIRCLE

Is it possible to meld traditional management approach with participatory management approach to group-. problem solving? Study circles offer a possible solution to those attributes limiting effectiveness of the task-force/quality-circle. One definition of the study circle is a systematic study of a common goal, with each member interacting and responsible *for* the circle, and with sufficient scope/flexibility to adjust activities.

The study circle will be examined employing the six attributes used to examine the task-force/quality-circle.

Participant Selection - subject-matter experts volunteer to serve on circle.

Participant Involvement - participants hold ownership as circle members share common goal.

"Training - circle utilizes facilitator, and receives training in group problem-solving techniques.

Participant Representation - in generating circle, all involved functional areas are assured representation.

Skill Level - circle participants are subject-matter experts, and receive training.

Goal Selection - objective of circle is pre-determined.

The six attributes may be used to predict the outcome of this problem-solving group - the study circle. In conceiving the study circle, the attributes enhance the effectiveness of the group. There are two rules the circle needs to follow to be effective. The cardinal rule is the study circle is voluntary. The second rule is interest in the goal. Adherence or lack of adherence to these rules determines success or lack of success of the study circle.

APPLICATION

The definition, attributes, and rules develop a model of the study circle. The proof occurs in application of the model. Application of study circles as a problem-solving group occurs at Mare Island Naval Shipyard.

The concept of study circles was first broached at the Quality Circle Steering Committee meeting by the Quality Assurance Officer. The author of this paper was a facilitator in the Quality Circle Office, and a member of the Steering Committee. The author was familiar with the concept of study circles from Union literature. After subsequent brief discussion, the Quality Circle Office agreed to develop a study circle model, and to facilitate study circles as-available/as-needed. Tenor of this discussion was that the rate of circle increase was declining, and the Quality Circle Office needed to expand services.

The definition/attributes/rules are parameters of the study circle model. The definition and attributes of the study circle are presented in the comparison of the three problem-solving groups - the task force, the quality circle, and the study circle. The rules of the model are presented in Figure 1. The office also developed a hand-out, founded on the model, for parties interested in initiating a study circle. Figure 1 is the *cover* sheet for the hand-out. Attached to the cover sheet were copies of articles listed in the bibliography of this paper on study circles.

The following is an historical narrative of the first study circle.

After developing the model, the Quality Circle Office published an article in the shipyard newspaper, "grapevine." The article paraphrased information in the study circle hand-out cover sheet (Figure 1).

After several weeks the Quality Circle Office had received several requests for study circles. The initial response of the Quality Circle Office was to provide a synopsis of study circles to interested parties. The synopsis stressed - in the hand-out and by the facilitator - though the goal may be pre-determined, the participants must be volunteers. If a party still expressed an interest; then, the Quality Circle Office advanced enough copies of the hand-out for potential participants. It remained for the interest party - the party interested in initiating a study circle - to select goal and participant representation. After preliminaries (goal selection, participant representation/involvement/selection) were discharged by the interested party, an initial meeting was scheduled by the Quality Circle Office for the study circle.

STUDY CIRCLES

STUDY CIRCLES HAVE LONG BEEN POPULAR IN SCANDINAVIA. THE QUALITY CIRCLE OFFICE WILL PROVIDE FACILITATION FOR STUDY CIRCLES, THE STUDY CIRCLE WILL OPERATE WITHIN THE FOLLOWING PARAMETERS:

I. MEMBERSHIP WILL BE BETWEEN 5 AND 15 MEMBERS,

II. EACH AREA REPRESENTED IN THE STUDY CIRCLE WILL HAVE A MINIMUM OF ONE MEMBER AT EACH STUDY CIRCLE MEETING.

III. EACH MEMBER SHOULD HAVE INTEREST IN THE PROJECT BEING EXAMINED BY THE STUDY CIRCLE.

IV. THE STUDY CIRCLE WILL MEET DURING NORMAL WORK HOURS.

V. THE STUDY CIRCLE WILL MEET FOR MINIMUM OF ONE-HOUR PER WEEK.

VI. MINIMUM TRAINING FOR ALL STUDY CIRCLE MEMBERS ARE QUALITY CIRCLE LESSON 3 (BRAIN STORMING), AND LESSON 4 (CAUSE/EFFECT ANALSIS).

VII. THE STUDY CIRCLE LEADER WILL BE SELECTED FROM STUDY CIRCLE MEMBERS,

VIII. THE STUDY CIRCLE LEADERSHIP WILL BE ROTATED,

IX. THE STUDY CIRCLE WILL MAKE A MINIMUM OF A FINAL, FORMAL MANAGEMENT PRESENTATION .

THE QUALITY CIRCLE OFFICE WILL PROVIDE THESE SERVICES, AS A MINIMUM TO THE STUDY CIRCLE:

1. PROVIDE MINIMUM OF ONE-HOUR PER WEEK OF STUDY CIRCLE MEETING FACILITATION.
2. PROVIDE QUALITY CIRCLE LESSONS TRAINING TO THE STUDY CIRCLE.
3. MAINTAIN SUMMARY OF STUDY CIRCLE MEETINGS.

FIGURE 1

MEETINGS

Figure 2 is “Summary of Meeting Activities,” used as minutes for each study circle meeting.

The first study circle - “Hull Patch,” accomplished the study in 16 weeks. The study circle had 12 meetings, taking 88 meeting-hours. A digest of the minutes for each meeting is presented in the following format: meeting leader, circle stage”, leader comments, focus, facilitator notes.

Meeting I - Facilitator led meeting.
Facilitator Notes: Everyone is committed/roarin’-to-go, study circle needs to learn problem-solving techniques; group determined extent of study circle and regular members; initial consideration for study circle came from departments of non-destructive test, shipfitters, and riggers; attending members requested participation from two additional departments - naval architects and welders; non-destructive test members will get support from naval architects and welders to join circle; assured all made commitment to be active participants, assured all aware of minimum support from circle office as outlined in hand-out.

Meeting II - Facilitator led meeting.
Stage: Group went through brainstorming training, and a ranking of ideas technique; new members from naval architects and welders were introduced.
Facilitator Notes: Good participation in brainstorming exercise and responses to questions; provided members w/book “How to Make Meetings Mork.”

Meeting III - Facilitator led meeting.
Stage: Group went through cause/effect analysis training exercise, and a different ranking of ideas technique was given to the circle.
Facilitator Notes: Group is coalescing into dedicated force group realizing definition of goal is fuzzy, expect better goal resolution at upcoming meeting.

Meeting IV - Member led meeting.
Stage: Problem/cause identification.
Comments: Good participation of members, meeting did not stop on-time, there are some problems in control, groups needs to remember brainstorming rules.
Focus: Missing member report was given; review goal - "Hull Patch l,” determined effect - "Hull Patch 1 not on-time," determined most significant cause - “Lack of communication."
Facilitator Notes: Group determined effect and most significant cause through brainstorming and ranking techniques, good application of previous lesson learned.

(Author’s Note: As stated in Figure 1, leadership of the circle would rotate among circle members. After the circle completed training in meeting III, leadership of the circle was given to members. Rotating leadership commenced with this meeting.)

Meeting V - Member led meeting.
Stage: Problem/cause identification, and presentation preparation.
Comments: Meeting did not stop on-time.
Focus: Group continued Hull Patch review, group has decided to simultaneously review all Hull Patches; group has also decided to change effect from “Hull Patch 1" to "Lack of communication;” group determined best possible solution - "Hull Patch overall coordinator."
Facilitator Notes: Group is taking bull-by-horns, group is making good progress.

Meeting VI - Facilitator led meeting.
Stage: Solution identification.
Comments: Groups needs to keep comments germane to purpose of study circle.
Focus: Group brainstorming coordinator duties, ranking most significant duties.
Facilitator Notes: There was much discussion by non-destructive test members why shipfitters should be coordinator, and by shipfitter members why non-destructive test should be coordinator; group needs to realize function of group is to provide mutual assistance, all in group need help whomever becomes coordinator based-on duties as proposed by group.

Meeting VII - Member led meeting.
Stage: Solution identification.
Comments: Meeting did not start on-time.
Focus: Group continuing brainstorming coordinator duties, ranking most significant duties; group given training in force-field analysis; force-field analysis first performed on shipfitters as coordinator.
Facilitator Notes: Group made good use of Ishikawa diagram to determine need for management presentation; group needs to perform force-field analysis on other group members to determine coordinator.

STUDY CIRCLE

SUMMARY OF MEETING ACTIVITIES

(This form to be completed by Study Circle Leader after EACH MEETING.)

Study Circle Name ____________________

Leader ______________ Facilitator ______________

Date ______________ Time from ______ TO ______

List names of members at meeting

______________ ______________

______________ ______________

______________ ______________

______________ ______________

______________ ______________

______________ ______________

What stage of the Study Circle process IS YOUR CIRCLE IN?

____ Training (Lesson)

____ Problem Identification _ Solution Identification

____ Cause Identification _ Presentation Preparation

____ Data Gathering ____ Other ______________

Meeting Evaluation (to be completed by LEADER)

____ Started on-time ____ Agenda set for next meeting

____ Agenda posted ____ Stopped on-time

____ Agenda followed

____ Participation of MEMBERS

Comments (leader)

____

____

FIGURE 2

FOCUS WHAT HAPPENED DURING THE MEETING)

AGENDA FOR NEXT MEETING

FACILITATOR NOTES

FIGURE 2

Meeting VIII - Member led meeting.
Stage: Solution identification.
Focus: Group continuing force-field analysis; force-field analysis performed on non-destructive test to be coordinator; group brainstorming $aving$ with coordinator.
Facilitator Notes: Group needs to gather time-savings of having coordinator - avoid rework (numbers of time and numbers of people involved in patch ready, not able to install due rust on previously cleaned area or paint on previously cleaned area and so on).

Meeting IX - Facilitator led meeting.
Stage: Presentation preparation.
Comment: Meeting did not start on-time.
Focus: Group preparing for management presentation; assignments have been made for all represented departments to have role in presentation; for presentation groups needs to generate - time-savings, coordinator costs, total $aving$; group developing presentation agenda.
Facilitator Notes: Group needs to have all areas represented in presentation.

Meeting X - Facilitator led meeting.
Stage: Presentation preparation.
Comments: Meeting did not start on-time, group did not set agenda for next meeting.
Focus : Group delayed presentation for week, while group smoothes presentation; non-destructive test member gave missing member report; group established who to invite; non-destructive test members and shipfitter members preparing force-field analysis charts.

Meeting XI - Facilitator led meeting.
Stage: Presentation preparation.
Comments: Group did not post agenda.
Focus: Group has scheduled management presentation next week, continuing presentation practice.
Facilitator Notes: Facilitator will invite Quality Circle Steering Committee, will assure all designated persons are invited.

Meeting XII - Presentation.

EVALUATION

In the presentation the shipfitters volunteered to provide a supervisor to be coordinator for Hull Patch. The first study circle - “Hull Patch,” accomplished the study in 16 weeks . The study circle had 12 meetings, taking 88 meeting-hours. The circle met again, 6 months later, to review their solution and savings. At the meeting the review revealed a separate supervisor was not required as coordinator. The shipfitter supervisor on Hull Patch performed the coordinator role as collateral duty. The review also revealed rework, due to lack of coordination between the parties, was eliminated by the coordinator. Examples of eliminated rework experienced by the review are: area closed-out, area not properly prepared, area not laid-Out, area not lighted, area painted-over, area rusted, and inclement weather. The review further revealed members of the circle had established an informal group to provide mutual assistance. The savings for the initial boat were documented by the study circle review to be in excess of $24k.

EXPANSION

When success of the first study circle was published in the “grapevine,” the shipyard newspaper, the Quality Circle Office received several requests for circles. After the Quality Circle Office provided a synopsis, only two interested parties were able to discharge preliminaries (goal selection, participant representation/involvement/selection) to initiate a study circle. “Lost Instruments,” was the commission of the second study circle. The commission of the third study circle was “Recycling Components.”

The second study circle - "Lost Instruments," failed in 18 weeks. The circle had 15 meetings, taking 86 meeting-hours. The third study circle - “Recycling Components," accomplished the study in 23 weeks. The circle had 14 meetings, taking 130 meeting-hours. In reviewing these two circles, the necessity of satisfying the cardinal rule (participation is voluntary) becomes evident to all.

The following is a chronology of the second study circle - "Lost Instruments," applying an abbreviation of the format used for the first circle (based on Figure 2).

Meeting I - Facilitator led meeting.
Stage: Organizational .
Comments: Not all in group are committed.
Focus: Group determined extent of study circle - “Lost Instruments,” determined regular members - metrology, productivity, tool, outside machine, electrical, calibration, pipe, electronics.
Facilitator Notes: Group is not sure there is a problem, metrology/

productivity members directed by off-shipyard sources to reduce lost instruments (one lost instrument is too many); several participants directed to attend.

Meeting II - Stage - Training.
Focus - Group went through brainstorming training, and a ranking of ideas technique.

Meeting III - Canceled (lack of attendance).

Meeting IV - Stage - Training.
Focus - Group went through cause/effect analysis training exercise, and a different ranking of ideas technique was given to the group.
(Author's Note: As stated in Figure 1, leadership of the circle would rotate among circle members. After the circle completed training in meeting III, leadership of the circle was given to members. Rotating leadership commenced with this meeting.)

Meeting V - Stage - Problem identification.
Focus - Using cause/effect analysis group determined goal - "Lost Instruments."

Meeting VI - Stage - Problem/cause identification.
Focus - Group brainstorming causes.

Meeting VII - Stage - Solution identification.
Focus - Group given training in pareto analysis, and using technique to analyze lost instrument reports .

Meeting VIII - Canceled (leader no-show).

Meeting IX - Stage - Solution identification.
Focus - Group brain-storming solutions.

Meeting X - Stage - Solution identification.
Focus - Group ranking solutions.
Facilitator Notes - Pipe has dropped circle, pipe members believe have no problems with lost instruments.

Meeting XI - Stage - Solution identification.
Focus - Group ranking solutions.

Meeting XII - Stage - Solution identification.
Focus - Group continuing ranking solutions.

Meeting XIII - Stage - Problem identification.
Focus - Group given training in force-field analysis, using-technique to determine root-problem.

Meeting XIV - Canceled (lack of attendance).

Meeting XV - Stage - Organizational.
Focus - Group decided to meet again in 90 days, determine results of trial implementation of partial solution to problem.
Facilitator Notes - This is end of the circle.

The following is a chronology-of the third study circle "Recycling Components," applying an abbreviation of the format used for the first circle (based on Figure 2).

Meeting I - Facilitator led meeting.
Stage: Organizational .
Comments: Everyone in circle is committed, group needs to learn problem-solving techniques.
Focus: Group determined extent of circle - "Recycling Components."
Facilitator Notes: Facilitator assured all in group made commitment to be active participants; group seems shaky about abilities as a group; turn-out for circle large, need more manuals for next meeting.

Meeting 11 - Stage - Training.
Focus - Group went through brainstorming training, and a ranking of ideas technique.

Meeting III - Stage - Training.
Focus - Group went through cause/effect analysis training exercise, and a different ranking of ideas technique was given to the circle.

Meeting IV - Stage - Problem identification.
Focus - Group brainstorming effect - "Recycling Components."
(Author's Note: As stated in Figure 1, leadership of the circle would rotate among circle members. After the circle completed training in meeting III, leadership of the circle was given to members. Rotating leadership commenced with this meeting.)

Meeting V - Stage - Cause identification.
Focus - Group brainstorming causes.

Meeting VI - Stage - Problem identification.
Focus - Group ranking causes.

Meeting VII - Stage - Solution identification.
Focus - Group brainstorming solutions.

Meeting VIII - Stage - Solution identification.
Focus - Group ranking solutions.

Meeting IX - Stage - Solution identification.
Focus - Group continuing ranking solutions.

Meeting X - Stage - Data-gathering/ solution-identification.
Focus - Group tracking-data/ generating-info.

Meeting XI - Stage - Presentation preparation.
Focus - Group generating $aving$ data.

Meeting XII - Stage - Presentation preparation.
Focus - Group practicing presentation.

Meeting XIII - Stage - Presentation preparation.
Focus - Group continuing presentation practice.

Meeting XIV - Presentation.

RE-EVALUATION

In reviewing these two circles, the necessity of satisfying the cardinal rule (participation is voluntary) becomes evident to all. The second study circle - “Lost Instruments,” failed in 18 weeks. The third study circle - “Recycling Components,” accomplished the study in 23 weeks.

To be effective the study circle needs participation. Without voluntary participation there is no ownership of the goal nor implementation of solution by the circle members. Ownership of the goal needs to be established before commencing the circle. The second rule of the study circle is interest in the goal. To be effective the circle needs to be goal-directed. Interest in the goal will transcend most non-functional roles played by circle members enhancing the study circle process.

LESSONS LEARNED

Study circles do and will function in an industrial environment. Study circles follow the management design of an organization, and may be the better problem-solving group juxtaposed task forces and quality circles.

There are two rules the circle needs to follow to be effective. The cardinal rule is the study circle is voluntary. In retrospect the first and third circles followed this rule at the first meeting. The digest of Meeting I for the first circle tells, "...everyone is committed/roarin’-to-go,... assured all made commitment to be active participants, ...will get support from ....” The digest of Meeting I for the third circle tells, “everyone is committed, ...assured all made commitment to be active participants . ...” The second circle failed this rule at the first meeting. The digest of Meeting I for the second circle tells, "not everyone is committed ,...group is not sure there is a problem,... directed by off-shipyard sources to reduce lost instruments (one lost instrument is too many), several participants directed to attend."

Another gauge indicating compliance with the cardinal rule is reason for circle meeting cancellation. Canceling a scheduled meeting is distinct from agreeing not to met for a specific period of time, with a meeting scheduled at end of the period. The second circle canceled: Meeting III - lack of attendance, Meeting VIII - leader no-show, and Meeting XIV - lack of attendance. Meeting XV was the terminal meeting of the circle.

The second rule the circle needs to follow is interest in the goal. In retrospect the first and third circles also followed this rule by accomplishing their studies. The second circle also failed this rule. In Meeting X pipe dropped the circle, believing having no problems with lost instruments. Dropping the circle indicates lack of interest in the goal. Failing to accomplish the study also indicates lack of interest in the goal.

Study circles are alive and well at the shipyard. The study circle concept is being expanded to reach into problem areas previously considered too institutionalized to be solved by any group. The experiences of quality circles are easily transferred to meet the needs of study circles. The addition of study circles to problem-solving groups by participatory management will enhance the effectiveness of the organization.

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A Study of the Construction Planning and Manpower Schedules for Building the Multi-Purpose Mobilization Ship, PD 214, in a Shipyard of the People's Republic of China

No. 31

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ABSTRACT

This paper presents the results of a study for building five PD-214 ships in a shipyard of The People's Republic of China. The study was performed by the author in 1987 at the Men jiang She.mulding Institute, The People's Republic of China A comparison of shipbuilding planning and resource expenditure estimates is made for building a series of identical ships in an advanced shipyard in the United States and in The People's Republic of China.

INTRODUCTION

The People's Republic of China (PRC) is generally regarded as a future major force among the world's shipbuilding nations. Starting about 1980 (known in China as the beginning of the "Reform"), the country placed major emphasis on a plan to upgrade its shipbuilding industry to be one of the world's leaders. Throughout the decade of the eighties, the Chinese shipbuilding industry has shown growth averaging a compounded increase of about 13.7 percent/year. [1][1] Importantly, an expanding portion of its output is being placed into the export market. [2] The tentative plan, according to Hu Chuanzhi, Managing Director of China State Shipbuilding Corporation (CSSC), is to have an annual output in excess of one million deadweight tons by 1990 [3]. Approximately one-third would be for the export market.

This study is the presentation of the construction planning and manpower schedules for building five PD214 general mobilization ships at Hudong Shipyard, Shanghai. (Earlier studies developed the construction plans and manpower schedules for building five PD214 ships at a shipyard in Japan and at a shipyard in the U.S.A. All studies used the same designs and made similar assumptions [4] [5].)

Hudong Shipyards, Shanghai, was selected as the shipyard for which the schedules and estimates would be prepared. It is one of the most advanced yards in the nation, and has been designated as a facility where major priority would be given to the implementation of advanced technology.

In January, 1987, the Chinese government announced new rules to "....promote the system of factory directors assuming full responsibility for production and management...''.[6] The new system makes the director fully responsible for production and management of the enterprise, with the political organization (which exists in all Chinese enterprises) being assigned the role of advisor. Now, the enterprise director has the right to control production and to make decisions on finance. He also has management appointment responsibility, and the right to "praise" and/or "punish" the' worker. Hudong Shipyard has been designated as one of the enterprises to implement the new rules on a pilot basis. This designation was further indication that the yard is considered one of the most progressive in China, and confirmed its selection.

The research was performed by the author and a team of staff and graduate students of Zhenjiang Shipbuilding institute (located in Zhenjiang, Jiangsu Province, PRC) during 1986-87. The team received the constant advise and counsel of Hudong's managers and engineers during the effort. All analyses and projections were approved by Hudong management as being accurate representations of the yard's planning documentation.

The baseline ship for the study was the PD214 general mobilization ship [7] with the following options multi-purpose design, Jumbo size option, steam turbine (vice

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[1] Numbers in brackets designate References at end of paper.

diesel) main propulsion plant, cargo cranes. and a slewing stern ramp. The study was prepared on the basis of practices and facilities in place in 1987, with a contract signing on January 1, 1986. Other study assumptions were

(a) the construction contract was signed on the final day of business negotiations;
(b) the engineering working drawings for the ship were complete and available to the shipyard at signing of the contract;
(c) the total shipyard facility was available to construct the five ships, and no existing contracts or follow-on work would impact the PD214 schedules;
(d) five ships of the PD214 (Jumbo) class were ordered in the contract, and all were identical;
(e) purchase orders for equipment, materials, and supplies would be issued subsequent to receipt of the contract; and
(f) the five ships would be consecutively constructed in the shipyard's main facility.

Figure 1 shows the inboard profile view and the main deck of the PD214 (Jumbo) ship. Table 1 is a listing of the principal characteristics of the ship. Table 2 is a list of the appropriate laws and classifications that would apply to construction of the PD214. The complete description of the ship with options is contained in the referenced Marad report. [8]

This paper is divided into four sections. First, there is a discussion of Hudong's facilities and organization. Then there is an analysis of the construction methods employed; next, a presentation is made of the time and man-hour budget for each of the production activities, Finally, general conclusions are made from the analyses,

Comparisons are made throughout the paper with the facilities and operations of Avondale Shipyards, Inc., New Orleans, Louisiana. The information and data source "for the Avondale comparison is a similar study [9] that developed the *construction* schedules and manpower planning to build a like series of PD214 general mobilization ships. In the Avondale case, however, the date of contract award was l/1/83--some three years earlier than the contract date assumption used in the Hudong study. (And, the reader should be aware that Avondale's facilities and productivity factors are now considerably different than those shown.)

TABLE 1
PRINCIPLE CHARACTERISTICS
PD-214 -GENERAL MOBILIZATION SHIP
JUMBO OPTION

Length Overall	719′
Length Between Perpendiculars ,	670′
Beam(Molded)	97′
Depth(Molded)	61′
Draft (Full Load)	30′
Draft (Scantling)	35′
Light Ship ·	14.520 L.T.
Crew Effects-and Stores	50 L-T.
Fuel Oil	3.000 L.T.
Cargo Oil	3.900 L.T.
Fresh Water	340 L.T.
S.W. Ballast	4.900 L.T.
Lube Oil & Diesel Oil	60
Cargo Deadweight	19,960 L.T.
Total Deadweight	23.3l0 L.T.
Total Displacement	37,380 L.T.
Bale Cubic Holds	1,963,900 Cu.ft
Liquid Cargo Volume	l7′4.800 Cu.ft
Crew Accommodations	37
Extra Mobilization Accommodations	7
Total Accommodations	53
Horsepower (Max. *Continuous* Rated	.22,500
Speed (Knots 100.% Power)	2l.l
Speed (Knots 80% Power)	20.l
Fuel Consumption @ SEA (bbl/day)	840
Fuel Consumption @ Port (bbl/day)	86
Range (In Nautical Miles)	13,800
Propeller -6 Blades	22′8″
Total Containers On Deck (TEU)	436
Total Containers Below Deck (TEU)	850
Total Containers (TEU)	**1.286**

FACILITIES DESCRIPTION AND ORGANIZATION[2]

Hudong Shipyard is one of the three largest yards in the Shanghai area it builds a variety of ships, including coastal oil tankers, coastal passenger and cargo vessels, oceangoing vessels, oceanographic research ships, oil drilling ships, and military frigates. [10] The yard is capable of producing ships up to 70,000 DWT; additionally, it has a diesel engine production facility that builds marine engines up to 25,000 brake horsepower. Table 3 shows the yard's production output for the five-year period, 1982-86.

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[2] All material in this section was obtained during a series of interviews with Hudong Shipyard management. The interviews occurred in Shanghai during March and April, 1987.

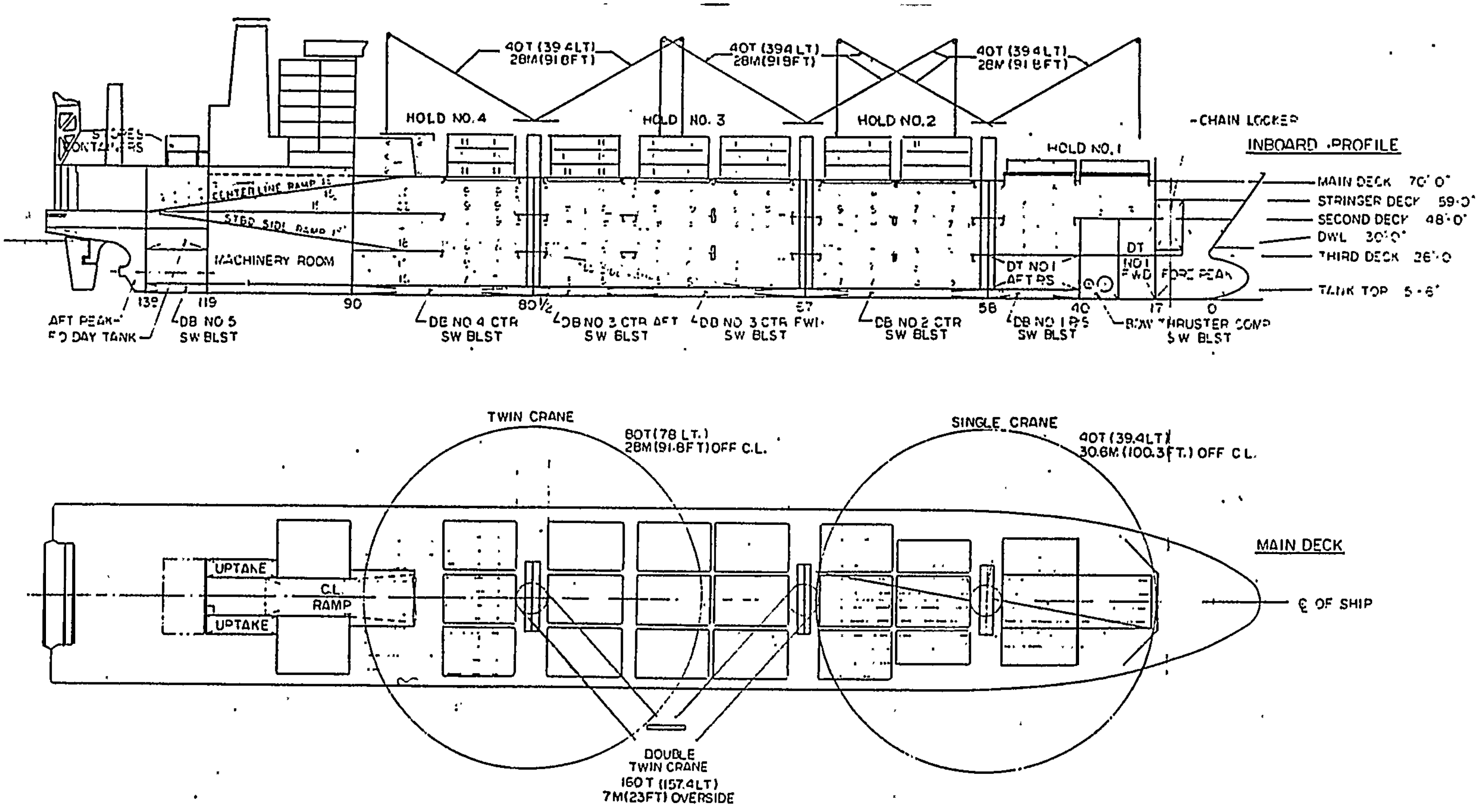


Figure 1: INBOARD PROFILE AND MAIN DECK PD214 GENERAL MOBILIZATION SHIP

TABLE 2
LIST OF APPROPRIATE LAWS AND CLASSIFICATIONS THAT WOULD APPLY TO CONSTRUCTION OF THE PD214

-- ABS Classification Rules + AIE + E + AMS
-- U.S. Coast Guard, including International Rules of the Road
-- USPHS Publication *393 (Sanitation) and PB1610I9 (Ratproofing)
-- SOLAS Convention 1974
-- USCG Panama Canal and Suez Canal Tonnage Certificates
— Panama Canal Company Regulation
-- Suez Canal Company Regulation
-- IEEE #45
-- Federal Communication Commission
-- ABS Cargo Gear Requirements
-- USDL Safety and Health Regulations for Longshoring

Sorce: References 4, 5.

The total employment for the yard was 12,000 persons on March 1, 1987, distributed as follows

Shipbuilding Division (Workers)	3,785	(31,4%)
Engine Division (Workers)	1,898	(15.8%)
Management	1,507	(12.6%)
Engineers	1,014	(8.5%)
Service	1,100	(9.2%)
All Others	22.5%	
Total	12,000	(100.0%)

Organization for the entire shipyard is shown in Figure 2. Besides the Shipbuilding Division, other line units are the Engine Division, the Material Supply Department Civil Engineering Department, and the Chief Engineer's Office. Administrative and staff groups include the Chief Economist, Accounting Department, and the Personnel Department.

The Engine Division designs, fabricates, and markets the low- and medium-speed engines, and associated auxiliaries. The unit also has large forging, casting, and heat treating shops.

The Material Supply Department is responsible for acquisition and transportation of all materials for the yard.

The Civil Engineering Department does all of the civil engineering projects for the yard, including employee housing. The group maintains all of the yard's facilities and all stationary equipment and tools. In addition, the department is responsible for the construction of all industrial projects that are fabricated and assembled at the yard. (An example would be steel bridges that the yard builds.)

The Chief Engineer is responsible for quality control, metrology, and for all other technology management within the yard, including physical and chemical analyses. The unit directs the CAD/CAM developments and application program.

On the staff side, the Economics Officer is responsible for long term planning, labor balance coordination, and contract administration. The Chief Accountant deals with all financial matters. The Personnel Division is responsible for training, education, personnel administration, and operation of the numerous support groups (like the hospital, visitor hostel, and children's nurseries).

TABLE 3
PRODUCTION OUTPUT FOR HUDONG SHIPYARD FOR A FIVE-YEAR PERIOD, 1982-1986

Year	Ship Production* (DW Tonnes)	Engine Production (Horse-Power)
1982	62,000	63,000
1983	91,000	95,000
1984	104,400	129,000
1985	117,500	133,600
1986	102,300	136,900

*--Excludes military production, estimated at less than two Jianghu-class frigates/year.

Source: Hudong Shipyards

The Shipbuilding Division is the principal division in the yard. This division has approximantely one-half of the yard's total workforce in its organization. There are four departments and SIX production shops/factories in the division.

The Shipbuilding Design Department designs the ships, including advanced concepts. It prepares production working documents, as well as material for regulatory approval. The Production Management Department handles the production management for the entire yard; It has responsibdity for preparing production plans and coordinating of the shop production. The Shipbuiding Planning Department performs the work load balancing it prepares the production instruction and coordinates the milestone schedules. And the Safety Department is responsible for safety in the entire shipyard

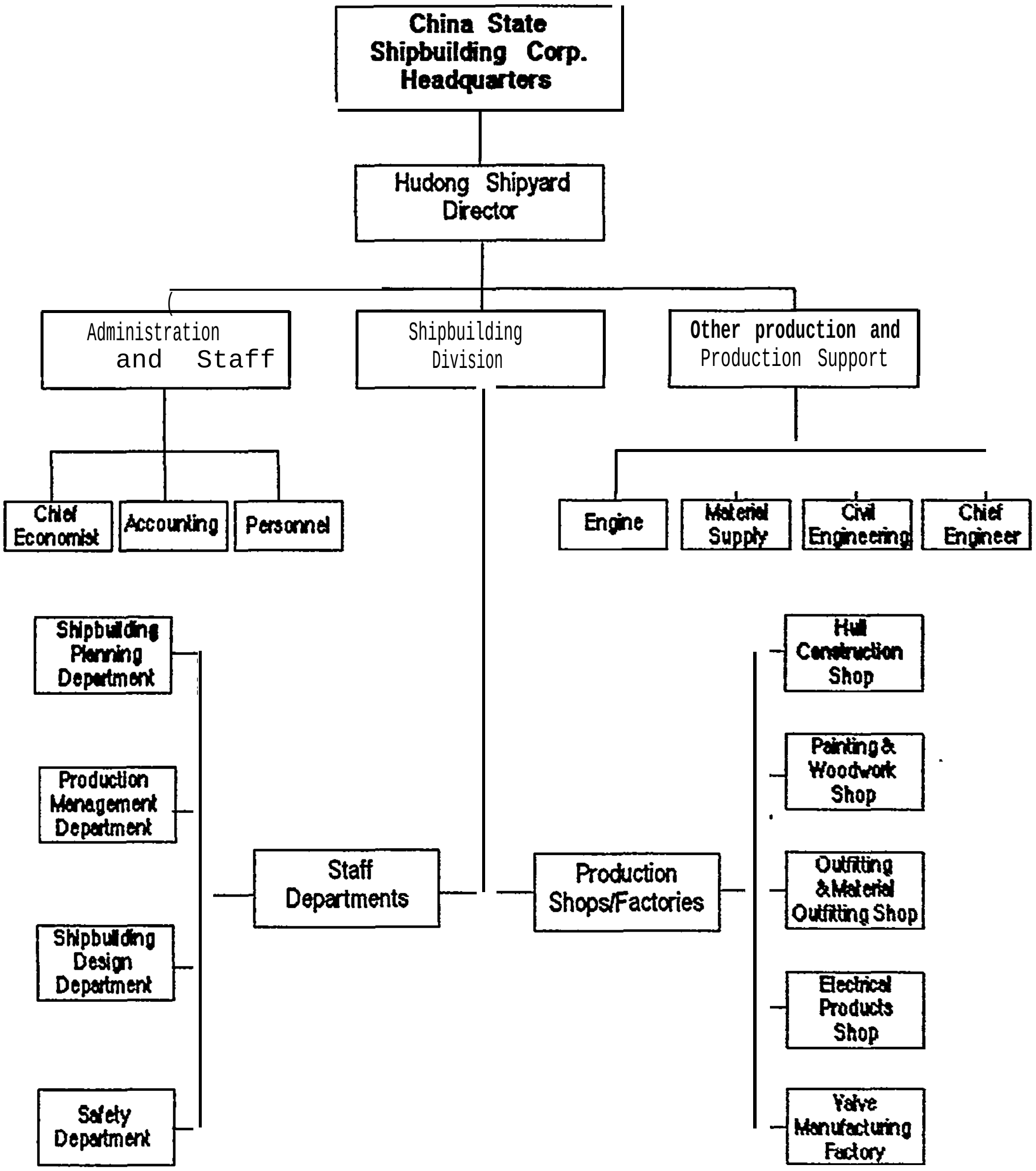


FIGURE 2: HUDONG ORGANIZATIONAL CHART

The Hull Construction Shop is one of the main shops for the division. It is responsible for all of the steel production for both ship and industrial products, and associated lofting.

The Machinery and Electrical Workshop is responsible for installation of the main engines, the navigational equipment, the electrical equipment, and sea trials. This shop is also responsible for processing of pipe, and its installation aboard the ship. 1t is considered one of the strongest shops in the yard.

The Painting and Woodworking Shop is responsible for all painting and coating operations and all woodworking Jobs, including the manufacturing and installation of any wooden furniture.

The Outfitting Material Fabrication Shop makes foundations, doors, boilers, small hatch covers, and aluminium doors/windows, and runs the galvanizing and oxide finishing operations. The shop does not perform any of the installation activities.

The Electrical Products Factory fabricates switchboards, cabinets, steel furniture and ship models. Its products are also sold outside the shipyard.

The Valve Factory manufactures all valves used on the ship. The casings are manufactured by the Casting Shop--a unit in the yard's Engine Division.

There is a labor union organization in Hudong; however, it is structured differently than in an American or Japanese yard. First, there is no focus on craft orientation by the union, and there are no work rules requiring that work be performed only by people with a recognized Journeyman skill, As a result, workers can be, and are, cross-crafted in their assignments.

There is only one labor union, and 90 percent of the workers participate. Some of the workers are elected to represent all of the workers they are called “Workers' Representatives”. The labor union leaders are elected from these representatives, At Hudong there are 1,000 Workers' Representatives, and about 40 labor union leaders.

About twice each year the shipyard director is obliged to make a formal report to the Workers' Representatives, After this meeting the representatives will caucus in a series of small, special focus sessions to develop comments on the director's report. Their comments will contain suggestions and recommendations for future direction of the yard, as well as suggested action for management.

The Workers' Representatives will also make decisions concerning how to allocate and spend the workers' portions of the company's profits. The worker's share is about 15-20 percent of the company's net profits. The management is bound to follow the Workers' Representatives directions on the profits allocated to the workers. There is no absolute requirement that management follow the suggestions/recommendations on any other topic.

The labor union leaders have the function of following up on the suggestions/recommendations of the Workers' Representatives. They make detailed reports to the representatives at the meetings as to what happened relative to each recommendation during the preceding period.

At Hudong shipyard, and at all Chinese enterprises, the union is under the leadership of the Communist Party. The Communist Party organization has a structure in the shipyard that replicates the production/management organization. At Hudong the party (or political) structure is comprised of about 200 persons. About 80 percent (160) are assigned full-time to the structure. The head is the Chief Political Officer. This person is always a member of the Communist Party and is elected to this position by a vote of the Communist Party members in the shipyard. At Hudong, this man is a university graduate who has been at the yard for all of his working career. Prior to becoming Chief Political Officer, he was head of the shipyard director's administrative office.

Figure 3 shows the layout for the shipbuilding portion of the shipyard as of January 1, 1987. (It should be noted that there is presently a 36,000 square meter assembly shed under construction. The facility will be completed in 1988, and will considerably enhance the production capability of the yard, The new facility is not shown in Figure 3.)

The total yard embraces 913,000 square meters (212 acres) of land, most of which is devoted to the ship production activities.

Table 4 shows the size of the ship production facilities, and makes a comparison with Avondale shipyards--a typical American yard, [11] As seen, the ship production area at Hudong is considerably less than that found at Avondale. The difference is especially evident in the space devoted to fabrication and to erection.

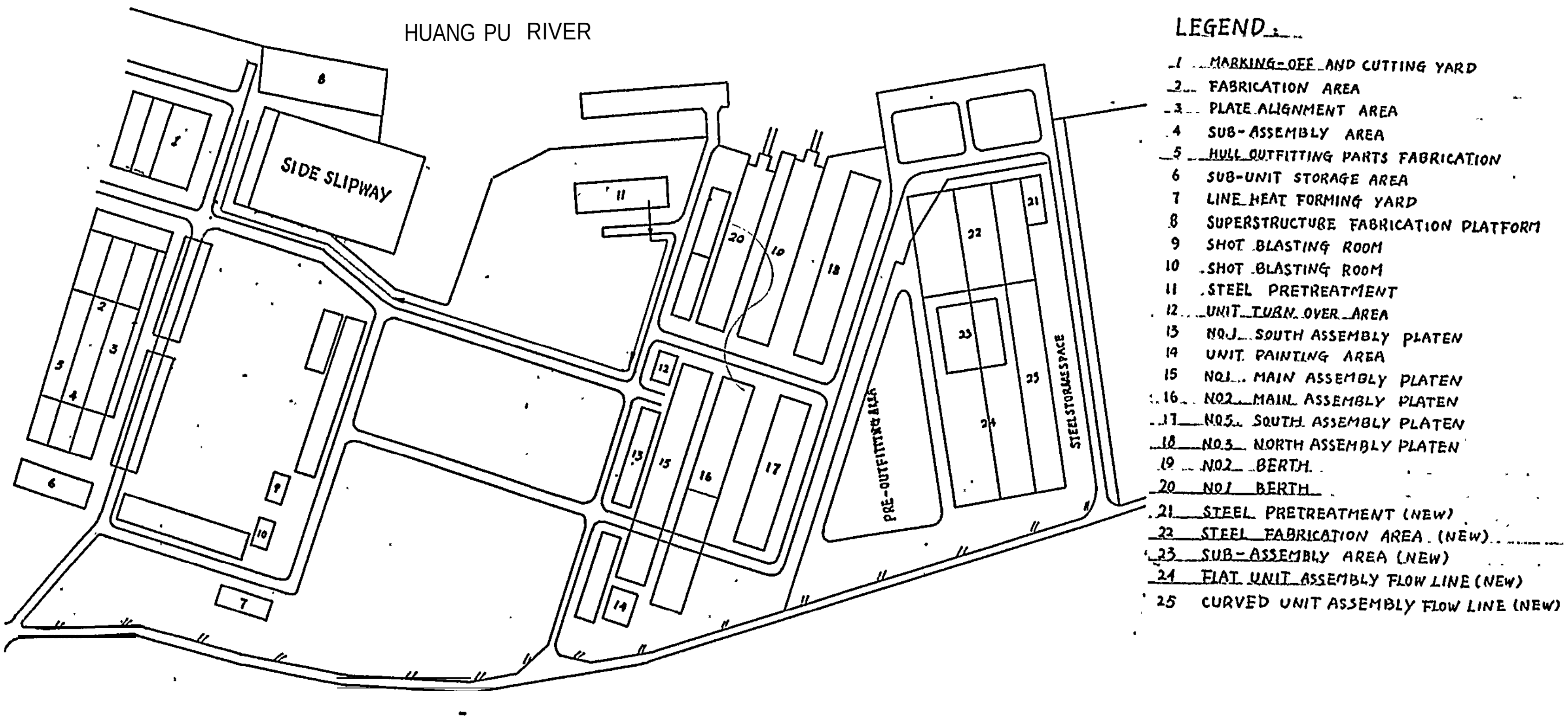


FIGURE 3: LAYOUT OF HUDONG SHIPYARD SHIP PRODUCTION FACILITIES

TABLE 4
SIZE OF PRODUCTION FACILITIES AT HUDONG AND AVONDALE SHIPYARDS
(IN SQUARE FEET)

	SHIPYARD				
	Hudong’		Avondale$^{\Omega}$	RATIO	
	Current(l/1/87)	Future(1988)	Current(t.llm)		
Production Category/	(A)	(B)	(c)	A/c	B/C
Fabrication	138,460	310,680	318,800	.43	.97
Sub-Assembly	99,030	314,330	112,700	.88	2.79
Assembly	335,190	335,190	441,150	.76	.76
Erection	203,480	203,480	421,800	.48	.48
Total	776,160	1,163,680	1,294,450	.60	.90
Approximate Processing Capacity (s. tons stl/Yr.)	33,075*	88,200*	50,400@		
Ratio ft2/tons/vear	23.5	13.2	25.7		

* Based on steel pre-treatment flowline capacity of 30K tonnes/year. *After* expansion, the steel capacity will be 88,200 tons of steel/year. Erection facilities will then be the limiting facility.

@ Based on average erection rate of 4200 tons/month [12]

Source: Hudong Shipyard Interview

Ω **Source: Avondale Studv**

Currently, Hudong only has one slipway capable of building the PD214 ship.

Hudong’s production facilities will be considerably enhanced when its new assembly shed is completed in 1988. At that time the total ship production space will nearly equal Avondale’s, and the sub-assembly area will be nearly twice that of Avondale’s.

Table 4 also relates the facility space with the stated steel production capacity for the two yards. (The indicated capacity is for the individual production unit that has the smallest tonnage output. For Hudong, this is the steel pre-treatment facility with an indicated capacity of 33,075 short tons/year (30,000 tonnes/year). At Avondale, expected erection rate is stated as 4200 short tons of steel/month which is the same as the capacities of the assembly lanes.) As seen, Hudong’s utilization ratio currently is 23.5ft^2/ton, Avondale’s is 25.7ft^2/ton. Completion of the new assembly shed will significantly change Hudong’s utilization ratio because the steel throughput capacity will increase to about 80,000 tons/year. The facility area/throughput ratio for Hudong will then become 13.2ft^2/ton.

Both Hudong and Avondale have approximately the same profile of open- versus covered-production facilities. The fabrication facilities are under cover at both yard; sub-assembly is partially covered at both yards; and assembly and erection are in the open at both yards.

Table 5 summarizes the machinery and crane capacities utilized by Hudong in its ship fabrication and assembly operations. Comparison of these specifications with those found at Avondale in like operations reveals many similarities. The gas cutting machines are of approximately the same capacity, each yard has the same number of numerical cutting and optical cutting machines; and each has about the same profile of forming equipment, even though there are marked differences in the capacities (Avondale’s equipment is generally larger).

There are major differences in the shipyards’ operational capabilities. The most significant differences are found in the cutting operations, welding operations, pipe shop operations, CAD/CAM operations and painting operations.

Of especial significance is the fact that Hudong does not have any plasma-arc cutting equipment. As a result its thermal cutting is confined to mild steels of less than 60,000 psi yield. Aluminum and high-alloy materials are cut mechanically.

Automatic and semi-automatic welding operations are more extensive at Avondale than at Hudong. At Hudong, approximately 55 percent of all welding is done manually; the percentage is considerably less at Avondale.

Avondale's pipe shop is nearly fully automated Hudong's pipe fabrication is completely manual, and is also segmented into three separate operating locations (thus reducing potential benefits from economics of scale),

Avondale has utilized CAD/CAM throughout its operations for several years, being one of the earliest American shipyards to emplace CADAM graphics software. Hudong, on the other hand, is only now beginning to utilize the more advanced systems of CAD/CAM software. Further, Hudong's planting and management control systems are still not fully emplaced on a computer data base.

Finally, Avondale has automated many of its paint shop operations by the use of robots in the application of coatings in hazardous and difficult situations. While both Hudong and Avondale have large paint sheds for painting complete blocks, Avondale's environmental controls are more complete and finely tuned than those found at Hudong.

The only major difference in the lift capacities for the two yards is found at the erection site. Hudong can lift 400 tonnes (by combining the four 100-tonne cranes) Avondale's capacity at the erection site is limited to a 200-ton lift. On some unique circumstances, a 400-ton lift can be accomplislhed by combining the two gantry

Because there is significant ground movement of the blocks at Hudong, the capacity of the flatbed carriers is a limiting factor. The yard has one 150-tonne flatbed carrier, and for that reason no block can exceed 150 tonnes unless it is built at a location where the gantry cranes from the slipways have direct access.

TABLE 5

DESCRIPTION OF FABRICATION MACHINERY AT HUDONG SHIPYARD

1. **Gas Cutting Machines: 5, with all but one being numerical control. Layout is 24m x 4m x IOOmm.**
2. **Plasma Arc Cutting Machines: None.**
3. **3. with largest hating a 500-ton capacity.**
4. Bending Machines: 3, largest is 13m x 43mm radius.
5. Plate Straightener One 5-roll, and one 7-roll machine.
6. Shears: None.
7. Plate-Edge Plans: 2, largest is .12m x 80mm.
8. Frame Machines: 2, largest is 400-ton capacity, with thickness of 400mm.
9. One-Side Welding Fixture 2, largest is 12m x 24mm.
10. Submerged Arc Welding Machines: Several all portable, except for one-side welding fixtures described above.
11. Crane Lifting Capacity:

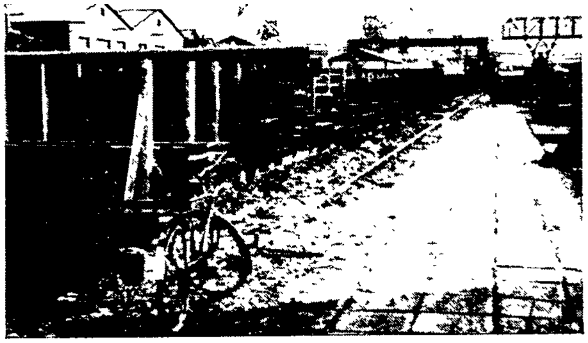
Location	Number	Largest Unit
Cutting Area	4	15 tons
Fabrication	2	5 tons
Sub-Assembly (including panel line)	10	15 tons
Inside Assembly Workshop	4	30 tons
Outside Assembly and Erection Areas		
Horizontal Berth	8	40 tons
Inclined Berth	16	100 tons
Quays	2	40 tons

Source: Hudong Shipyards

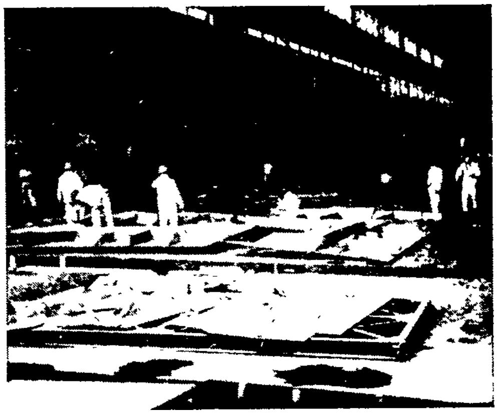
Figure 4 displays some scenes of the Hudong ship production facilities. The reader's attention is especially directed to the photographs of the pipe and structures storage and the fabricated parts and sub-assembly storage. In China, the national planning system permits the ordering of material only two times per year. As a result, the purchasing department does much anticipatory ordering and stockpiling of material to prevent outages. The result is seen in the large amount of pipe and structural material found in the storage lot (Figure 4a).

The photographs of the fabricated parts and sub-assembly storage areas (Figures 4c and 4d) indicate the extent to which the yard cuts and fabricates parts for future use. The large numbers of identical parts reflect the extent to which the yard builds "standard" ships, and the confidence that the identical parts will eventually be called for by the assembly operations.

A final observation concerning Hudong's facilities relates to the use of permanent jigs in the assembly of curved blocks. Until recently all of the Jigs at Hudong were of the permanent rigid style, indicating that the yard constructed the Jigs fully expecting to reuse them several times. This fact indicates that the yard's management felt their work would be almost exclusively directed toward ships of a standard design. The yard has only recently acquired and installed pin Jigs, indicating its feeling that future work might contain one-of-a-kind ship construction projects.



4.a Pipe and Structures Storage



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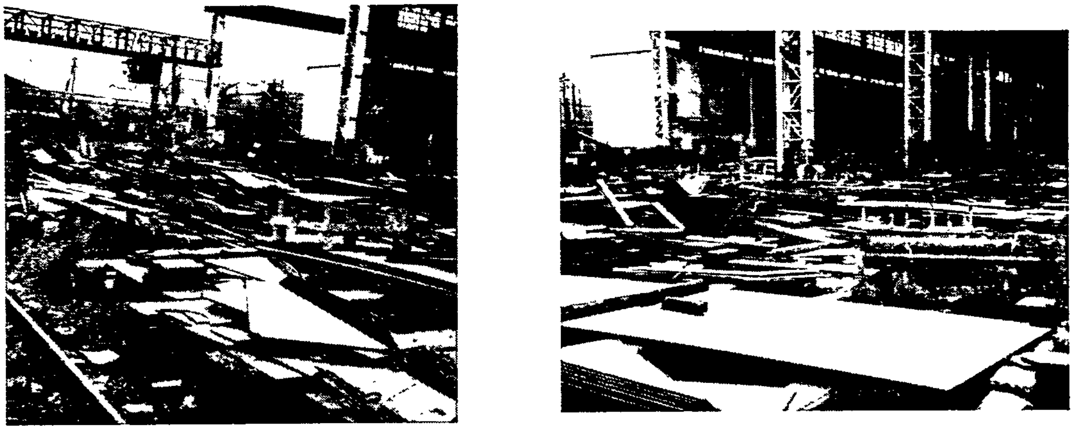
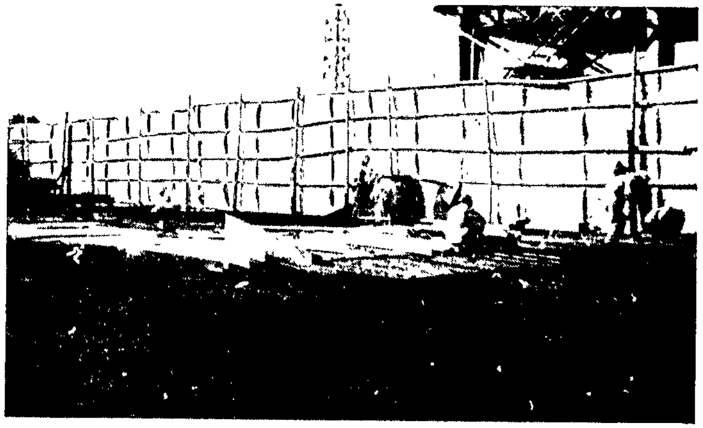


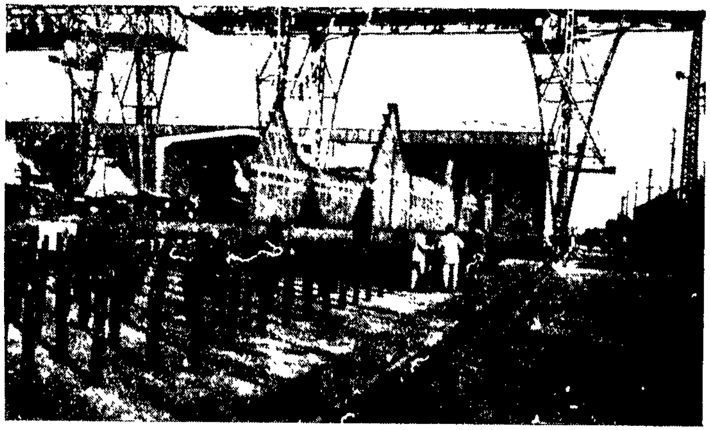
4,c and 4.d Fabricated Parts and Sub-Assembly Storage

FIGURE 4: VIEWS OF HUDONG SHIPYARD

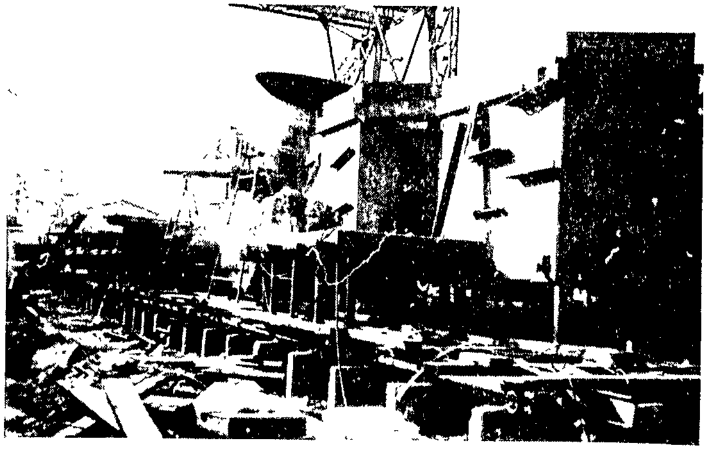


4.e Small Block Assembly

4.f Pallet Storage for Piping

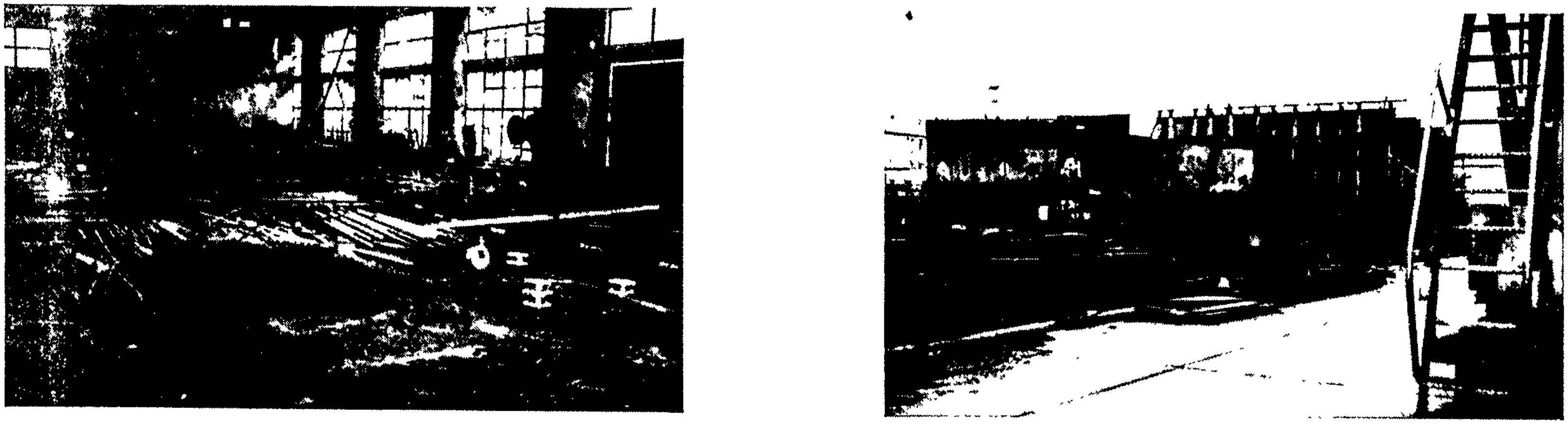


4.g Flat Block Assembly



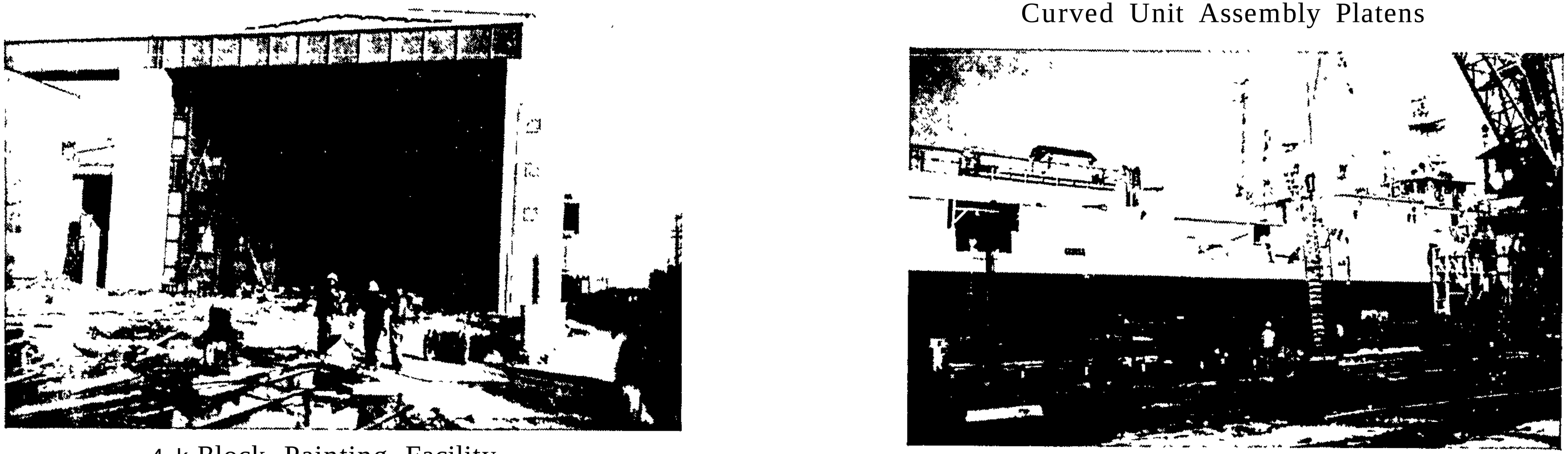
4.h Superstructure Assembly

Figure 4 (continued): Views of Hudong Shipyard



4.1i Small Pipe Fabrication Facility

4.j Portion of Superstructure and Curved Unit Assembly Platens

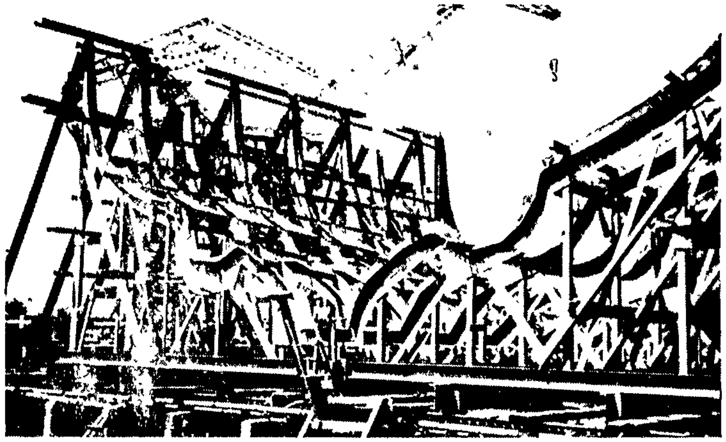


4.,k Block Painting Facility

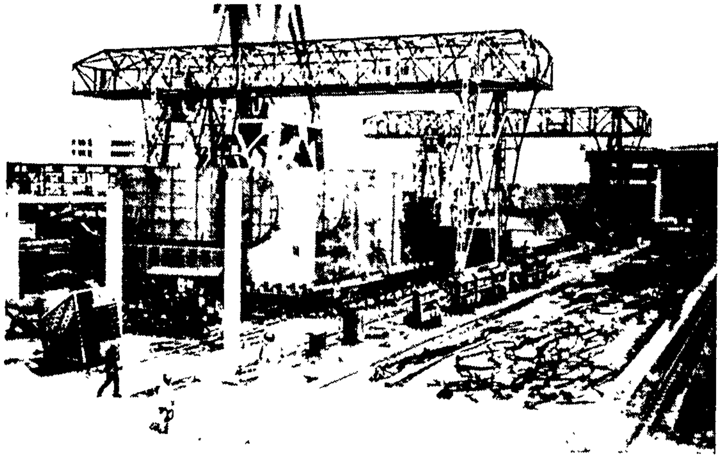
4.1 Horzontal Building Berth Facility

Figure 4 (continued) Views of Hudong Shipyard

4.m Fabricated and Sub Assembly Parts Storage



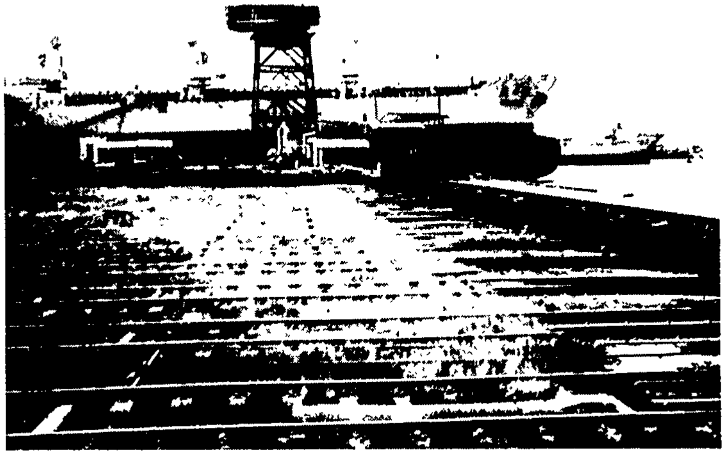
4.n Fixed Jig used for Block Assembly of Navy Ship



4.o Flat Block Final Assembly

4.p Block with Partial Outfitting

Figure 4 (continued): Views of Hudong Shipyard



4.q Horizontal Berth Launch Area

4.r Industrial Product Assembly

4.s Storage of Fittings Manufactured in Yard

4.t Sub Assembly Area

Figure 4 (continued): Views of Hudong Shipyard

CONSTRUCTION METHODS

Figure 5 is an isometric presentation of Hudong's block definition for the PD214. ln making the divisions, Hudong's planners followed these principles

- -- no block to exceed 180 tonnes, except for the superstructure final lift
- -- attempt to control the weight of most blocks to less than 100 tonnes;
- -- attempt to pre-outfit blocks before erection;
- -- avoid breaking blocks at the major stress zones (e.g., the areas of the big hatches in the decks);
- — recognize the standard steel plate sizes in making the block breaks (lengths of 6, 8, 10, and 12 meters, widths of 1.5, 1.8, and 2.0 meters);
- -- make breaks at major ship's structure points, especially in the Dow and stern, and
- -- make breaks so that the most effective construction technology can be utilized.

For comparison, Avondale's block definitions for the same ship are shown in Figure 6. There are areas of major difference in the break points for the two yards, Hudong, for example, divides its double bottoms so that the centerline units in the mid-ship section extend to the outboard longitudinal bulkheads (35′ 6″ off centerline). The entire bilge radius is included in a side-shell block. Avondale, on the other hand, divides the double bottom into three sections the centerline unit that includes the pipe tunnels (14′ 6″ off center-line), and the port/starboard outboard units that includes part of the bilge radius. Figure 7 shows the block-breaks in the mid-body area in the two yards. (Avondale completes many of its double-bottom blocks before erection starts. Their unit break points permit easy storage of the completed blocks by simply stacking them. On the other hand, Hudong would have only four blocks completed when erection starts, and storage would not be a factor in the break point decisions.)

Another difference is at the break points for the side-shell blocks. Hudong makes its break at the 3rd deck or below; Avondale divides its units at the 2nd deck.

A third major difference occurs in the superstructure. Here, Hudong divides each deck of the structure into a port and starboard unit the two-unit sequence is caused by the fact that erection occurs after launch, and transporters must move the units from the assembly area to quay-side. At Avondale, space and lift limitations don't exist and the superstructure is erected as a single unit.

Although Hudong has not implemented group technology through a rationalized product work breakdown structure, the yard does have in place a process system that incorporates many of the features of product work breakdown. As Table 6 shows, hull structure blocks are divided into six categories

a. Cargo area double bottoms, bilges, decks, and ramps (standard flat blocks);
b. Three-dimensional side shells, decks with side shells (special flat blocks);
c. Engine room double bottoms (curved and/or flat blocks of heavy weight);
d. Bow and stern curved sections (curved special blocks);
Superstructure;
f; Hatches, transverse and longitudinal bulkheads and beams (other blocks).

Hudong divided the ship into 194 production blocks, each with an average weight of 56.9 short tons (51.6 tonnes), as shown in Table 6. There was a wide dispersion in the block sizes, with the standard deviation calculated at 27.7 short tons, or 48.7 percent of the average weight. For comparison, Avondale's block count is 210, with an average weight of 52.7 short tons. Standard deviation was 20.5 short tons, or 38.9 percent of the average weight. The data shows clearly that Hudong does not maintain the same consistency of block size as Avondale this fact can also be visually verified by close examination of Figures 5 and 6, the isometric views of the block divisions for the two shipyards.

Table 6 shows, for each category, the following information: block count and its percentage of the total count, the weight range of blocks, the total steel weight for the category and its percentage of the grand total, the average weight of the blocks, the dispersion of these weights (expressed as standard deviation), and distance of movement of the material as it is being processed. The same information is also shown for Avondale's production s ystem for comparison.

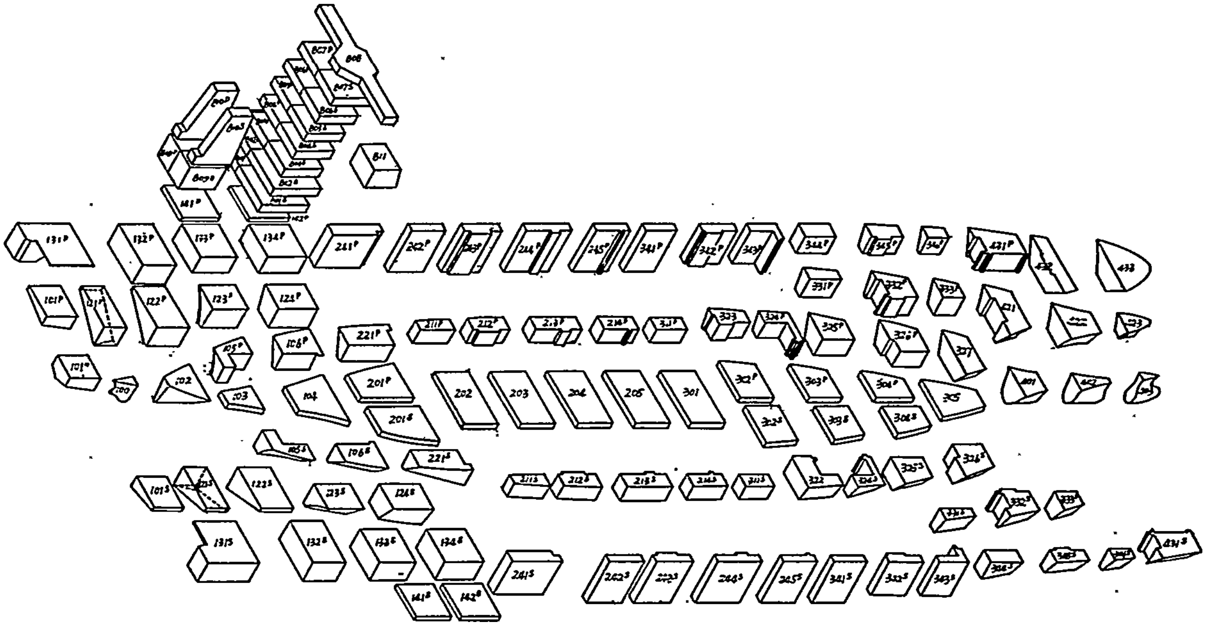


FIGURE 5: ISOMETRIC VIEW OF HUDONG'S BLOCK DIVISIONS

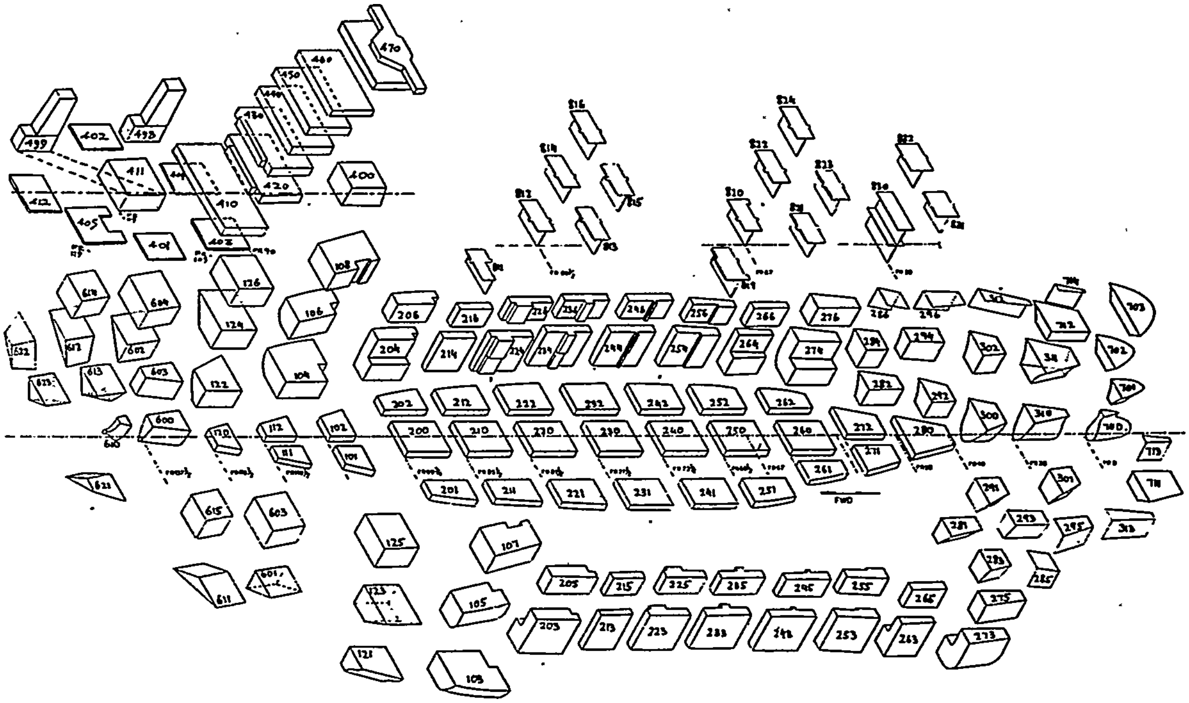


FIGURE 6: ISOMETRIC VIEW OF AVONDALE'S BLOCK DIVISIONS

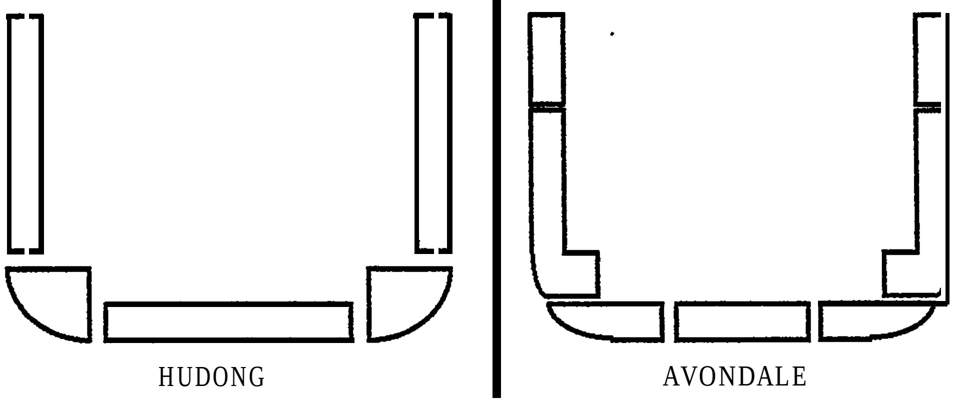


Figure 7: Schematic of Block Divisions at Midship Section for Hudong and Avondale Shipyards

TABLE 6
BLOCK PRODUCTION CATEGORIES FOR HUDONG AND AVONDALE SHIPYARDS

HUDONG SHIPYARD								
			weights (Shorttons)					lProcess PathJ
BlockCategory	#	%	Range	sum	% of Total	Avg.	Sigma	Distance(ft)
A.-Flat(cargo area double bottoms bilge, decks, and ramps.)	51	26.3	4.9--143.5	3,498	31.7	68.6	39.4	7,870
B.-FlatSpecial(3-dimenziom&iide-shell, deckd with side-shells.)	63	32.5	21.9--155.7	5,023	45.5	79.8	35.3	7,870
C.-Curved (Engineroom double bottoms.)	2	1.0	50.7–142.9	194	1.8	96.8	46.2	7,550
D.--CurvedSpecial (Bow and Stern)	15	7.7	i3.2–i38.9	1,191	10.8	79.4	31.1	8,350
E.-Superstructure	20	10.3	25.1-31.1	541	4.9	27.0	3.8	6,250
F.-Other(hatch, transverse and horizontal beams)	43	22.2	2.8-41.7	588	5.3	13.7	7.3	7,400-8,050
TOTALS	194	100.0	2.8--155.7	11,035	100.0	56.9	27.2	7,800

A VONDALESHIPYARD								
	count		Weights (short tons)					Prucess Path
BlockCategory	#	%	Range	sum	% of Total	Avg.	Sigma	Distance(ft)
I.-Flat Pannel Units(mid part, double bottoms, side-shells, long blkheads)	97	46.2	9.7-123.9	6,814	61.6	70.2	29.0	7,050
2.-Curved Shell Units (Aft&Fore PartUnits, side shell.)	31	14.8	19.3-100.6	1,630	14.7	52.6	24.6	2,900
3.-superstructure	19	9.0	23.1-71.2	807	7.3	42.5	14.6	2,850
4.–Fore Peak and Aft Peak Units (large & very heavy 3D curved)	13	6.2	13.1-97.2	778	7.0	59.5	34.9	2,900
5.--EogineRoomInner Bottoms(large and Heavy, intricate, flat units)	6	2.9	31.0-97.2	292	2.6	48.7	22.2	4,600
6.-Special Units (skegs, rodders, bulbous shapes, stern castings)	44	21.0	8.6--130.6	749	6.8	17.0	18.8	3,050
TOTALS	210	100.0	13.1--140.0	11,070	100.0	52.7	20.5	5,500

Importantly, Avondale has rationalized its system to incorporate the features of group technology. This rationalization has included the requirement of expanding engineering activities to meet the increased planning needs associated with group technology and zone outfitting.

The data presented in Table 6 reveals the wide dispersion of block weights within every Hudong production category. The difference between the largest block and the smallest block is great in one instance (category #l) the ratio is 29:1. For the entire ship the weight difference is a ratio of 55:1. Avondale's weight difference for its blocks is significantly less for the entire ship the ratio is 11:1 (140 tons versus 13.1 tons). And, the greater dispersion in block weights at Hudong is further confirmed by the greater standard deviation in the unit weights, as discussed earlier.

Finally, Table 6 indicates that an average ton of steel being processed for the PD214 at Hudong will travel a distance of nearly 7900 feet. (By contrast the average travel distance for a ton of steel at Avondale would be about 5500 feet.) It is noted, however, that when the new assembly shed at Hudong is completed (scheduled for mid-1988), the travel distance for a ton of steel will be significantly reduced.

The high priority that Hudong places on the time that a ship is on the slideway is indicated in Table 7. This table is a comparison of the time (in weeks) that Hudong and Avondale processed components for each of the ship's areas as a function of the production activity. For the erection activity, Hudong needed only 21 weeks; Avondale took 32 weeks or about 50 percent longer.

Further examination of the erection activity indicates that as the erection continues, Hudong increasingly concentrates its attention on getting the ship launched. Note that those areas of the ship that are early in the erection sequence (engine room and holds) take longer times at Hudong than at Avondale. The reverse is true for those areas that occur late in the erection process (bow, foreholds, and stern); here, the period of involvement is significantly shorter at Hudong. (In fact this phenomena exists for all of the production activities; the engine room and holds area material consistently being processed longer at Hudong than at Avondale, and the reverse is true for the foreholds, bow, and stern material. Hudong executives indicated in a personal interview at Hudong Shipyards on May 16, 1987 that this occurs because of the system of work load leveling that is employed. Hudong's system is to allow more time for the early units, thus giving the production shop additional leeway in adjusting its daily work load.)

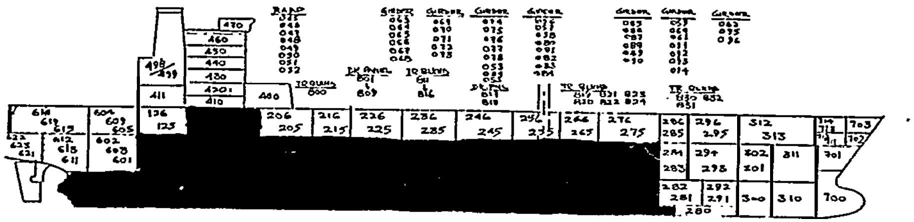
Hudong's fabrication space is limited (as seen in Table 4, shown earlier); this is refleeted in the fact that the time allowed for fabrication is greater. As Table 7 indicates, the fabrication of material at Hudong is 1.1 times that needed at Avondale. Hudong overcomes its space limitation by starting the fabrication process earlier and stockpiling material until it's needed. (The stockpiles are shown in the photographs in Figure 4.)

Figure 8 compares the erection status of the PD214 ship for the two shipyards at the quartile points from keel to launch: one-fourth, midway, and three-fourths. One-fourth of the way from keel to launch (five weeks after keel at Hudong, and nine weeks after keel at Avondale), depicted in Figure 8a, both shipyards have laid well over half of the double bottoms, and the

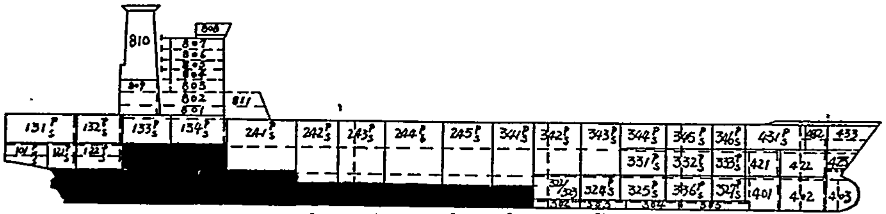
TABLE 7

COMPARISON OF PRODUCTION ACTIVITY BY SHIP'S SECTION

	Fabrication			Assembly			Erection		
	HSY		Ratio	HSY	ASI	Ratio	HSY	ASI	Ratio
SHIP'S AREA	(1)	(2)	(1)/(2)	(1)	(2)	(1)/(2)	(1)	(2)	(1)/(2)
Engine Room	27	15	1.8	23	18	1.3	15	12	1.3
Holds	32	18	1.8	29	17	1.7	21	11	1.9
Fore Holds	17	21	.8	16	24	.7	6	16	.4
Stern	14	1.8	.8	23	22	1.1	14	17	.8
Bow	21	18	1.2	17	**20**	**.9**	**2**	**15**	.1
Entire Ship	32	2.8	1.1	29	30		21	32	.7

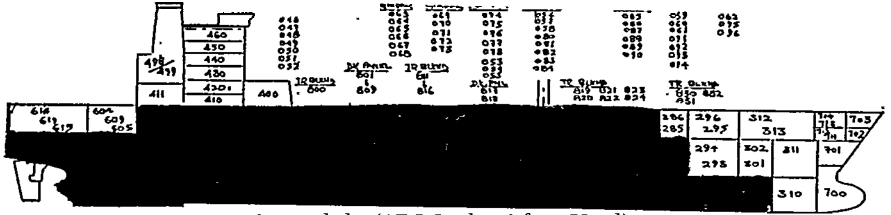


Avondale (9 Weeks After Keel)

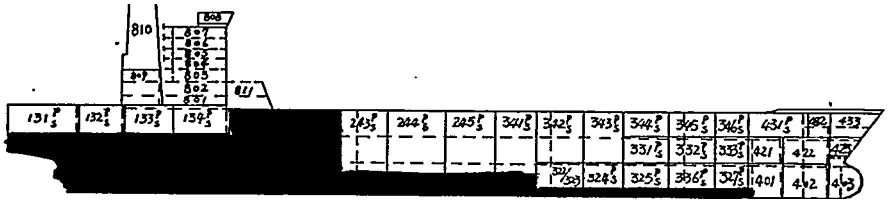


Hudong (5 Weeks After Keel)

FIGURE 8A: COMPARISON OF ERECTION STATUS HUDONG AND AVONDALE SHIPYARDS ONE-FOURTH OF THE WAY BETWEEN KEEL AND LAUNCH)

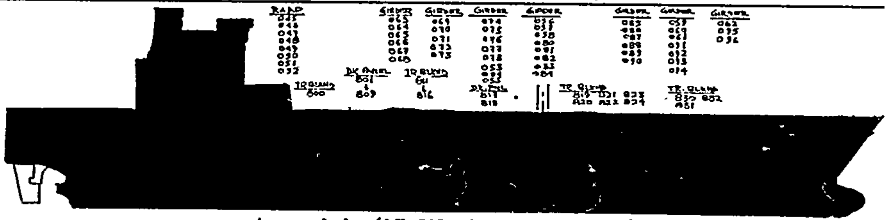


Avondale (17 Weeks After Keel)

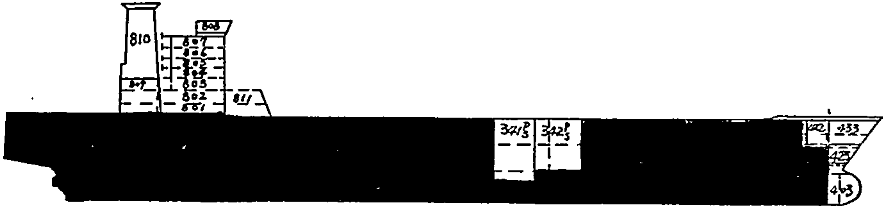


Hudong (9 Weeks After Keel)

FIGURE 8B COMPARISON OF ERECTION STATUS HUDONG AND AVONDALE SHIPYARDS (HALF WAY BETWEEN KEEL AND LAUNCH)



Avondale (27 Weeks After Keel)



Hudong (15 Weeks After Keel)

FIGURE 8C COMPARISON OF ERECTION STATUS HUDONG AND AVONDALE SHIPYARDS (THREE-FOURTHS OF THE WAY BETWEEN KEEL AND LAUNCH) stern tube casting is in place. Avondale, however, has progressed further in its erection of side-shell units, with the major blocks in place up to the second deck. While it's not evident in the figure, both yards started their erection process at the same point the forward engine room bulkhead. And, each yard erected units both fore and aft of this point in approximately the same sequence.

At the mid-point of the erection period (shown in Figure 8b) Hudong would have finished laying all of the double bottoms, and begun to put the side-shell units in place. In the engine room area, all of the units to the second deck would be in place, and a limited number of blocks to the main-deck height would have been erected. At the same point in time, Avondale would have erected all of the side-shell blocks in the parallel mid-body area.

At the three-quarters point (Figure 8c) Hudong would have most of the ship's structure in place except for the final blocks at the bow and at the "close-up" section in the parallel mid-body. The superstructure is landed after launch. Avondale would have completed its entire erection process at this point, including the superstructure. Because Avondale has ample erection locations, its policy is to leave the ship on the erection way for an extended period while it continues outfitting work. In the case of the PD214, Avondale's schedule indicates the ship stays at the erection site for approximately nine weeks after the final block has been put in place.

SUBCONTRACTING

The general policy of Hudong is not to subcontract any of the production activities. On rare occasions specific portions of the engineering work will be subcontracted to another division of China State Shipbuilding Corporation, such as CSSC'S Shipbuilding Research Institute. These organizations are utilized when a technical question arises that cannot be adequately dealt with by the shipyard's own staff. Seldom, if ever, is work subcontracted because of facility overload.

It has traditionally been the policy in Communist China that each enterprise is assigned a mission, and then it is to develop itself both vertically and horizontally to accomplish that mission. Until recently there was no economic penalty imposed for such an expansion. As a result, a typical Chinese shipyard has production facilities enabling it to build, from basic raw materials, most of the equipment found on a ship, Hudong, for example, builds its own engines, makes its own valves and fittings, and makes all of the castings and forgings that are required. Likewise, all of the support services necessary to design and build a ship are contained within the shipyard organization. The result has been a shipbuilding enterprise that typically will operate without recourse to outside sources of supply.

MATERIAL PURCHASING

As mentioned above, Chinese shipyards will fabricate internally as much of the equipment as possible. As a result, a greater portion of their requisitions will be for "raw materials". The remaining materials will be divided into two categories (1) those materials (or equipment) that can be purchased from domestic sources within China, and (2) those materials that must be purchased abroad.

Materials acquired within the Chinese domestic system, either raw materials or finished goods, are ordered at specified times each year. The typical order months for shipyards are February and August; at those times the purchasing agents indicate to the central organization their material needs 6-12 months fnto the future. These requests are then forwarded to the specified supplier, or to a supplier of the central organization's choice if it is deemed necessary to make the supplier change.

1f for some reason it is necessary to acquire the material from abroad, the shipyard must first secure approval from the central organization. This process takes approximately three months; only after the approval is given will the purchasing agent be in a position to place the purchase order with the overseas supplier. Approval of the central organization is only given if one of the following conditions exist: (1) the equipment is specifically requested by the owner; (2) the material of acceptable quality is not available from a Chinese source or (3) the material is not available from a Chinese source within the time period required.

CONSTRUCTION SCHEDULES

Figure 9 shows the milestones for the first ship and the purchase schedule for the principal items. The figure reflects the fact that almost one-half of the items (12 out of 25) will be manufactured by the yard. (By contrast, Avondale would only manufacture two items in-house: the funnel and tanks.)

It should also be noted that all of the principal items are purchased within the second month of the contract, in keeping with the specified purchase "window" of the central government.

Table 8 compares the lead time requirements for those items that are not purchased in the yard. The Hudong time period included an additional three months in each case to allow for the necessary approvals from the central organization.

In only one instance-the electric generator--is the Hudong lead time period greater than that at Avondale. The quicker overall delivery is reflected in the faster delivery time for the ships, as is shown in Figure 10. This figure compares Hudong's building milestones with those of Avondale. The building period for Hudong's first ship is 104 weeks after contrack by contrast Avondale's building period for the first ship is 140 ***weeks*** after contract. A second milestone chart was prepared for Avondale (also Shown in Figure 8) that revises the production schedule based on critical material being delivered on a schedule comparable to that found in a Japanese shipyard. ln this instance, Avondale's schedule for the first ship is reduced to 117 weeks, nearly the same as that of Hudong.

TABLE 8
LEAD TIME REQUIREMENTS FOR
SELECTED MATERIAL, FOR THE PD214

Item	Lead Time Requirement (months)	
	Hudong	Avondale
Steel Plates	6	8
Auxiliary Machinery	12	12
Main Boiler	14	14
Bridge Console	**10**	15
Electric Generator	10	15
Main Turbine	14	14
Propeller	6	15
ProDeller Shaft	6	6
Steering Gear	12	12

Source: Hudong Shipyard and Avondale Shipyard

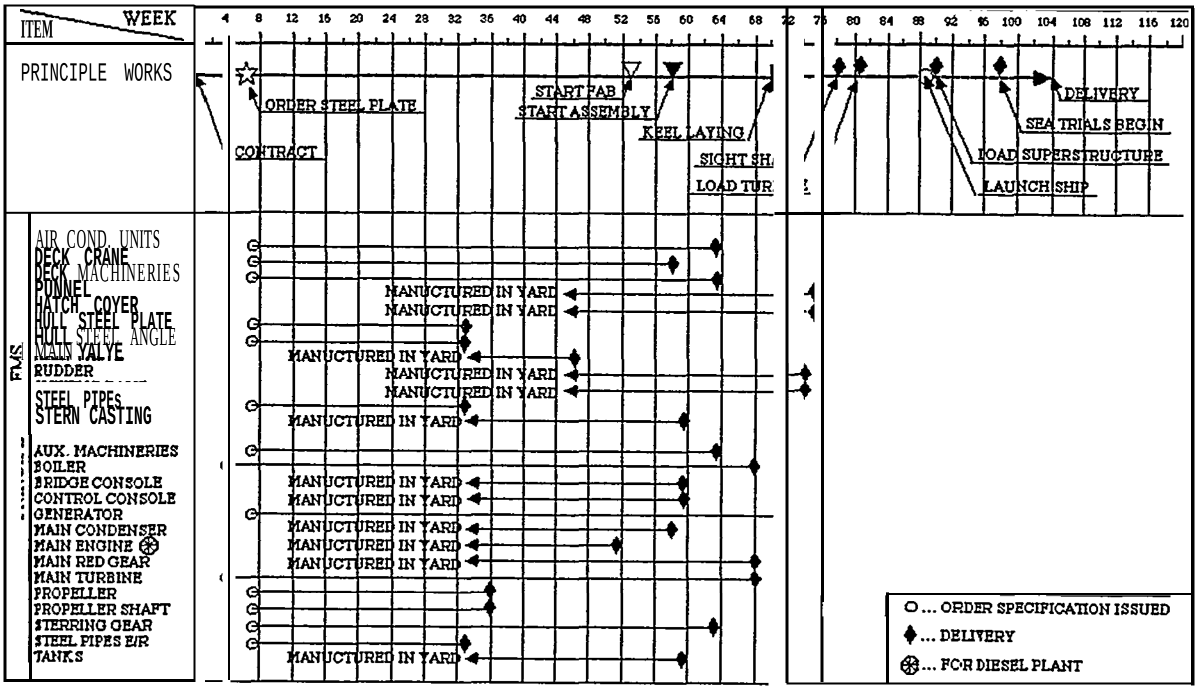


FIGURE 9: GENERAL CONSTRUCTION AND PURCHASE SCHEDULE FOR FIRST SHIP

The schedule for building all five ships is shown in Figure 11. Even though Hudong's delivery schedule is considerably less than Avondale's on the first ship, the difference nearly disappears over the five-ship series. The difference attenuation is caused by the fact that Hudong can only erect one ship at a time, whereas Avondale can have several under erection simultaneously. Hudong's fifth ship is delivered at 179 weeks after contract; Avondale's is turned over to the owner 189 weeks after contract. (It should be noted, however, that Avondale's final delivery would be 169 weeks after contract if the company were given the option of purchasing critical lead time equipment outside the United States.)

Figure 11 reflects the fact that there is a reduction in the production time for each ship as it is being processed. At Hudong this reduction is one week, from 51 ***weeks*** for the first ship to 50 weeks for the fifth ship. The reduction is consistent with the experience curve benefits that are discussed later in this paper.

The effect upon changes in erection man hour rates by having only one launch way is shown in Figure 12. This illustration is a three-week-moving-average plot of the weekly erection tonnages for the five ships. The sharp valleys and fast recoveries are evident as each ship is launched and the keel for a new ship is laid. Hudong's average erection rate is 573 short tons per week over a 97 week period. As the chart visually reflects, there is wide variation in this rate the standard deviation is 241 short tons per week, or 42 percent of the average. Avondale's is only slightly better its weekly erection rate is also plotted in Figure 12 for comparison. The average is 717 tons per week, with a standard deviation of 274 tons, or 38 percent of the average.

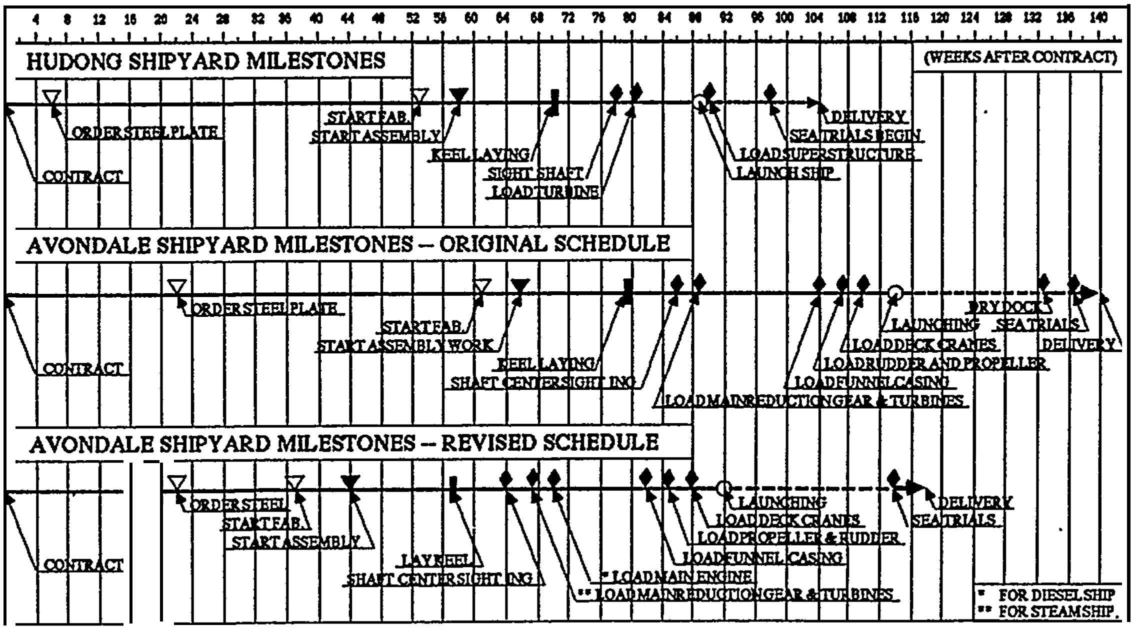
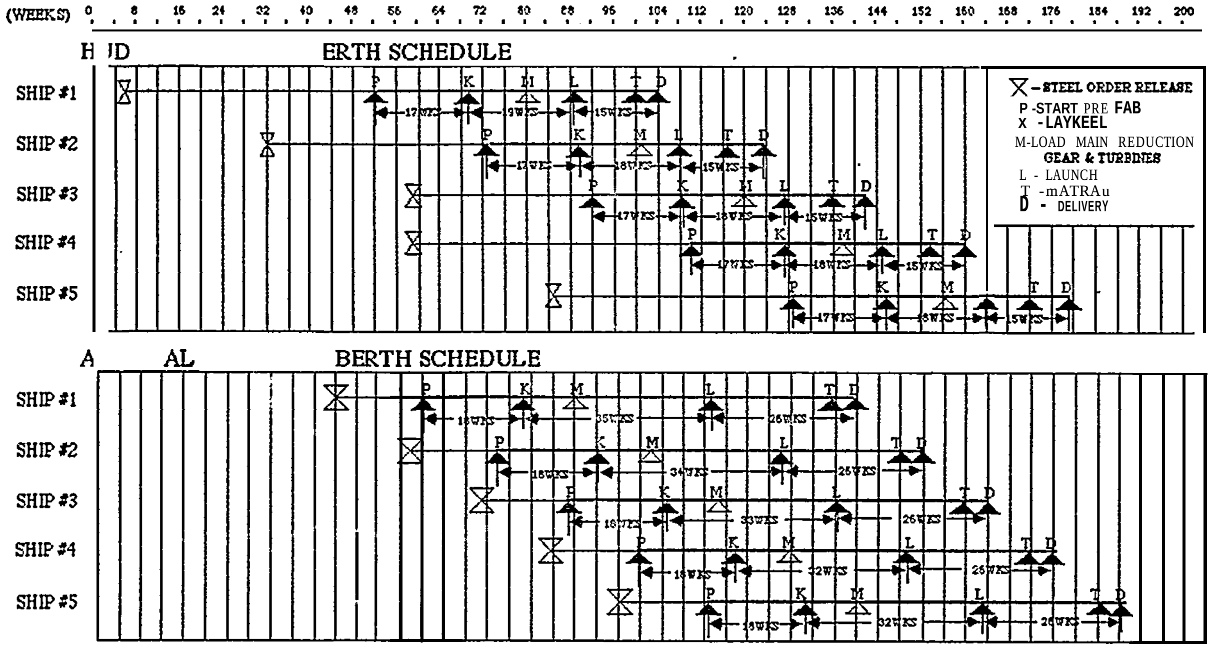


FIGURE 10: COMPARISON OF MILESTONES FOR BUILDING FIRST PD214 SHIP
HUDONG SHIPYARD VERSUS AVONDALE SHIPYARD



* — ORDERING EQUIPMENT & MATERIAL

☆ 70–75% OF STEEL PLATE REQUIREMENTS ORDERED BY WEEK 22 OF CONTRACT

FIGURE 11: BUILDING BERTH SCHEDULE FOR FIVE PD214 SHIPS

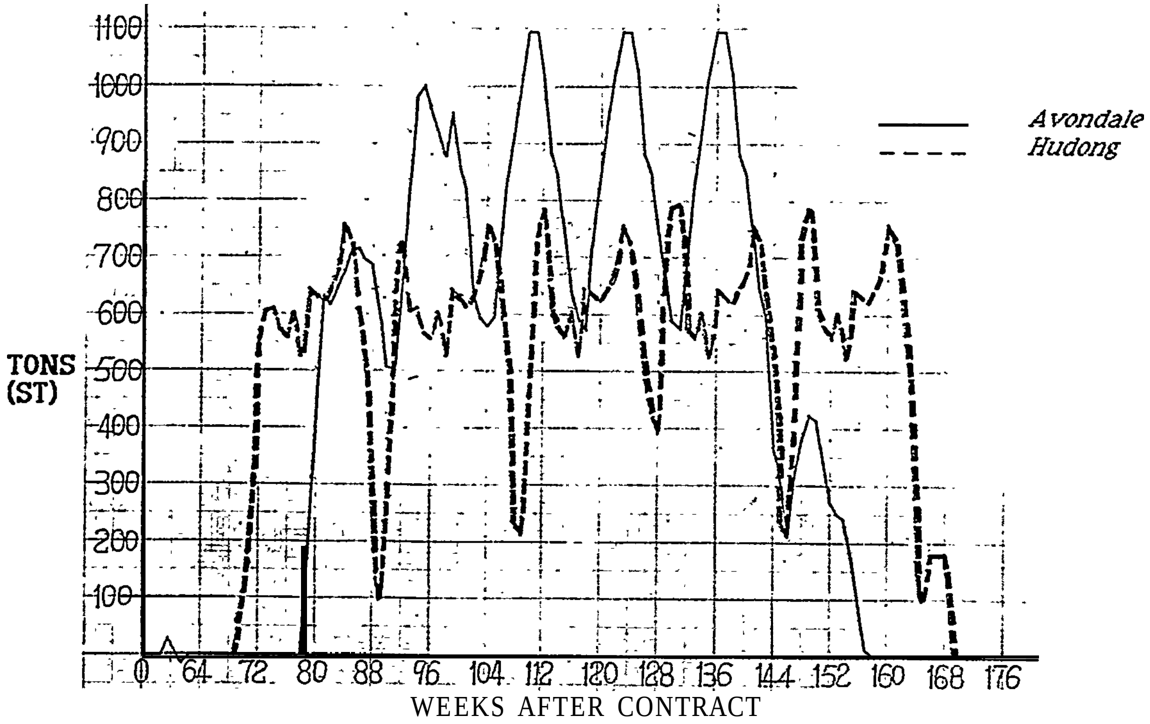


FIGURE 12: ERECTION TONNAGE SCHEDULE FOR BUILDING FIVE PD214 SHIPS
(THREE WEEK MOVING AVERAGE)

DIRECT MANHOURS REQUIRED TO BUILD FIVE PD 214 (JUMBO) STEAM TURBINE SHIPS
HUDONG SHIPYARD AND AVONDALE* SHIPYARD (000M/H)

ACTIVITIES	SHIP NUMBER											
	1 st		2 nd		3 rd		4 th		5 th		5-ship Average	
	HSY	ASI*	HSY	ASI*	HSY	ASI*	HSY	ASI*	HSY	ASI*	HSY	ASI*
Mold Loft & Prefabrication	141	54	122	52	122	51	121	51	121	50	125	52
Hull Sub-Assembly & Assembly	491	256	478	247	471	242	462	239	457	238	472	244
Hull Erection	347	205	339	198	327	193	324	191	322	190	331	196
Fitting & Outfitting	204	143	196	139	190	136	189	135	189	134	194	137
Piping	170	125	162	115	157	110	156	108	155	106	160	113
Machine (including SheetMetal)	261	113	247	110	245	108	243	108	241	107	248	109
Electrical	119	60	112	56	111	54	109	53	108	52	112	55
Painting (including Insulation)	212	136	208	131	202	129	201	128	197	127	204	130
Testing & Trials	30	32	28	31	27	29	27	28	27	28	28	30
All Other (including Cranes & Services)	44	165	44	159	43	156	42	155	41	154	43	158
Subtotal	2020	1289	1931	1238	1895	1209	1875	1195	1859	1188	1916	1224
Planning & Production Control Engineering	58	134	41	13	38	13	35	12	32	12	41	37
Engineering	248	412	25	41	22	39	20	37	17	35	66	113
Subtotal	306	546	66	54	60	52	55	49	49	46	107	150
Grand Total**	2326	1835	1997	1292	1955	1261	1930	1244	1908	1234	2023	1374

* Based on a contract awarded 1/1/83. The reader should be aware that there has been significant change in Avondale's productivity since that date.

**Numbers may not add correctly because of rounding.

MANPOWER REQUIREMENTS

In spite of the faster construction time, Hudong requires significantly more direct manhours to build the PD214 than does Avondale. The direct manhour estimates for both yards for each of the five ships are shown in Table. 9. For all of the production activities Hudong requires an average of 1,916 thousand man hours for each ship, which is about 156 percent greater than Avondale's requirements for each of the five ships.

The Chinese yard offsets part of this disadvantage however, when the planning and engineering manhours are factored into the estimates. On the basis of the total direct manhours, which includes both production and engineering, Hudong is about 1.27 times greater than Avondale on the first ship (2,326 thousand manhours versus 1,835 thousand manhours), and about 1.47 times greater for the five ship average. As seen, Avondale improves on its greater investment in engineering manhours for the first ship as the series progresses. (It should be noted, also, that Avondale's estimates were developed at a time when the yard was in the throes of implementing group technology and zone outfitting technology. As a result of this implementation, engineering investment for the PD214 increased 150 thousand manhours. [13] Prior to implementation of group technology concepts Avondale's engineering investment would have been approximately that shown for Hudong.)

Relative to Table 9, it must be remembered that Avondale's estimate was based on production procedures in place as of January 1, 1983—nearly three years before Hudong's assumed contract date. During that three-year period, Avondale has probably continued to improve its productivity making the actual difference in productivity for the two yards greater than that shown in Table 9.

Table 10 rearranges the Table 9 data into summary form by major production area. The production estimates for producing the ships with a diesel engine power system (instead of the steam turbine) are also shown. As would be expected, there is a significant reduction in the manhours estimate when the diesel engine is specified–about 95 thousand manhours per ship in the case of Hudong's estimate, and approximately 65 thousand manhours per ship for Avondale. There is no change in the relationship of the estimates between the yards; Hudong requires about 1.47 times as many manhours in either case.

As would be expected, the savings in manhours by use of the diesel engine are reflected in specific areas outfitting, painting and insulation, and engineering. The major savings occurred in outfitting where 91 thousand manhours/per ship is accounted for at Hudong, and 51 thousand manhours/per ship occurs at Avondale.

TABLE 10
COMPARISON OF MANHOUR REQUIREMENTS FOR MAJOR PRODUCTION & ENGINEERING ACTIVATES FOR A SERIES OF FIVE PD 214 SHIPS (000 M/H)

STEAM TURBINE POWER PLANT

Production Category	FIRST SHIP			5 SHIP AVERAGE			FIFTH SHIP		
	HSY	ASI	Ratio HSY/ASI	HSY	ASI	Ratio HSY/ASI	HSY	ASI	Ratio HSY/ASI
Hull Production Activities, including Mold Loft	980	515	1.90	928	492	1.89	900	478	1.88
Outfitting Activities	754	441	1.71	714	414	1.72	693	399	1.74
Painting & Insulation Activities	212	136	1.56	204	130	1.57	197	127	1.55
Testing & Trials Activities	30	32	0.94	28	30	0.93	27	28	0.96
All Other Activities	44	165	0.27	43	158	0.27	41	154	0.27
Total Production Activities*	2020	1289	1.57	1916	1224	1.57	1859	1188	1.56
Engineering & Planning Activities	306	546	0.56	107	150	0.71	49	46	1.07
Total Production & Engineering	2326	1835	1.27	2023	1374	1.47	1908	1234	1.55

* Number may not add correctly because of rounding

DIESEL ENGINE POWER PLANT

Production Category	FIRST SHIP			5 SHIP AVERAGE			FIFTH SHIP		
	HSY	ASI	Ratio HSY/ASI	HSY	ASI	HSY/ASI	HSY	ASI	HSY/ASI
Hull Production Activities, including Mold Loft	980	515	1.90	928	492	1.89	900	479	1.88
Outfitti	658	387	1.70	623	363	1.72	606	350	1.73
Painting & Insulation Activities	212	128	1.66.	204	122	1.67	197	119	1.66
Testing & Trials Acdvities	30	32	0.94	28	30	0.93	27	28	0.96
All other Activities	44	165	0.27	43	158	0.27	41	154	0.27
Total Production Activities *	1925	1225	1.57	1827	1165	1.57	1771	1130	1.57
Engineering & Planning Aaivities	284	532	0.53	101	146	0.69	48	46	1.04
Total Pruducdon & Engineering	2209	1757	1.26	1928	1310	1.47	1819	1176	1.55

* Number may not add correctly because of rounding

The effects of learning on productivity improvement are shown .Table 11. The production activities show approximately the same rate-of-change for the two shipyards over the five ship series, with the fifth ship requiring only 90-93 percent of the manhours estimated on the first ship. The major improvement occurs in the engineering and planning activities where the estimated manpower requirements for the fifth ship is only 16 percent of the first at Hudong, and only eight percent of the first at Avondale.

On a total manhour basis, Avondale's reductions are greater than Hudong's. The American yard needs only 67 percent of the manhours for the fifth ship as for the first, whereas Hudong's reduction is only to 82 percent of the first.

There is a marked difference in the "S" curves for the two shipyards. Figure 13 displays the estimates of the cumulative expenditures of manhours. as a percentage of the total manhours. As seen, Avondale starts quicker, increases more slowly, and terminates at 100 percent later (196 weeks). Hudong has expended 50 percent of its budget manpower at about 109 weeks, about 60 percent of the way to completion. Avondale's 50 percent point is at 118 weeks, about 60 percent of the distance to final delivery of the fifth ship.

TABLE 11
EFFECTS OF EXPERIENCE ON PRODUCTIVITY IMPROVEMENT

Activites/Ship of Series	(% of 1st ship Man			urs)	
	2nd ship	3rd ship	4th ship	5th shi	5 Ship Avg.
Hull Production					
Hudong	96	94	93	92	95
Avondale	97	94	93	93	96
Outfitting					
Hudong	95	93	92	92	95
Avondale	95	93	92	90	94
Painting & Insulating					
Hudong	98	95	95	93	96
Avondale	96	95	94	93	96
Engineering & planning					
Hudong	22	20	18	16	35
Avondale	10	10	9	8	27
Total Manhours					
Hudong	86	84	83	82	87
Avondale	70	69	68	67	75

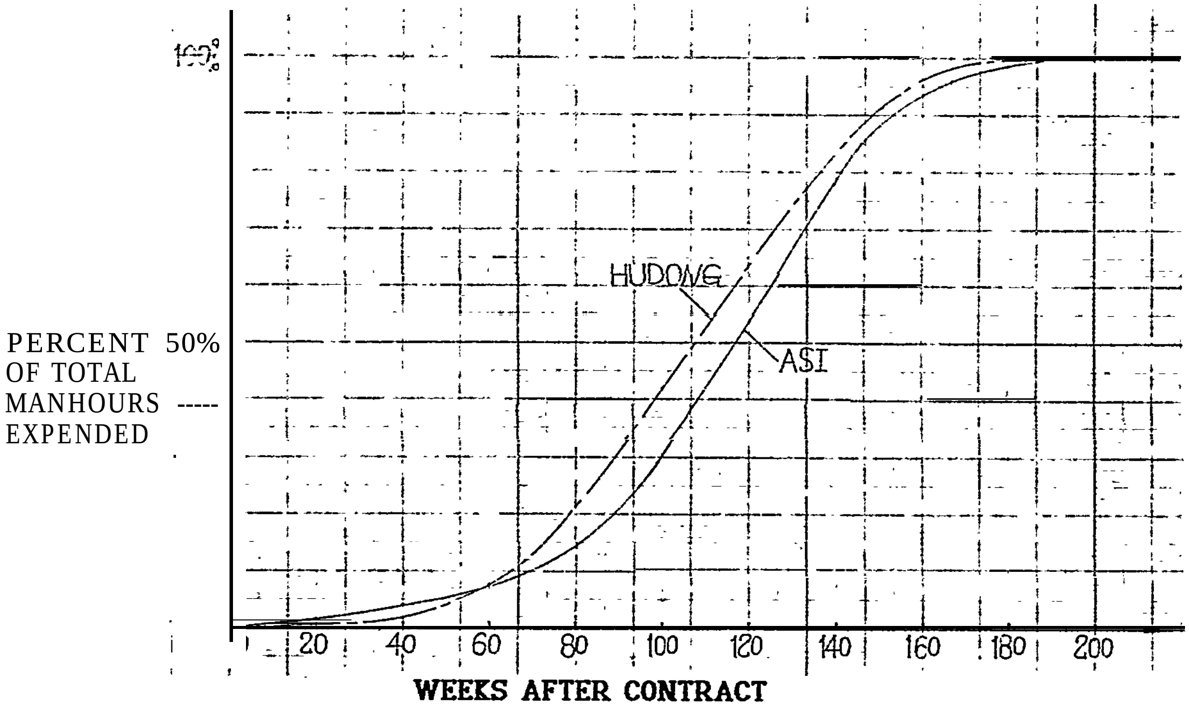


FIGURE 13: CUMULATIVE EXPENDITURE OF MANHOURS

Figures 14 and 15 show the manhour expenditure estimates on the basis of 20-week periods through the contract. Figure 14 presents the estimates for Hudong, and Figure 15 makes the same presentation for Avondale. Both tables show that the early manhour expenditure is for engineering, as would be expected. The early "production" hours shown are for production planning (which for these illustrations has been considered a production function).

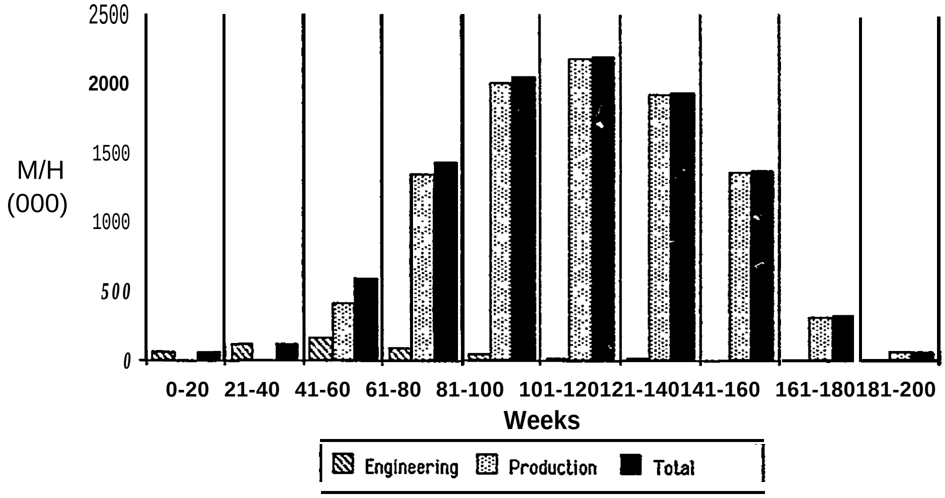
Hudong's peak expenditure is during the 101-120 week period, when about 2.2 million manhours are budgeted. Avondale's peak spending period is during the 121-140 week time frame, when slightly over 1.7 million manhours are budgeted.

CONCLUSIONS

Hudong's production facilities are generally adequate for its assigned mission, i.e., building merchant ships up to approximately 70,000DWT, and navy surface ships up to about 5,000DWT. When comparing these facilities with a typical American shipyard (Avondale), one also finds the two yards approximately the same in most areas. Where differences do occur, they generally have significant impact on limiting Hudong's ability to expand or to improve on its mission. The major deficiencies are (1) lack of plasma-arc cutting equipment; (2) lack of automatic welding equipment; (3) lack of state-of-the-art CAD/CAM hardware and software (this deficiency is currently being overcome with the installation of an IBM 4310 computer); (4) limited launch-way capacity and antiquated erection area; and (5) limited space for fabrication processes (this problem is only being partially overcome with the construction of the new assembly shed currently being built).

Hudong's organizational structure is more complex than that typically found in an American shipyard, in that it has a much more extensive basic design capability and associated equipment manufacturing capability. In fact, most of the ships built at Hudong have been designed by technical staff within the yard, and much of the outfitting equipment and machinery is built at the yard. The yard's managers are well-trained (most have university technical degrees), and are experienced (all have been in the yard most of their professional careers).

The relationship between "management" and "labor" is totally different than that found in the United States. There is only one labor union; it is controlled by the



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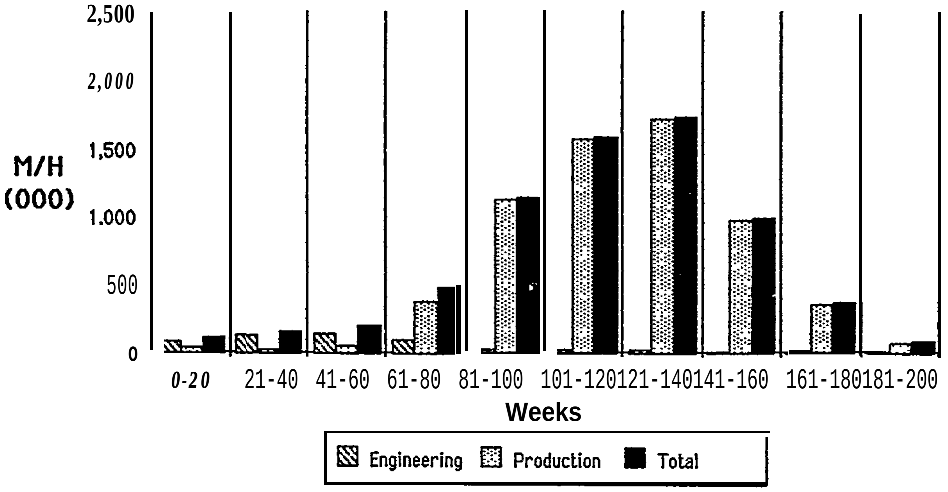

FIGURE 15: HISTOGRAM EXPENDITURE OF MANHOURS AT AVONDALE SHIPYARD

Communist Party, which also maintains the political organization that exists in the shipyard. The impact of the party and the state control is pervasive and strongly influences all decisions that are made by management. Since the beginning of the "Reform" (about 1980), however, management has slowly expanded its ability to make decisions on purely economic bases with less of a political orientation. The result has been more rational economic operations and a steady improvement in productivity.

The yard has not implemented a rationalized group technology production system, even though many of the characteristics associated with such a system are in place. The lack of a developed group technology is evidenced in the wide range of sizes of blocks that are processed in each of the production lanes. The same spread in block size is also evident in the total system the smallest block is nearly 50 times smaller than the largest block. (At Avondale this difference is a multiple of only 11:1).

The material lead time at Hudong, while better than that found in an American yard where only American-built material is permitted*, is nonetheless burdensome. The Chinese yard can only order material from domestic sources twice a year; obtaining supplies or material from an overseas source requires approval of CSSC headquarters, This process adds about three months to the lead time requirements.

Hudong estimates that it will require 2.02 million manhours to build each of five steam turbine powered PD214 General Mobilization Ships. This is about 147 percent more manhours than was estimated in 1983 for Avondale, and about 340 percent more than was estimated by Kawasaki-Kobe in its 1980 study, [14] The only area where the American yard requires more manhours than Hudong is for engineering activities. But this difference is explained by the fact that Avondale has incorporated group technology and zone outfitting into its production system; such an approach requires significantly more man-hours, especially in the early years of implementation, Before adoption of group technology and zone outfitting, Avondale's engineering manhours were in the same approximate range as was that estimated by Hudong for the PD214 ship.

Much of the difference in the productivity can be explained by the effect on Hudong of the political and social system in which the yard must operate. The Chinese manager cannot adjust his labor force at will; he must provide continuing employment and many of the social services to all of the workers assigned to his organization. ln the case of Hudong, this is 12,000 people and their families. This fact colors every decision made by management. Manpower is approached as if it is a constant fixed cost. An improvement in productivity for a Process may not, in fact, reduce the yard's cost since the worker must still be paid. (There is, however, some change beginning to occur in this situation, and indications are that the manager will have greater control over work forces in the future.)

ln the final analysis productivity is not the issue in a Chinese shipyard. The country is already one of the world's low-cost producers. The man-day rates (defined **as** direct costs and apportioned indirect costs) in the U. S. and Japan are at least 10 times that of China, and the differences in productivity are much less than that ratio. The issue is the purchaser's perception of quality. The ships put into the export market by China are still not perceived to be at a standard of quality that exists in Japan, South Korea, Taiwan, Western Europe, and the United States. The Chinese shipbuilders are aware of this difference, and are striving to change this image. Only time will tell the extent of their success.

ACKNOWLEDGEMENTS

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*At the time of the Avondale study, commercial ships built in U.S. yards for American-flag registrations were required to be built of American-made material. This is no longer the case, and Avondale today would have the option of purchasing equipment from abroad.

paper was based on data and analysis performed by the study team, which worked together on the project for the better part of a year. The dedication and cooperative spirit of the members of the team was an inspiration to the author, and the individual and group efforts are acknowledged with appreciation.

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