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THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

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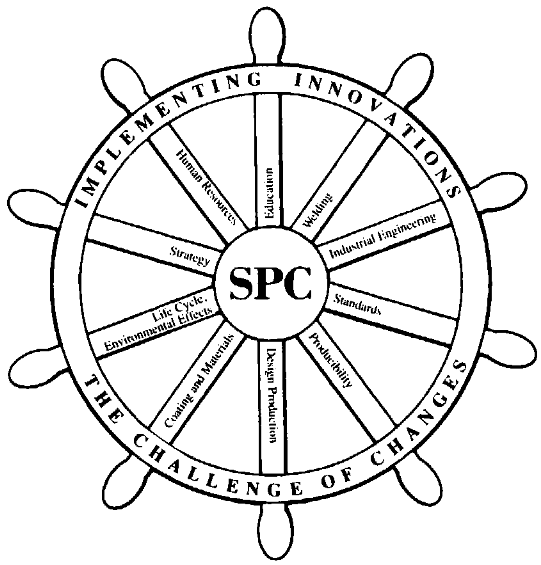

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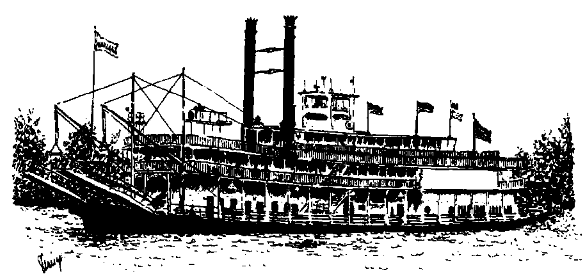

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Environmental Pollution Control: Regulatory Considerations and a Case in Point

No. 2A-1

Jonathan Ross, Member, Ross-McNatt Naval Architects

ABSTRACT

During recent years, the United States has paid increasing attention to controlling and minimizing environmental pollution. One result of this attention is the development of new laws and regulations, enforced bY the Environmental Protection Agency (EPA) and by state and local agencies. These new environmental laws and regulations are considerably more stringent than those of past years and they directly impact how shipyards must conduct their operations. This paper discusses these laws and regulations at the national, state (including California, Virginia and Connecticut), and local levels.

With the environmental regulatory background in focus, the paper proceeds to explore the effects of the regulatory trend on one particular segment of the shipbuilding and ship repair industry: floating drydocks. Floating drydocks provide an illuminating example, because of the environmentally sensitive industrial activities carried out on board, such as grit blasting and painting with antifouling paints. The operational norms of floating drydock pollution control are discussed, starting with present day commercial and Navy facilities, and culminating with the Navy's newest floating drydock design, the AFDB 10.

NOMENCLATURE

- BMPs - Best Management Practices, which are plans to minimize pollution by industrial facilities such as drydocks
- CHT - Collection, Holding and Transfer system for shipboard sewage
- EPA - The United States Environmental Protection Agency
- NPDES - National Pollution Discharge Elimination System
- VPDES - Virginia Pollution Discharge Elimination System
- WQS - Water Quality Standards

INTRODUCTION

The United States is paying increasing attention to pollution control. One result of this attention is the development of new environmental requirements, enforced by the EPA and by state and local agencies (in the context of this report, "requirements" include laws, guidelines, standards, regulations and other legal limitations). These new requirements are considerably more stringent than those of past years and they directly impact how drydocks must conduct their operations.

The following presentation addresses the subject of pollution control by providing an overview of applicable regulatory requirements: examining selected approaches to successfully complying with those requirements; and presenting a recent design which is responsive to the requirements and builds upon past lessons learned.

In order to provide focus in what is a complex subject, the presentation explores the effects of the regulatory trend on one particular segment of the shipbuilding and ship repair industry: floating drydocks. Floating drydocks provide an illuminating example because of the environmentallY sensitive industrial activities carried out on board, such as grit blasting and painting with antifouling paints. Other types of ships and marine structures will have their own particular requirements, but will also share many elements in common with floating drydocks.

TYPES OF POLLUTANTS AND APPROACHES TO THEIR CONTROL

Following is a description of the types of pollutants generally found on floating drydocks and approaches to their control (1,2,3).

Spent Abrasive

The most significant pollutants from

floating drydocks are the heavy metals present in spent abrasive. Here, the term "Spent abrasive" refers to used blast grit mixed with particles of scale, rust, old paint and marine growths removed from ships during blasting operations. Spent abrasive accumulates on the floor of the drydock during blasting and painting operations. The old paint particles present in the abrasive are a potential source of pollution. With a much greater surface area exposed than was present while on the hull, the old paint is subject to leaching of heavy metals.

The objective in controlling this pollutant is to prevent the discharge of spent abrasive overboard or the leaching of the heavy metals out of the spent abrasives as they lay on the deck (leaching agents include rain water and liquids that leak from sanitary waste lines, cooling water lines and air scrubber systems).

Sanitary Waste

Shipboard sanitary waste includes "black" and "gray" water. Two alternatives exist for the proper handling of sanitary waste: (1) it may be discharged directly to a shipyard sewer system: or (2) it may be placed into a holding tank for subsequent removal from the drydock and drainage to a sewer system.

Trash and Sediment

Miscellaneous trash and sediment accumulate on the floor of drydocks during shipbuilding and ship repair operations.- If not removed -prior to undockining. this material is discharged during ballasting. The discharge of trash and sediment may be minimized through the diligent use of waste receptacles or a thorough cleanup of prior to flooding.

New paint

An estimated 5 percent of the total paint to be applied to the hull is lost to the drydock and can be discharged to the receiving water. These losses include: paint spilled within the drydock; excess applied paint which drips to the floor of the dock: overspray due to improper use of: and wind carried paint which lands in the dock.

APPLICABLE REGULATORY REQUIREMENTS

Generally speaking, state water and air quality control regulatory requirements derive from Federal laws, administered by the EPA. Each state builds upon the Federal laws, adds its own needs and concerns, and passes its own water and air quality control laws. These form the basis from which state boards develop regulations and the administrative structure of a state water and air quality control program. When such a program is in place and accepted by the EPA, the EPA delegates its water and air quality control enforcement functions to the state, and the state board implements the functions through state and regional departments. Figure 1 illustrates a typical structure of the laws and regulations, and Figure 2 presents typical administrative structure for this approach.

Federal Laws

Clean Water Act | Clean Air Act

State Laws

Water Pollution Control Law | Air Pollution Control Law

State Regulations 1

Regulations for the Control and Abatement of Water Pollution | Regulations for the Control and Abatement of Air Pollution

Interface With Industry

National Pollution Discharge Elimination System (NPDES) Permit | Memorandum of Understanding

Industry

Best Management Practices | Shipyard Procedures

FIGURE 1
WATER AND AIR QUALITY CONTROL
TYPICAL REGULATORY STRUCTURE

Following is a description of EPA and selected state and local regulatory requirements, focusing on the states of Connecticut, virginia, and California.

Federal Requirements

The Federal requirements consist of two laws, the Water Quality Act and the Clean Air Act (4, 5, 6). Each of these laws is discussed below.

Water Quality Control. Almost all of the EPA requirements that affect drydocks fall within the water quality control category, that is, within the Water Quality Act. Within the framework of this Act, the EPA requires that industrial direct dischargers of pollutants, such as floating drydocks, obtain and comply with a National Pollution Discharge Elimination System

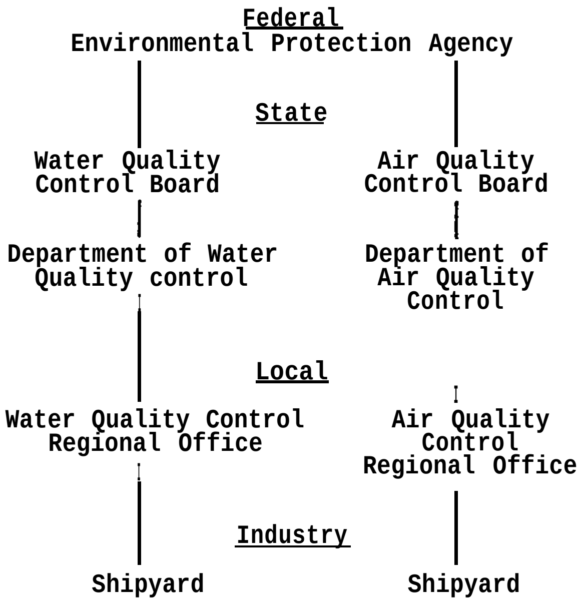

FIGURE 2
WATER AND AIR QUALITY CONTROL
TYPICAL ADMINISTRATION STRUCTURE

(NPDES) permit (7). This permit is tailored to each industrial facility and its aim, as its name implies, minimize pollution discharge. It does this by either stipulating discharge limitations and monitoring requirements, or stipulating Best Management Practices (BWPS).

The discharge limitations comprise numerical maximum amounts of named pollutants that the industrial facility may discharge during specific periods of time (e.g., weekly) into named waters (e.g., a bay or river). The monitoring requirements call for the industrial facility to monitor discharges for pollutants at specific intervals of time and to report the findings to the agency that issued the NPDES permit.

BWPs are designed to help minimize pollution discharges in those cases for which numerical discharge limitations are not practical. The BRPs are guidelines that are to be followed by the industrial facility in the conduct of its day-to-day operations. An example set of BRPs for drydocks is presented below.

BMP 1. control of Large Solid Materials. Scrap metal, wood and plastic, -miscellaneous trash such as paper and glass, industrial scrap and waste such as insulation, welding rods, packaging, etc., shall be removed from the drydock floor prior to flooding or sinking.

BMP 2. Control of Blasting Debris. Cleanup of spent paint and abrasive shall be undertaken as part production activites the degree technically feasible to prevent its entry-into drainage systems. Mechanical cleanup may be accomplished by mechanical sweepers, front loaders, or innovative equipment. Manual methods include the use of shovels and brooms. Innovations and procedures which improve the effectiveness of cleanup operations shall be adapted, where they can be demonstrated as preventing the discharge of solids. Those portions of the drydock floor which are reasonably accessible shall be "scraped or broom clean" of spent abrasive prior to flooding.

After a vessel has been removed from the drydock and the dock has been deflooded for repositioning of the keel and bilge blocks, the remainins areas of the floor which were previously inaccessible shall be cleaned by scraping or broom cleaning prior to the introduction of another vessel into the drydock.

BWP 3. Oil, Grease, and Fuel Spills. During the drydocked period oil, grease, or fuel Spills shall be prevented from reaching drainage systems and from discharging with drainage water. Cleanup shall be carried out promptly after an oil grease spill is detected.

BWP 4. Paint and Solvent spills Paint and solvent spills shall be treated as oil-spills and segregated from discharge water. Spills shall be contained until cleanup is complete. Mixing of paint shall be carried out in locations and under conditions such that spills shall be prevented from entering drainage systems and discharging with the drainage water.

BMP 5. Abrasive Blasting (Graving Docks) Abrasive blasting debris' in graving docks shall be prevented from being discharged with drainage water. Such blasting debris as deposits in drainage channels shall be removed promptly and as completely as is feasible.

BMP 6. Segregation of Waste Water Flows in Drydocks The various process wastewater streams shall be segregated from sanitary wastes. Gate and hydrostatic leakage may also require segregation.

BMP 7. Contact Between Water and Debris. Shipboard cooling and process water shall be directed so as to minimize contact with spent abrasive and paint and other debris. Contact of spent abrasive and paint by water can be reduced by proper segregation and control of wastewater streams. When debris is present, hosing of the dock should be minimized. When hosing is used as a removal method, appropriate methods should be incorporated to prevent accumulation of debris in drainage systems and to promptly remove it from such systems to prevent its discharge with wastewater.

BMP 8. Maintenance of Gate Seals and Closure. Leakage through the gate shall be minimized by repair and maintenance of the sealing surfaces and proper seating of the gate. Appropriate channelling of leakage water to the drainage system should be accomplished in a manner that reduces contact with debris.

BWP 9. Maintenance of Hoses. Soil [illegible] connections, valves, pipes, hoses, and soil chutes carrying either water or wastewater shall be replaced or repaired immediately. Soil chute and hose connections to the vessel and to receiving lines or containers shall be positive and leak free as practicable

BWP 10. Water Blasting, hydroblasting and Water Cone Abrasive Blasting (Graving Docks). When water blasting, hydroblasting, or water-cone blasting is used in graving docks to remove paint from surfaces, the resulting water and debris shall be collected in a sump or other suitable device. this mixture then will be either delivered to appropriate containers for removal and disposal subjected to treatment I?: concentrate the solids for disposal and prepare the water for reuse or discharge.

Note that, while these BMPs address a variety of pollutants, the EPA's major concern with respect to potential water pollution is with spent paint and abrasive blasting material. This concern is addressed by BWPs 2, 5, 7 and 10.

Air Quality Control. Federal air quality requirements are presented in the Clean Air Act of 1990 (6). Note that certain drydock-related requirements are still in the developmental stage by EPA, examples of which follow (8).

Spray Painting - a control technique guideline is being written. It will be given to the states to assist them in writing their regulations and will be within the area of "marine vessel coating."

Sandblasting - No Federal regulatory initiatives are presently under way.

Diesel Engine Emissions - there will be additional NO_x requirements in the coming years. They will apply throughout the north-eastern U.S., mainly for major emitters, i.e., stationary internal combustion engines. For small engines, such as those typically found on floating drydocks for cranes or diesel-generators, these future EPA regulations would not apply (9).

Connecticut State and Local Requirements

As is the case with the Federal requirements, the state water and air quality control requirements are divided into the categories of water quality control and air quality control. A discussion of these requirements follows.

Water Quality Control. Connecticut's water quality control program is based upon its "Water Quality Standards" (WQS)(lO). These Standards set the overall policy for management of water quality in accordance with the directive of Section 22a-426 of the General Statutes of Connecticut. The WQS consists of three elements:

Standards for water guality, inculuding classification of different water resources according to the desirable use, degradation, allowable types of discharges and fundamental principles of waste assimilation.

2. Criteria, consisting of descriptive and numerical standards, that describe the allowable parameters and goals for the various water quality classifications.

3. Maps, which show the classification assigned to each surface and groundwater resource throughout the state.

The presentation in the WQS is not to the level of detail of industrial activities, such as shipyards or ship repair facilities.

Air Quality control connection's air quality program is described in the "Regulations of Connecticut State Agencies, Abatement of Air Pollution" (11). The regulations are based on Section 22a-174 of the General Statutes of Connecticut. Included are sections that deal with registration and other instructions: regulations; and civil penalties. As with the water quality regulations, the treatment is not to the level of detail specific to certain industries, much less to drydocks.

Virginia State and Local Requirements

Following is a summary of Virginia's water and air quality control requirements.

Water Quality Control Virginia's water quality control requirements are set forth in the State Water Control Law, which is implemented by the Virginia Water Control Board, within the guidelines of the "Commonwealth of Virginia State Water Control Board Statutes" (12). As with other states, the Virginia Water Control Board is authorized by the EPA to administer the National Pollution Discharge Elimination System (NPDES) permitting program (13). Toward this end. Virginia issues Virginia Pollutant Discharge- Elimination System (VPDES) permits, which tailor the NPDES regulations to the needs and conditions of Virginia. For example, shipyards are required to acquire VPDES permits for saecific effluent. and must provide BMPs control the pollutant loadings that are stated in those permits (14).

Virginia has focused particular attention on shipyards, and has developed a document entitled "Best Management Practices Manual for the Shipbuilding and Repair Industry (Draft)" (2) - This document provides 24 BMPs, of which the following directly impact the operation (and often the design) of floating drydocks:

- Sanitary Waste Disposal
- Gray Water Disposal
- Bilge and contaminated Ballast Water Disposal
- Leaking Pipe, Hose and Valve Connections
- Floating Drydock Cleanup
- Sally port Screening and Filtering
- Shrouding
- Water Cleaning
- Water Blasting, Hydroblasting, Water-Cone Blasting and Slurry Blasting.

Virginia's main area of concern regarding water pollution by drydocks is rain water runoff, which may contain entrained paint pollutants in blast grit as well as oil and grease (12).

An example of where the VPDES requirements are being used is the VPDES permit for the U.S. Navy's Sewells Point Naval Complex, Norfolk, Virginia. This VPDES permit is presently in the draft form and specifically addresses the BMP areas described above. Following are examples of practices stipulated in this permit (15).

> Acceptable methods of control shall be utilized during abrasive blasting and spray painting, with the intent of preventing blast dust and overspray from falling into the receiving water. These include the following: downspraying of blast materials and paint: barriers or shrouds beneath the hull: barriers or shrouds between the hull and the wing walls of the drydock: and barriers or shrouds hung from the flying bridge to the drydock, from the bow or stern of the vessel, or from temporary structures erected for that purpose.
>
> When water blasting. hydroblasting, or water-cone blasting is used to remove paint from surfaces, the resulting water and debris shall be collected in a sump or other suitable device. This mixture then will be either delivered to appropriate containers for removal and disposal subjected to treatment to concentrate the solids for proper disposal and prepare the water for reuse or discharge through an authorized outfall.
>
> All shipboard cooling water and process water shall be directed away from contact with spent abrasive, paint and other debris. Contact of spent abrasive and paint with water will be prevented by proper segregation and control of wastewater streams. When debris is present, hosing of the dock shall not take place.
>
> For vessels in which sanitary waste tanks (holding tanks) are installed, all sanitary wastes from the vessels shall be removed and disposed of by a commercial waste disposal company or discharged into the shipyard's sanitary waste system.
>
> For vessels without sanitary waste holding tanks installed, the vessel's sanitary systems shall not be permitted to discharge overboard into the adjacent river. Vessels

without holding tanks shall be connected to a holding tank or shoreside system in compliance with Virginia Department of Health Regulations.

[illegible] **air quality control, Virginia has** developed the Virginia Air Pollution Control Law (Title 10.1, Chapter 13 of the Code of Virginia). This law fulfills Virginia's responsibilities under the EPA's Federal Clean Air Act and serves as a basis for Virginia's Department of Air Pollution Control's "Regulations for the Control and Abatement of Air Pollution" (16).

To implement the Virginia Air Pollution Control Law at the shipyard level, the Virginia Department of Air Pollution Control develops memoranda of understanding with individual organizations. A typical memorandum of understanding with a shipyard is about three pages in length and stipulates requirements such as those shown below (17).

- Establish, implement, and submit a written policy and procedure for outdoor abrasive blasting and spray painting operations which takes "reasonable precautions to prevent particulate matter from becoming a airborne." This procedure shall be subject to mutual agreement.

- Install wind direction and wind speed instruments located conveniently to central shipyard outdoor abrasive blasting and spray paint operations, and shall maintain records of wind direction and speed.

- Terminate abrasive blasting or spray painting operations if the wind speed exceeds a sustained 25 (twenty-five) miles per hour at the facility, unless effective containment methods are utilized or wind direction is such that particulate matter will not be improperly transported to adjacent property.

- Use adequate containment methods such as curtains or shrouds where possible and practical, and locate the operations to minimize particulate matter from being transported adjacent property. When **it is** not possible and practical to take reasonable precautions to prevent particulate matter from becoming airborne and the wind direction and speed is such that particulate matter is transported to adjacent property abrasive blasting or spray painting operations will be terminated.

Thus, the content and scope of the air quality memorandum of understanding is similar to the BMP approach, even though virginia has established numerical ambient air quality standards. These are set forth in Reference 16. For example, **Section 120-03-02 states that the primary ambient air** quality standards for particulate matter are a maximum 24-hour concentration (not to be exceeded more than once per year) of 260 micrograms per cubic meter, and an annual geometric mean of 75 micrograms per cubic meter.

Hawaii State and Local Requirements

Water Quality Control. As is the case with other states, Hawaii operates its water quality program within the EPA framework. Hawaii's water quality control requirements are set forth in Chapter 342 of the "Hawaii Revised Statutes." The water quality program is administered by the State Department of Health, which uses its Water Quality Standards" (18) to provide the administrative guidelines. The "Water Quality Standards" classifies the State waters for various uses: provides water quality criteria: and describes water quality certification and inspection and analysis. The Hawaiian State Department of Health issues NPDES permits to facilities.

The draft NPDES permit issued by Hawaii to the floating drydock COMPETENT (AFDM 6) is an example of effluent limitations at the Naval Submarine Base, Pearl Harbor (19).

Air Quality Control. Hawaii's air quality control requirements are set forth in Chapter 342 of the "Hawaii Revised 'Statutes." The air quality program is administered by the State Department of Health, which uses its "Air Pollution Control Rules" (20) to provide the administrative guidelines. The "Air Pollution Rules" describe prohibitions and general requirements, describe and limit open burning, discuss stationary sources of air pollution, and discuss source applicability and exemptions. The rules are general in nature.

California State and Local Requirements

Water Quality Control. The California water quality requirements are contained in the Porter-Cologne Water Quality Control Act (21) and the Water Quality Control Plan for Enclosed Bays and Estuaries of California (22). The State Water Resources Control Board is designated as the state water pollution control agency for all purposes stated in the Federal Water Pollution Control Act and is authorized to issue NPDES permits. Under the State Board are nine regional boards, one of which is the San Diego

Regional Board, to implement the Act at the regional level.

The requirements in (21 and 22) are not specific to drydocks, but are general in nature. Following are examples of water quality objectives from Reference (22).

Narrative Water Quality Objectives

Enclosed bay and estuarine communities and populations, including vertebrate, invertebrate, and plant species, shall not be degraded as a result of the discharge of waste.

The natural taste and odor of fish, shellfish, or other enclosed bay and estuarine resources used for human consumption shall not be impaired.

Toxic pollutants shall not be discharced at levels that will bioaccumulate in aquatic resources to levels which are harmful to human health.

The concentrations of toxic pollutants in the water column, sediments, or biota shall not adversely affect beneficial uses.

Toxicity Objectives

There shall be no acute toxicity in ambient waters, including mixing zones.

There shall be no chronic toxicity in ambient waters outside mixing zones.

Numerical Water Quality Objectives

For enclosed bays and estuaries, numerical water quality objectives for the protection of saltwater aquatic life are presented (in Tables 1 and 2 of Reference 22).

Air Quality Control. California air quality requirements are contained in Titles 13, 17 and 26 of the California Code of Regulations. The Code designates that the Air Resources Board is the State agency charged with coordinating efforts to attain and maintain ambient air quality standards and to conduct research into the causes of and solution to air pollution. The Air Resources Board publishes a document entitled "California Air Pollution Control Laws" (23), which restates the air quality laws of the California and serves as a quide for the public and the Board.

California is divided into air pollution control districts. One of these districts is the County of San Diego Air Pollution Control District, which publishes a guidance document entitled "Rules and Regulations" (24) and issues permits to operate equipment that may pollute the air. For example, the District issued a permit to the Naval Submarine Base, San Diego for ARC0 (ARDM 5) to operate the diesel engines for its two cranes; to operate its emergency diesel generator; and to apply marine coatings (25).

EXISTING DRYDOCk ENVIRONMENTAL PROTECTION APPROACHES

Following are three examples of how floating drydocks comply with Federal, state and local water and air quality control requirements. The examples are National Steel and Shipbuilding Company's NASSCO BUILDER; Southwest Marine's PRIDE OF SAN DIEGO and the U.S. Navy's ARC0 (ARDM 5). All three facilities are located in San Diego Harbor. Their environmental protection approaches are summarized in Table I.

TABLE I
APPROACHES TO DRYDOCK
ENVIRONMENTAL PROTECTION

Approach	NASSCO	SWM	ARDM 5	AFDB 10
Sedimentation Sump and Pump	x	x	x	x
CHT With Connection to Shore	x	x	x	x
Abrasive Blasting Shrouds	x	x		
Pontoon Deck Coaming	x	x	x	x
Manual Sweeping of Pontoon Deck	x	x	x	x

National Steel and Shipbuilding Company

The environmental protection approach of National Steel and Shipbuilding Company (NASSCO) is contained in its "Best Management Practices Plan" (26). This document addresses environmental protection from a shipyard-wide perspective and includes sections on policy, objectives, risk identification and assessment, reporting of BMP incidents, inspections, records and training. Its focus is operational in nature.

One part of the BMP is NASSCO's water pollution control plan. It states that "NASSCO"s general strategy for water pollution shall be the-- continued avoidance of the deliberate discharge of any waste category directly into San

Diego Bay." Regarding their steel floating drydock, NASSCO BUILDER, the policy is that "no deliberate discharge into San Diego Bay of any waste category shall be allowed."

Southwest Marine. Inc

Southwest Marine's BMP (27, 28) is similar in scope and content to that of NASSCO, as are the procedures followed aboard the company's drydocks, such as the 22,000-ton, steel floating drydock, the PRIDE OF SAN DIEGO.

ARDM 5

The Navy's steel, 7800 ton capacity floating drydock ARDM 5 (ARCO) is spud moored to a concrete pier at the Naval Submarine Base, Point Loma, San Diego. ARC0 provides docking services to Navy attack submarines.

For ARDM 5, the Navy's environmental pollution control approach is similar to those of NASSCO and Southwest Marine. The environmental features aboard ARDM 5 for water quality control include a sedimentation sump and pump system and a CHT system. There is no need for air particulate containment curtains on ARDM 5, because sandblasting is not carried out: hydro-blasting is used instead.

For air quality control, ARDM 5 holds permits to operate two non-emergency diesel engines (for its two traveling cranes): one emergency diesel generator: and one marine coating application station (30). All three permits were issued by The County of San Diego Air Pollution Control District.

For the non-emergency diesel engines, the permit restricts operating time on an hours-per-day and an hours-per-week basis; the number of gallons of fuel on a gallons-per-day and a gallons-per-year basis: and the sulfur content in the fuel. Also, daily records of fuel usage must be maintained, and the engines may be operated only with turbo chargers and aftercoolers functioning (the emergency diesel engine permit does not include these restrictions).

The marine coating application station permit is for four Grace Hydra-Spray supply pumps and eight Wagner Airless spray guns. The permit requires that detailed daily records be maintained.

ENVIRONMENTAL PROTECTION ON AFDB 10

AFDB 10 is the Navy's newest floating drydock. It is still in the design stage. The design approach to ensure that AFDB 10 complies with applicable Federal, state and local water quality and air quality requirements is twofold:

1) Minimize the production of pollutants, and

2) Maintain maximum control of any pollutants that are produced.

Table I summarizes the environmental protection features on this drydock.

As is the case on ARDM 5, there will be no grit blasting, only water blasting on AFDB lo. Thus, there is no need for air particulate containment curtains. Also, the cranes are electrically powered, so there will be no diesel emissions during normal operations. Finally, AFDB 10 has a stand-by diesel-generator system. This will be operated only if shore power is interrupted and, thus, emits a minimal amount of pollution into the air.

CONCLUSIONS

The Federal government and the governments of the three states reviewed have developed detailed requirements to help control environmental pollution. These requirements are becoming more stringent and they are becoming more detailed in their scope. For example, new requirements focus on particular industries, such as the marine industry, and on specific types of facilities, such as floating dry docks. Commercial and Navy facilities are complying with the requirements. In particular,-the Navy's newest floatina drydock. AFDB 10. will incorporate environmental pollution control features that were instituted at the inception of its design.

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Integration of Measurements and Maneuvering Technologies Used to Modify Caisson

No. 2A-2

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ABSTRACT

The modification of the caisson drydock is in many ways more difficult than conventional ship modifications. This is because of the accuracy required, location of the measurements and the size of the structure. The development of computer based multi-headed electronic theodolite systems made it possible to extract accurate data on large structures. This data was formatted so it could be input directly into a computer aided design system. The multi-headed electronic theodolite system was used to transfer new design information directly to the structure. The caisson structure was modified and moved safely into position with the aid of a water castor system for final assembly. Final dimension checks verified the accuracy of the system.

BACKGROUND

Philadelphia Naval Shipyard's Drydock No. 3 is one of the deepest graving docks on the East coast. Built in the 1920's, its original planned mission was to provide a-full service drydock for all ships of the United States Navy, including battleships. The original caisson for this drydock was still in use in 1990. It was a hydrometer style caisson of riveted construction. The caisson acts as a dam to seal the drydock opening and needs water ballast to maintain its position and provide an effective seal. AnY significant reduction in ballast due to loss of water could result in catastrophic flooding of the drydock. The caisson had major corrosion of structural members in the trim and ballast tanks. Its top deck or walkway was wooden and in need of replacement and the rivet seams were in poor condition and weeping. Because of the poor condition of the caisson, major repairs were budgeted so the drydock could continue in a certified status.

Repairing this old riveted structure in the 1990's posed major problems. Major structural elements on the inside would have to be replaced. There would have to be a great deal of welding close to rivets. Major structural members embedded in concrete appeared to be corroded. Most importantly. all of the rivets on the structure had been ring welded and seams were leaking, so there was no way to properly sound rivets and certify the structural integrity of the overall structure.

A new caisson was estimated to cost over 4 million dollars, which exceeded the repair budget. Fortunately there was a large caisson on the base which was built by the now defunct, New York Shipbuilding Corporation (NYSC) Figure (1). It had been in service in Camden, New Jersey, for a special drydock used in the construction of the USS KITTY HAWK (CV63) in the mid 1950's. Because the caisson was stored in fresh water and had only limited use at NYSC, it was in virtually new condition. The overall dimensions of the caisson, with the exception of the length (8.38 m, 27.5 ft longer) were very similar to the original caisson. Its all welded construction made it easy to modify.

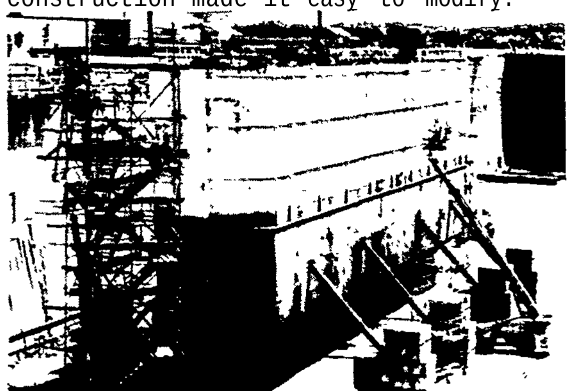


Figure 1.
New York Shipbuilding Corp. Cassion

As a final feasibility check, the dimensional attributes of both the drydock seat and the NYSC caisson were measured using conventional tools such as steel tapes and plumb bobs. The survey was accurate enough to verify that the NYSC caisson could be made compatible with the drydock opening. However, it failed to show discrepancies based on existing plans in the slopes between the caisson and the drydock and the radii at the corners. In addition, the overall length of the drydock opening appeared to be in error. It was therefore determined that a more accurate means of measurement would have to be used if accurate design modification details were to be developed.

INITIAL SURVEY

The measurement tool of choice for this project was multi-headed electronic theodolite system (AIMS II; Analytical Industrial Measuring System). This system consist of two (2) theodolites linked electronically to a personal computer to give real time data. The theodolite system was the logical choice due to several factors. Data points of the drydock opening (seat), although visible only from the river side could be captured from the drydock floor. Secondly, the new caisson would be located in the center of the same drydock. The stability of the drydock floor allowed the measurement group to use the theodolite system and not be restricted to other measurement tools, such as photogrammetry. Finally, time constraints required a quick turnaround of accurate data.

The first task for the measurement group was to provide data of the existing drydock opening (figure 2). Determination of theodolite positioning was the first concern. Placing the instruments between the inner and outer seat was eliminated for two reasons. First, a limited sight distance and very poor geometry between the theodolites and the data points impeded the accuracy. Second, with the existing caisson continuously leaking and the readings taken in the winter months, very hazardous safety conditions existed in this area with partial freezing of standing water. It was then determined that the theodolites would have to be located on the drydock floor. This created a situation where most of the data points would be hidden from sight (figure 2).

Hidden points were captured using a hidden point stick which is a targeted measured rod. By sighting the targets of the rod the theodolite system can automatically interpolate for the hidden point using the software (hidden point routine) provided with the system. Data for the drydock seat area were taken at various stations with two points per station. One representing the upper edge of the seat, which was visible and the other representing the bottom corner which was hidden. Points were taken at four stations along each side. Also, points were taken at 15 stations in the radius area, because it was critical for fit.

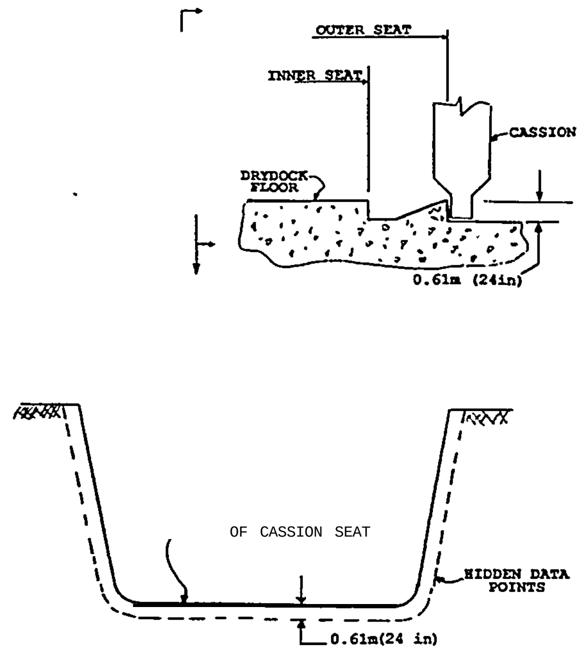


Figure 2.
Drydock NO.3 Opening

The second part of this initial measurement phase was to establish the outline dimensions of the new caisson. With the new caisson on blocks in drydock 3 the theodolites were located on the drydock floor. From this vantage point, the dimensions required were captured. Data points were taken along the sloping ends at four locations. The radius corners were identified by data points at each tangent point and three intermediate points. Other key dimensional locations were captured such as the top deck of the knuckle areas and the bottom seat area. Each point was located first by sighting with a laser attached to the theodolite. These points were then scribed in for reference for future modification and dimensional checks.

The measurement data from this initial phase was electronically transferred to the structural department's CAD (Computer Aided Design) system. This would lay the ground work for the entire project and allow the structural department to work from accurate data when determining the structural modifications required for not only correct fit of the new caisson to the drydock opening, but also to ensure proper buoyancy and structural integrity.

CAD DEVELOPMENT

Data taken from the survey was transferred (using a 5 1/4" floppy disc) directly into the shipyard CAD system. This allowed viewing all the data taken in three dimensions. By using curve fitting techniques, an accurate picture of the seat of the caisson and the drydock opening could be obtained. figure 3 shows a CAD overlay of some measurement data taken.

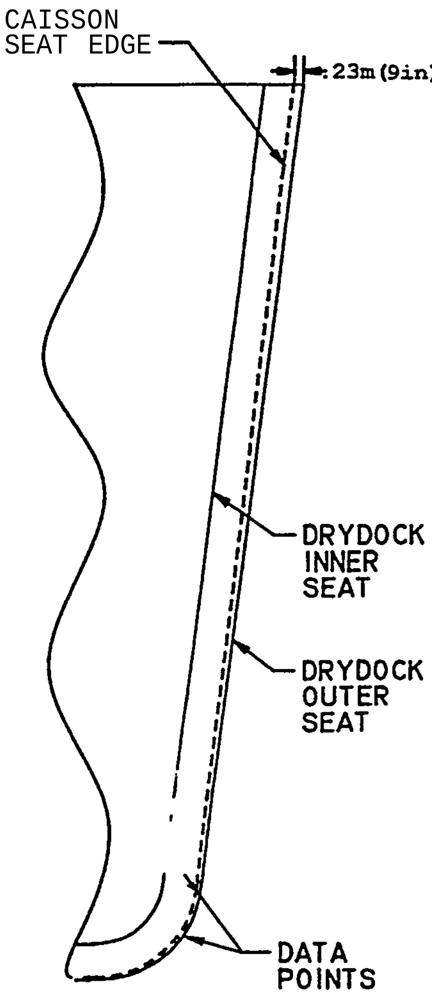


FIGURE 3.
CAD OVERLAY OF THEODOLITE DATA

The slope, radius and depth of the seat would all be critical dimensions which interplay with one another. It was decided early in the design process that the modified caisson should have approximately .076 meters (3 inches) clearance on each side of the sloping drydock side walls. This clearance would provide for dimensional changes in the structure and allow sufficient operational clearance to seat the caisson in a muddy river environment where debris can easily be lodged between the caisson and the drydock wall. While the task may seem easily solved by a conventional layout process, it becomes much more difficult when one considers that the design must allow for a good seal if all clearance is shifted to one side. Also, mud in the seat under the bottom of the caisson could cause it to tilt forward from the side walls. A CAD simulation would allow for these or any combination of other conditions to be examined with the caisson modified in many different ways.

The measurement data verified our initial dimensional analysis of the caisson proving that the drydock seat and the seal area of the NYSC caisson had different slopes. Additional structure would have-to be added to the sides of the caisson which had less slope. This would prevent an excessive clearance at the top of the seal area.

The radii between the ends of the caisson and drydock wall were sufficiently different to allow for clearance but the position of the centers between the two would be critical in determining fit clearance. If positioned too close. the curved surfaces would intersect which would cause the caisson to rest on its curved edge rather than rest along its base. If too much clearance was allowed it would be impossible to maintain a good seal along the sloped sides.

Several different scenarios were evaluated. The most cost effective one was to modify the caisson asymmetrically by adding structure to one side only. This would make the clearance different at the ends if the caisson were positioned at the centerline of the drydock. But the clearance would still be within allowable tolerances if the caisson were shifted to one side or rotated 180 degrees. By jogging the seal about 6.1 meters (20 feet) from the base and removing 8.38 m (27.5 ft) from the center of the caisson we were able to meet all dimensional clearance criteria. Final dimensions are shown in Figure 4.

LAYOUT

The second task for the measurement group involved translating the dimensional data. for removing the center section, from CAD to the caisson itself. Design engineers had determined the optimum location for the center section removal which would ensure the structural integrity of the two remaining ends once rejoined. To establish these dimensions the existing caisson, physical measurements from internal structural members were made. These data points were then established by drilling a hole through to the outside of the caisson. This

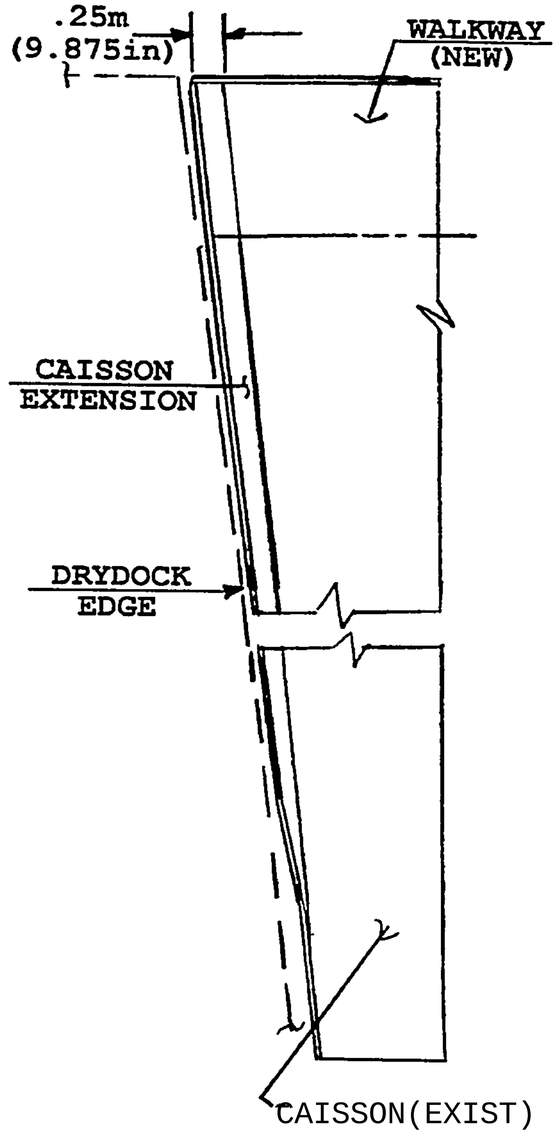


Figure 4.
Caisson Final Dimensions

hole was sighted by the theodolites and used as a reference point for inside and outside dimensions. Laying out of two parallel lines is relatively easy until one realizes that these lines must pass under the caisson up the backside, along the top and eventually end up at the same starting point while remaining paralleled throughout. Several setups and transitions from pass point to pass point were required. The accuracy of the system and the attention to detail of the system operators proved to be the cornerstone to the success of this project.

MODIFICATION AND ASSEMBLY

Production shops used the cut lines layed out by the measurement team to precisely cut a perfect match between the two halves of the caisson. Shipfitters and welders worked to remove the large portions of plating and beams from the center section (Figure 5).

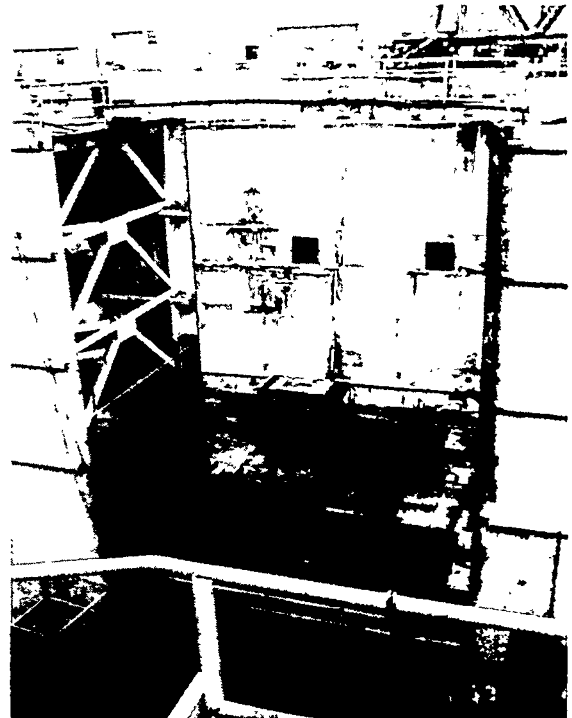


Figure 5.
Steel Removal, Center Section

The area of steel removed was about 8.38 38 (27.5 feet) long, 10.67 m (35 feet) high and 6.1 m (20 feet) wide across the top.

The bottom portion of the casisson contained a large amount of concrete used mainly for ballast. A concrete cutting company was tasked to make one cut at each end of the center section so that shipyard riggers could "roll" the loose wedge of concrete out of the way (Figure 6 and 7). The wedge removed was about 8.38 m (27.5 feet) long by 6.1 m (20 feet) wide by 3.35 m (11 feet) high and it weighted about 250,000 KG (275 short tons). The cutting of the concrete was accomplished using a diamond strand blade which runs through a main drive assembly around the concrete to be cut and back through the assembly. Each cut took about 10 hours.

The shipfitters then installed temporary supports to the concrete section's steel skin (Figure 8). The supports were designed by shipyard engineers and a drawing was prepared to provide direction to the shops for fabriction of the supports. In addition, steel plates were laid on the floor of the drydock to provide a path for the concrete section to travel. A steel plate guide was placed on the inside of the path to keep the section from drifting. Riggers then used the

273,000 KG (300 ton) jacks to raise the

Figure 6.
Concrete Cutting; Top View

section about 0.1 m.(4 inches) to insert 4 mini-rollers under the temporary supports. The main problem with the mini-rollers was shifting of the rollers under the supports which caused delays in the move. The rollers had to be realigned under the center of the load from time to time to avoid any instability. Unevenness in the drydock floor, regardless of the presence of the steel plate path was the main reason for the mini-rollers shifting.

Keel blocks were stacked about 12.2 m (40 feet) from the concrete wedge at the end of the steel path described above.

Chain falls were connected between the keel blocks and the temporary supports to allow riggers to pull the section from between the two halves of the caisson (Figure 9). This process took about six hours.

The movement of the two halves of the caisson was accomplished by using water castors to "float" one half to the other along a steel plate path. The process was very safe, provided maximum control, required very little horizontal force to move the section, and was cost effective. Two other options were considered, floating the sections in place and using a rail system. The idea of floating one half of the caisson to the other is the typical one of choice used by shipyards in shortening or enlarging ship midsections. For example, this was the method used in the down sizing of the *KEYSTONE CANYON* in 1990 by Northwest Marine. As noted in reference (1), the bow section had to be refloated three times before alignment was

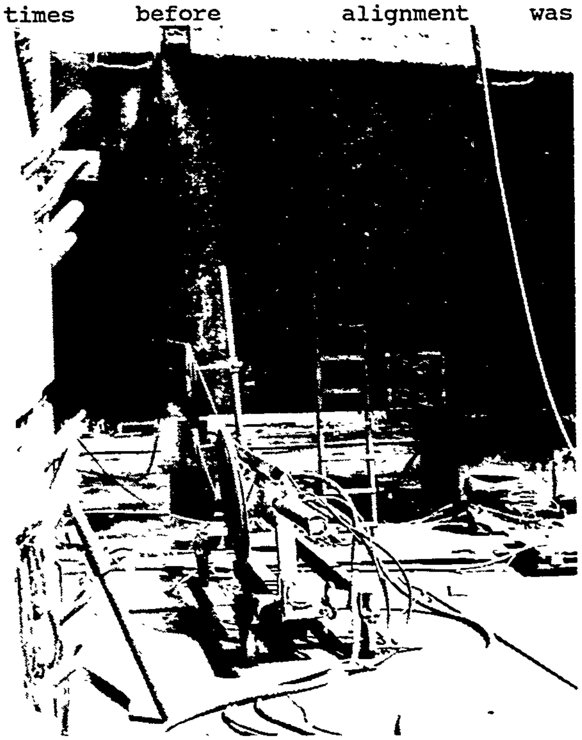


Figure 7.
Concrete Cutting; Side View

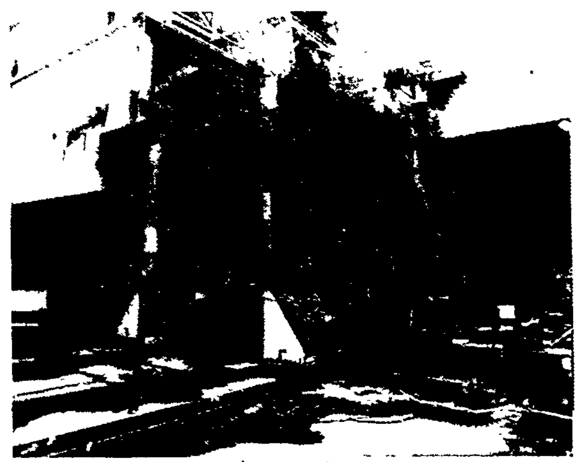


Figure 8.
Temporary Supports For Concrete Removal

adequate to begin welding. This method was quickly eliminated due to the cost of flooding the drydock and the need to build a coffer dam at the open end of the section. In addition, the lack of total control of the buoyant section for repositioning made this method unacceptable. Another option considered was a rail system but it proved to be too expensive due to the high cost of building a very large structural system to accommodate multiple rollers.

The castors operate on a water film created under the castor by water leaking from the bottom of a diaphragm (Figure 10).

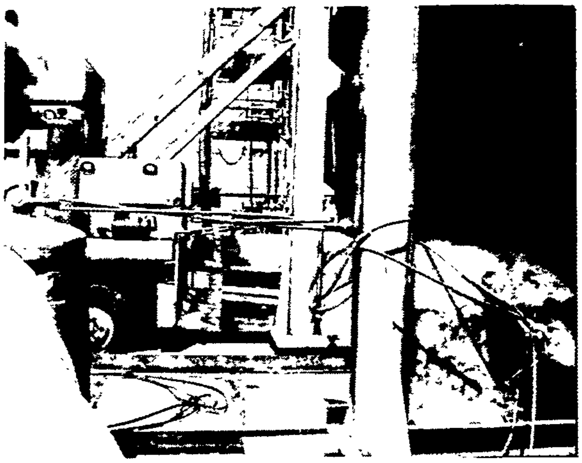


Figure 9.
Rigging For Concrete Removal

This allows the entire castor/caisson to "float" just like a glass filled with fluid on a wet smooth surface. The castors are flexible, so they could accomodate the lack of flatness of the

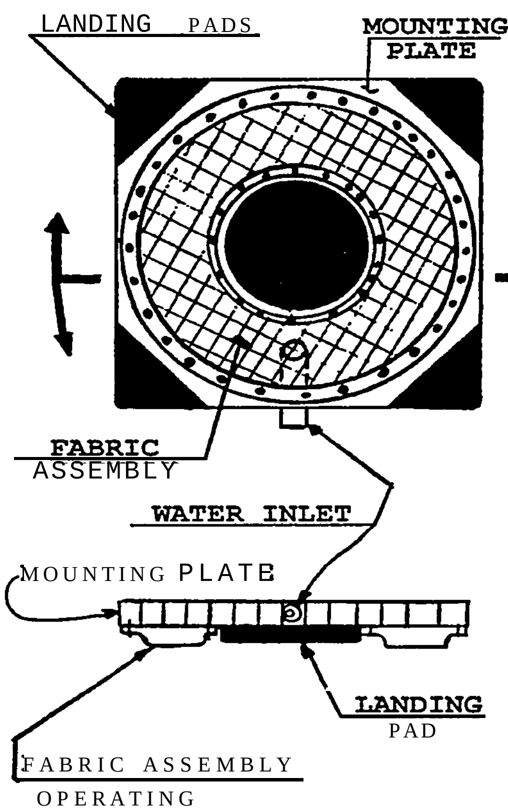


Figure 10.
Water Film Castor

drydock floor. Also, because of their flexibility the load per castor would remain fairly constant during the move, allowing the supporting steel fixture to be optimised around well defined factors of safety. Steel plates welded together were placed along the drydock floor to prevent loss of water due to small irregularities such as holes in the concrete surface. The castors moved with the caisson along the steel plate track due to the differences in friction between the temporary support surface and the steel path surface. The castors used during the move required about 0.483N/mm^2 (70 PSI) of water pressure at each of the castors in order to obtain 0.08 m (3 inches) of lift off the keel blocks. Production shops manufactured two separate manifolds with ten gauges, each dedicated to one castor for monitoring purposes.

The castors were rented with a representative from the vendor providing technical characteristics such as load capacity, friction factors, surface slope, and water supply. Using this information, temporary supports made of steel I beams and plates were designed. Each support was fabricated out of three I beams spaced like a tripod, over each castor to handle any rotations (Figure 11).

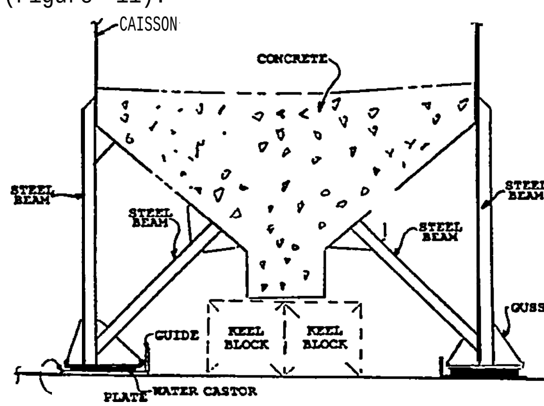


Figure 11.
Tempoary Supports For Floating Half of Caisson

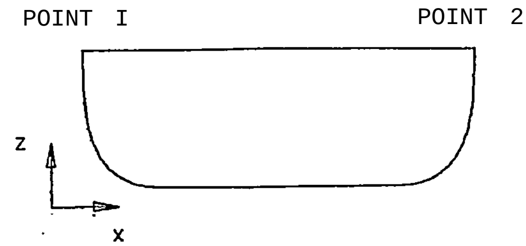
In this way the lifting force at the center of pressure of the castor, would remain stable in the area defined by the supporting legs. Calculations showed that a total of 20 castors would be required providing a capacity of 725,750 kilograms (1.6 million pounds). The section to be moved was 589,670 kilograms (1.3 million pounds) and the center of gravity was calculated to be 3.05 m (10 feet) up from the bottom. The castor model chosen was by AERO-GO and its designation was 4K48HDL. It was 1.22 m (4 feet) by 1.22 m (4 feet) by 0.07 m (2.75 inches) thick with a lift of 0.08 m (3.0 inches). The castors were placed between the temporary supports and a relatively "flat" steel path similar to one provided for the concrete removal.

A guide track was installed along the path, laid on both sides of the caisson, to keep the caisson from "floating" off the steel path. In addition, guide wires were placed from the top of the caisson to tiedown fixtures at the top of the drydock to provide additional control. The floating section of the caisson was pulled to the stationary section by using chain falls. The final position of the two halves are shown in figure 12.

Figure 12.
Final Position of Caisson Halves

Two ten ton chain falls proved more than adequate as the floating section moved easily. A maximum of 0.15 m/min (.5 ft/min) movement between the stationary and floating section was maintained to avoide the moving section from developing excessively high momentum. Shipfitters quickly welded steel flat bars perpendicular to the two caisson accross the unwelded seam to prevent relative misalignment of the two halves.

The third and final task for the measurement group was to make a final check prior to production welding. The bringing together of the caisson was complete by the end of the first shift on a Tuesday. With the start of the second shift, the measurement group set up the theodolite system and began the final check of key control points along the entire caisson. With the data points measured in three dimensional coordinate system, it was possible for the measurement group to verify the final construction configuration during the same second shift. Table I shows a comparison of design dimensions and final measured dimensions. The go ahead for final production welding was given the following morning (1st shift Wednesday).



	POINT I		POINT 2	
	DESIGN	MEASURED	DESIGN	MEASURED
X	0.0	0.0	39.61M (1559.50IN)	39.63M (1560.107IN)
Y	0.0	0.0	0.0	0.005M (0.19271N)
Z	15.11M (595.00IN)	15.13M (595.61IN)	15.11M 595.00IN)	15.12M (595.2462IN)

TABLE 1. DESIGN DlMENSlONS VS. MEASURED DIMENSIONS

There was no need for additional fitting, and welding the large seam connecting the two halves could begin, as well as welding many internal stiffeners. Shipfitters also proceeded to install an additional steel section to one end of the caisson so that the rubber seal would rest on the drydock seat when the caisson was finally installed. In addition, they also added a steel walkway about 1.21m (4 feet) on top of the caisson to raise the height of the caisson to that of the existing drydock opening.

Internal modifications and repairs to electrical and mechanical systems of the caisson were also made. Paint and preservation measures were made inside and out, making the completed caisson ready for operation.

CONCLUSION

This project proves that a multi-headed electronic theodolite system in a drydock environment can extract data and layout data accurately to achieve a first time quality fit for large structures.

In addition, the use of the theodolite system and CAD system allowed for the rapid and accurate transfer of large amounts of data.

These systems made it possible to implement a well coordinated plan of attack throughout the project's duration. Communication between design, measurment and production groups was an essential ingredient to the success of this project.

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Computer Integrated Manufacturing: A Perspective

No. 2B-1

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Lawrence Zeidner, Visitor, Boston University

ABSTRACT

The introduction of computer integrated manufacturing in shin production will involve- more than linkage of separate automated ship production processes. It will create major changes from design through delivery. This paper presents the results from a three-part project: (1) a manufacturing literature survey of Computer Integrated Manufacturing (CIM) and supporting technologies, (2) a National Science Foundation (NSF)-sponsored Workshop on CIM in ship production, and (3) research and development recommendations to facilitate CIM in ship production.

ACRONYMS

AGG Automatic Geometry Generators
AI Artificial Intelligence
APG Automatic Process Generators
CAD Computer-Aided Drafting
CAM Computer-Aided Manufacturing
CE Concurrent Engineering
CERC Concurrent Engineering Research Center
CIM Computer-Integrated Manufacturing
DARPA Defense Advanced Research Projects Agency
DFM Design for Manufacturability
DFA Design for Assembly
DOD Department of Defense
EBD Electric Boat Division
EDI Electronic Data Interchange
FMS Flexible Manufacturing Systems
GMT General Motors Truck and Bus
GT Group Technology
IBM International Business Machine
IDA Institute for Defense Analysis
IGES International Graphics Exchange Standard
JIT Just-in-Time
LOM Laminated Object Manufacture
NC Numerical Control
NSF National Science Foundation
PDES Product Definition Exchange Standard
SDTM Seamless Design-to-Manufacture
SE Simultaneous Engineering
WIP Work in Process

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NSRP Ship Production Symposium 9/92
New Orleans, LA

INTRODUCTION

The use of computers in ship production has resulted in savings in costs and manhours in scheduling. material tracking and Computer-Aid& Drafting (CAD) drawings. The reduction in schedule and labor-is illustrated in Fig. 1 (1). Developments in manufacturing are now aimed at the integration of overall production from design to delivery through CIM (l-5).

CIM has grown from data exchange and the connection of individual automated activities (5) into an activity encompassing computers, software and production hardware. CIM introduction represents a substantial change in how ships and offshore structures will be designed and produced. Resolution of construction-activity problems, done today by the foreman and crew on site, will shift to being resolved during the initial planning phase of production. Full implementation of CIM in ship production involves more than purchasing and installing a system.

The authors have been involved in a three-part project of technology assessment of CIM for shipbuilding:

1) manufacturing literature survey of relevant publications on supporting technologies for ship production:
2) organization of NSF-sponsored workshop on CIM in ship

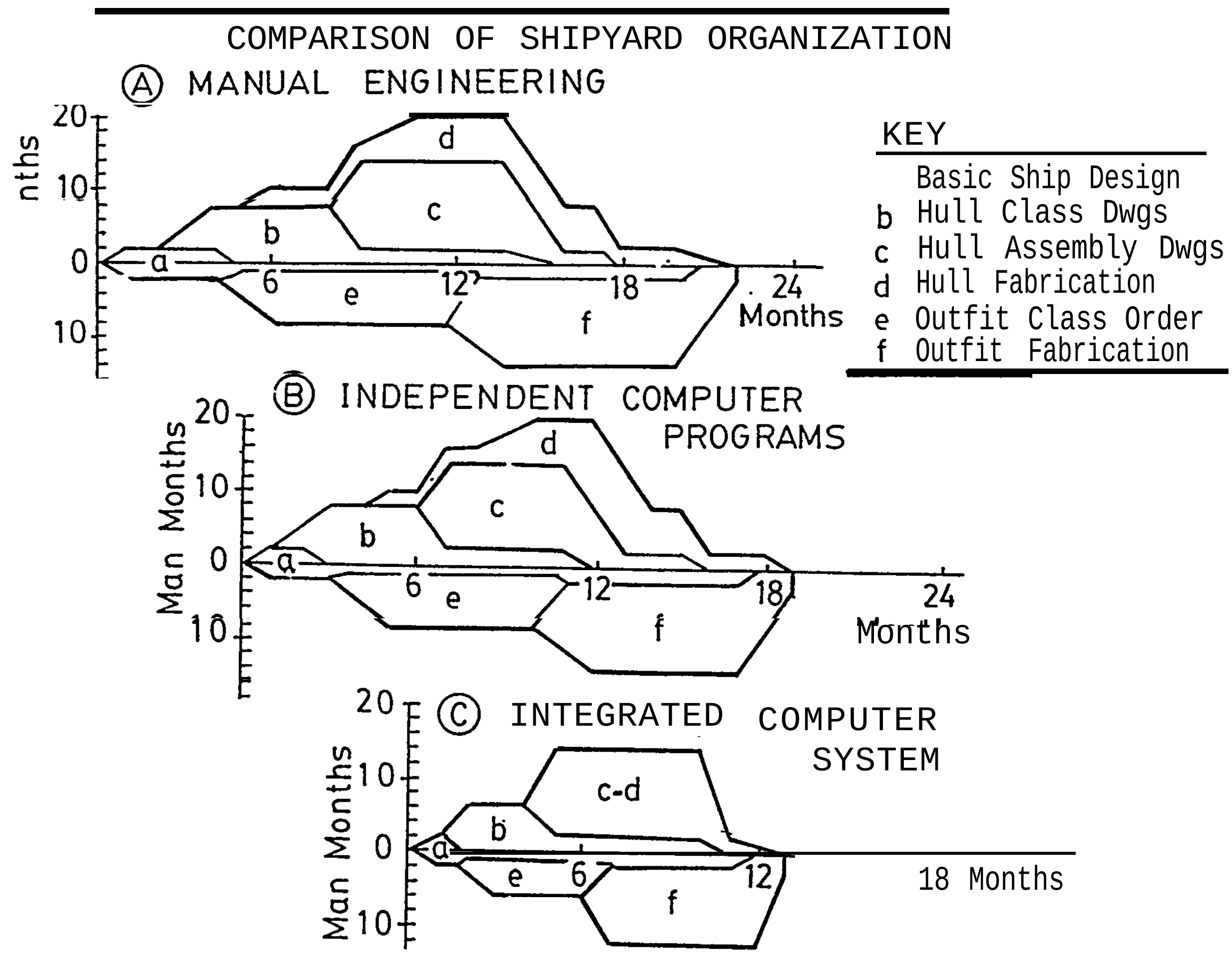

Figure 1. Example of Savings in Time and Manhours from adopting Integrated Computer System for Ship Production Engineering [1].

production (February 6-7, 1992 New Orleans, Louisiana); and

3) development of research and development recommendations to facilitate CIM introduction in ship production.

BACKGROUND PERSPECTIVE

CIM is analogous to shipboard automation which replaced the engine room telegraph with an electronic system. Stage I involved the component automation shown in Figure 2. Stage II involved connecting them and the development in stage III of an overall computerized engine room system. The engineer's activities expanded to maintaining the machinery and the monitoring system, and the rational scheduling of maintenance work. In an analogous manner, the shipyard staff will use the CIM computer system to do traditional shipbuilding and analyze their activities to improve productivity.

LITERATURE SURVEY OF CIM TECHNOLOGIES AND METHODS

Shipbuilding is unique among the industries adopting CIM. The shipbuilding industry differs from other manufacturing industries in its structure, methods, and functions. This characterization forms a basis for cost-benefit comparisons of before- and after-CIM use.

Eight existing or emerging CIM technologies have been identified in the literature search. Of the technologies relevant to CIM, these are the technologies that are also potentially relevant to shipbuilding. Most CIM systems do not employ all of these technologies, nor would they all be appropriate. These CIM technologies are:

Artificial Intelligence (AI)/knowledge-based systems,
Just-in-Time (JIT),
Vendor relationships/Electronic Data Interchange (EDI),
Concurrent Engineering (CE)

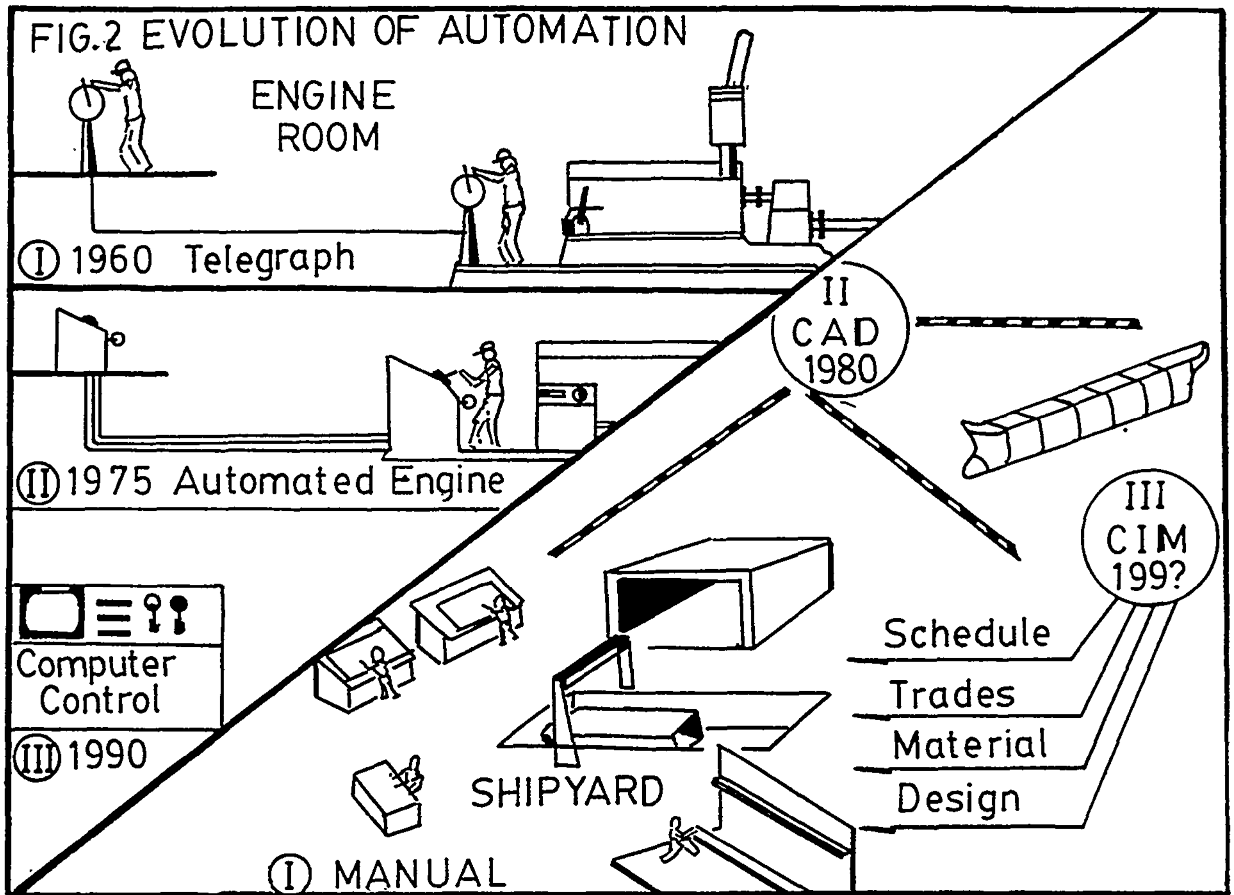

Figure 2. Development of Ship Engine Room Automation 1960-1975 and Today's Shipyard Automation.

- Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) systems,
- Rapid prototyping systems,
- Flexible Manufacturing Systems (FMS), and
- Virtual Reality.

The literature search involved over 110 articles and abstracts (87 articles, and 25 abstracts) from 36 journals and technical publications. It covers 21 industries, including shipbuilding/repair. Specific care was taken to isolate reports of technical accomplishments from the more numerous reports of anticipated benefits.

AI/Knowledge-Based Systems

AI has been developed to capture human expertise and create automated systems that appear to be (artificially) intelligent. AI distinguishes information (data) from knowledge (rules). Knowledge is viewed in AI as rules describing behavior of the data. The classical AI approach consists of a "knowledge engineer" interviewing experts, such as skilled shipfitters, to capture their expertise, and transforming this expertise into AI rules. Such a knowledge-based system (or "expert system") consists of rules, data, and "inference engine" software, shown in Fig. 3. AI systems have been successful in static diagnostic applications such as equipment fault diagnosis/repair (11) and medical diagnosis (12).

AI systems differ from sequential algorithmic systems. The rule order in AI systems is not critical. At the International Business Machine (IBM) Burlington semi-conductor plant, an AI system was developed to examine process rules used in plant operation, to identify sequential patterns of application. These patterns were subsequently captured in algorithmic software (13).

At General Dynamics Electric Boat Division (EBD) in Groton, Connecticut, attempts were made to develop a rule-based AI system to deal with "non conformance," involving lost, defective or damaged parts that did not conform to specifications. Although case by case rules were introduced, EBD found this rule-based AI approach to be too "brittle." Ultimately, a case-based reasoning system was developed. It inquires about the nonconformance details and matches them

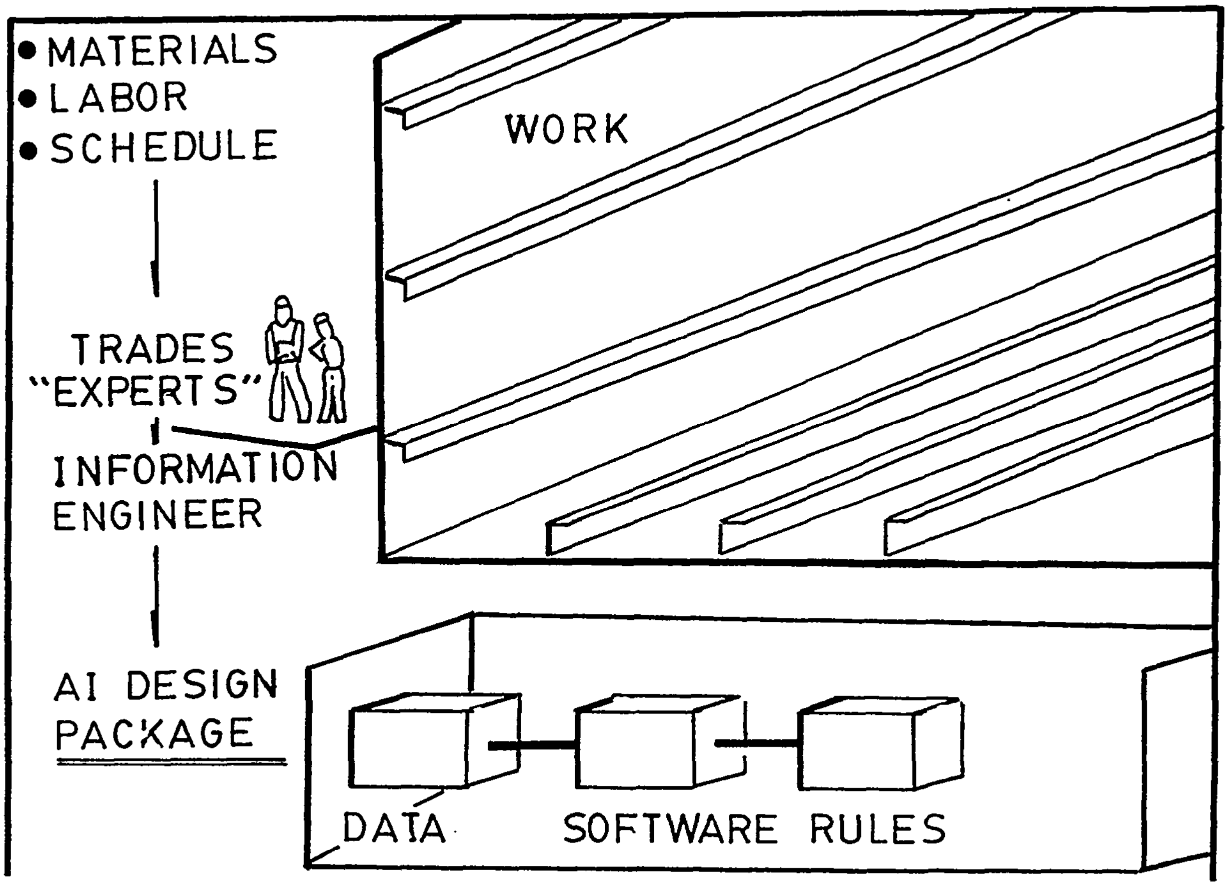

Figure 3. Illustration of AI-Knowledge Based Assembly **Work.**

with a database to find similar cases (14).

At Corning Asahi Video Products, in State College, Pennsylvania, the ICAD Lisp-based AI-CAD system was used to design and simulate molds for television-screen glass components. Glass video components must be free of defects. Corning achieves roughly 60% defect-free production. Although ICAD reduced mold-design time from ten weeks to one, the variety of product differentiation has offset this gain. While Corning's hopes to reach this 60% level after only 20 production hours, it still takes 2,000 hours (15-17).1

AI's use in manufacturing is often justified by the scarcity of young machinists and the need to capture an expert's expertise before retirement. Engineering experts are valuable due to their engineering ability, not for their ability to explain how they work. Experts are reluctant to participate in an exercise aimed at automating their job. Even if an AI system could capture their expertise, the AI system would lack their ability to continually develop new knowledge to respond to new materials, processes and computer techniques. An AI system is a static container for present knowledge. Current thinking is that an expert should be encouraged to train a "naturally intelligent" successor who will advance the state of the art by adding new rules.

The Edison Welding Institute in Columbus, Ohio, is developing AI systems for welding. One 'AI system, called Preheat, is designed to avoid hydrogen cracking of thick steel plates. AI systems for welding are under development at Carnegie Mellon University and the American Welding Institute (18).

Project-based management systems (PBMS) are an AI-based approach to the task of planning and labor-assignment phase of ship repair. The cost of ship repair is roughly 60% labor and 40% material. PBMS systems are therefore organized around the labor component, as compared with material requirements planning (MRP) systems. PBMS systems tie material to labor, and schedule material to be available, based upon lead times. PBMS systems include hierarchical indices which contain information in their nodes, and use expert relations to link these nodes. Ship-repair work assignment is expressed as the establishment of a relation between a trade (a node in the

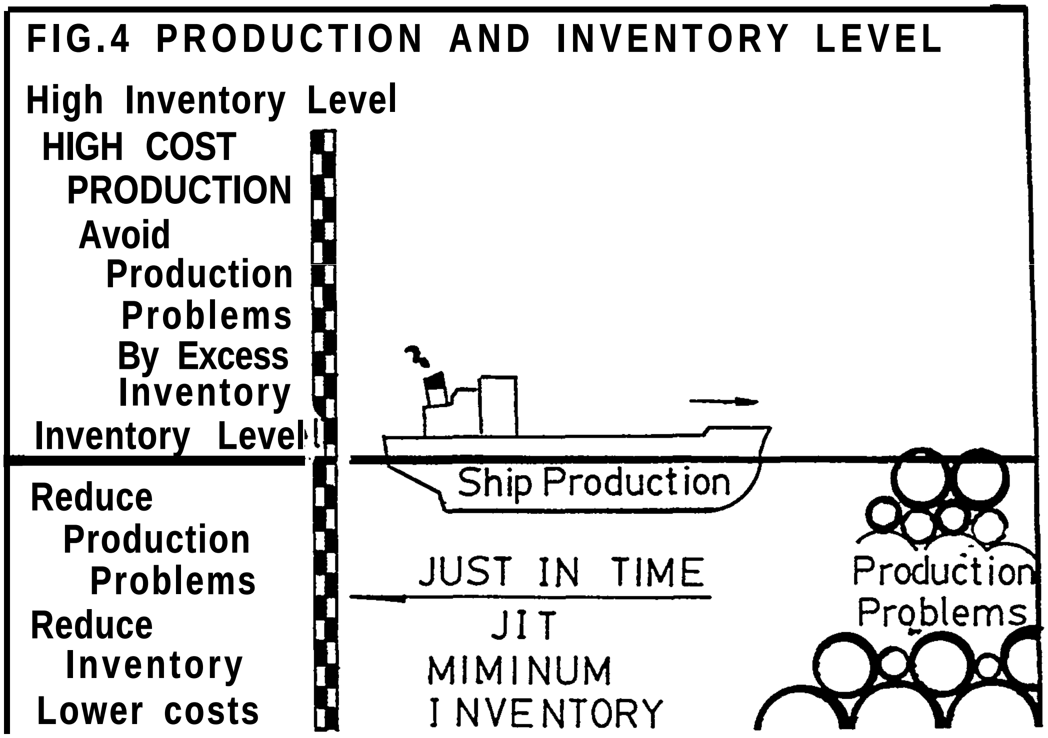

Figure 4. Illustration of How Excess Inventory Covers Ship Production Problems but also Results in High Production Costs.

personnel index) and a task (a node in the operation index) (20).

Just-In-Time (JIT)

JIT is a production philosophy that attempts to operate closer to deadlines, with less inventory, to reduce the cost of maintaining this form of production-delay insurance. The JIT philosophy is often expressed as in Fig. 4. Ship production is similar to navigating a ship in shallow water. Manufacturing problems are analogous to rocks, and inventory is analogous to the water that covers them. Two strategies exist: 1) add more water (inventory) to raise the ship above the rocks (problems), or 2) decrease the water (inventory) level to expose the rocks (problems) completely and ultimately remove them. Shipyards have, in the past, raised inventory levels to maintain production, hiding but not solving the delivery/manufacturing problems. JIT reduces inventory and its associated costs, thus exposing inherent delivery/manufacturing problems so they can be solved. "Just-in-case" inventory is eliminated, along with "expediters," since there is no excess inventory with which to expedite production. However, without the excess inventory, navigating around manufacturing problems, requires closer relationships with vendors (21).

A comprehensive JIT program at the Minneapolis Valve Plant of Dana Corp., has yielded a 32% increase in productivity. This represents a 92% reduction in through time, a 40% reduction in paperwork, a 50% reduction in inventory costs, and a reduction of customer lead time from six months to a week (22).

At Mack Truck in Winnsboro SC, the JIT system reduces errors and insures parts are presented to assemblers in the order they are needed for assembly. Vendors are given precise delivery lists. The suppliers then load delivery trucks in inverse order so the parts arrive in the required order for assembly (21).

Vendor Relationships/Electronic Data Interchange (EDI)

Japanese shipbuilders have benefited from maintaining long term relations with their suppliers. This has been recognized in the U. S. and adopted in a number of nonshipbuilding industries. Bose Corp. in Framingham, Massachussetts has limited its critical vendors to a full-time in-house representative who participates in design meetings by suggesting products that cut cost or better fit Bose's needs (24). In addition to material and component vendors this includes service vendors like trucking companies. The vendor benefits by "evergreen" contracts, that are not periodically rebid, as well as reduced costs and paperwork. Vendors manage an account, rather than reacting to it. Bose benefits by a smaller supplier Pool, better vendor service, and pricing flexibility since the vendor does not have to make large profits on each sale.

The Boeing Company conducts supplier "surveillance." It sends out representatives to monitor suppliers' capacity, production rates, and product work for other customers (25).

Longer contracts provide stability, reduced bidding costs, and reduced need for short-term economic gain. Some of Boeing's contracts reach 14 years into the future, assuming the vendor provides better product quality. In such long-term contracts the customer and vendor share some of the risk of expanded or specialized production, along with sharing associated benefits. McDonnell Douglas Corp. furnishes certain suppliers with business projections and strategies. It provides technical assistance as problems arise, rather than switching suppliers (25).

EDI is a CIM technology that helps industry maintain close relationships with their suppliers and customers. EDI is a combination of communication and computer hardware and software that replaces the normal flood of customer-vendor paperwork. As a significant step toward paperless JIT, EDI sends computerized "forms" containing price quotes, orders, delivery notices, invoices, bills, and account summaries. This is illustrated in Fig. 5.

In 1990, General Motors Truck and Bus (GMT) in Indianapolis was the first plant to order raw-materials by EDI. The plant, using 1,980 tonnes (2,200 tons)- of sheet metal to produce truck and bus panels, turns over its inventory 55 times per year. GMT transmits order schedules to steel vendors. The vendors reply with information describing the truck number, shipping company, departure and expected arrival time. This information is used throughout GMT, from the guard who directs the truck to the appropriate dock, to the schedule to unload the steel. GMT monitors vendor and carrier performance and traces job status in process. Outgoing shipments are also controlled by EDI. GMT communicates with CONRAIL, ordering rail cars configured to hold specific panel types. With EDI, fewer shipments are lost or misplaced, cutting the use of premium shipments by more than 50% (26).

Commercial EDI began with sets of corporations defining communication formats and has evolved into whole industries and EDI vendors adopting standard forms. The emphasis has always been on the data formats with the EDI investment in the complex software systems that send, receive, and Process the EDI data. These systems are constantly modified to handle new types of data formats. The EDI users are developing advanced software-development methods for designing, implementing, testing, and maintaining these distributed EDI software systems. "Server networks" are software systems distributed across computing networks which cooperate to solve engineering and computing problems (27). Their primary advantage is the ease with which they can be programmed and reconfigured graphically (28). Their applicability to EDI systems is in their flexibility to meet the needs of the EDI partners.

Concurrent Engineering (CE)

As international markets became competitive, several approaches were developed to improve product quality, accelerate the transition from concept to manufacture, and reduce manufacturing costs. Each approach encompasses product design, process design, product development, product quality, customer satisfaction, process improvement, employee empowerment, and vendor relationships (20). Many companies have attempted to implement these approaches, and have reported varying levels of success. The Department of Defense (DOD) received many success claims attributed to these improvement programs. It tasked the Institute for Defense Analysis (IDA) to examine the evidence to predict potential benefit. In 1988, this DOD-sponsored IDA study [29] of thirteen American companies explored the use of CE, and found that CE was characterized by changes in corporate culture and management combined with adoption of a few existing methods and technologies. CE was associated with improved design quality, reduced manufacturing cost, and faster product development.

A variety of names are used to describe this approach. The names include CE, simultaneous engineering (SE), design for manufacturability (DFW), and design for assembly (DFA). In these approaches process design begins when initial assembly design is complete (Fig. 6-B). In sequential engineering the assembly design is completed before process design begins (Fig. 6-A). Experienced part and process designers have long recognized the advantages of simultaneously doing the assembly and process designs. The entire design-to- manufacture cycle is shortened, and more design problems are found and corrected at initial design

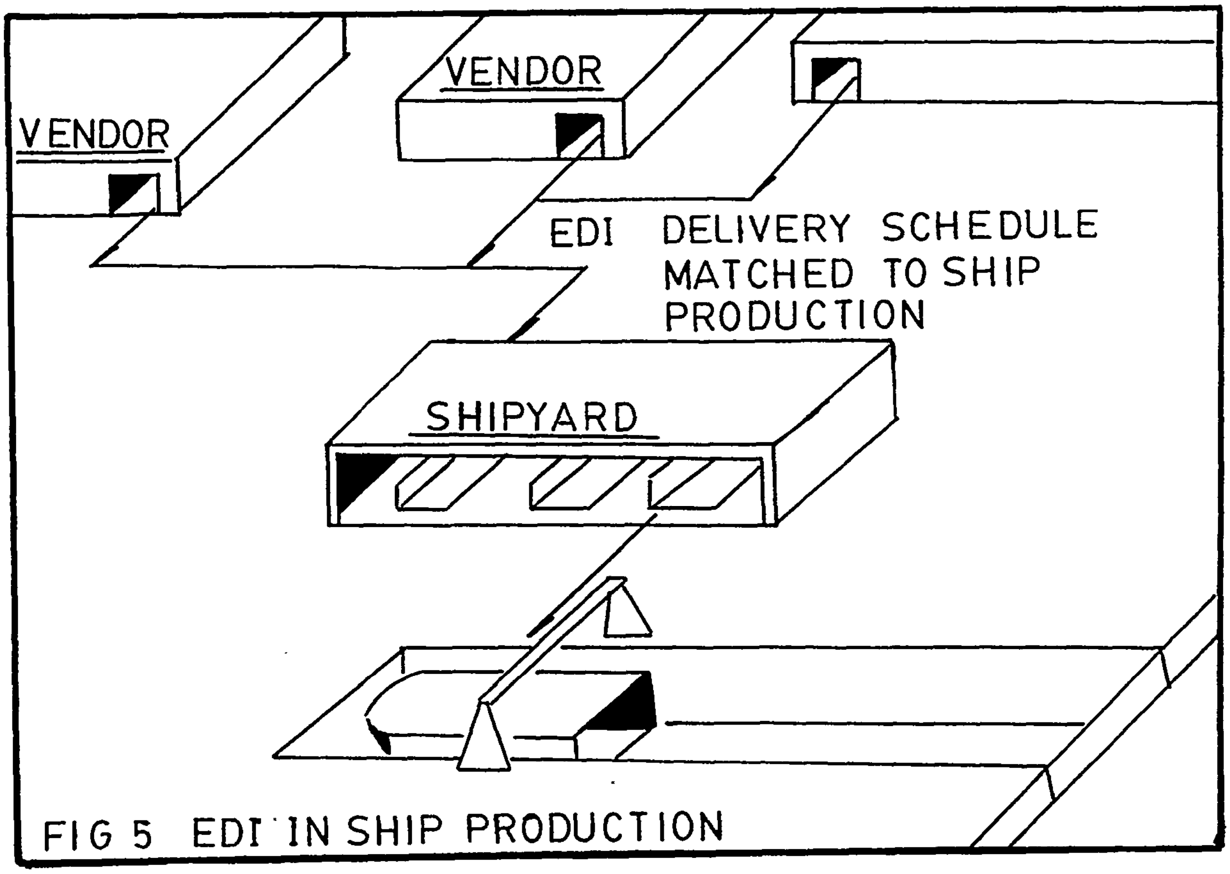

Figure 5. Illustration of EDI in snip Production.

stages, rather than later. This is illustrated in both Figs. 1 and 6, showing a 12-month reduction in engineering time. Difficulties with CE lie in performing downstream design work with incomplete upstream design decisions. This requires reorganizing the design process to identify downstream information dependencies and decoupling independent tasks.

In 1988 the Defense Advanced Research Projects Agency (DARPA) awarded funding of a 5-year $100M Concurrent Engineering Research Center (CERC) to the University of West Virginia at Morgantown. This effort includes a demonstration testbed consisting of different engineering workstations networked together to illustrate the implementation of a collocated CE virtual team. The software approach adopted was to employ (without modification) an existing set of CAD, CAE, and CAM software packages interconnected via a CE communication platform. Attempts were made to employ relevant data-exchange standards such as the International Graphics Exchange Standard (IGES) and the Product Definition Exchange Standard (PDES). Effort made to integrate incompatible systems is Often several times the cost of either original system (32).

At Ingersoll-Rand's Portable Compressor Division in Mocksville, North Carolina, DFM techniques were used. In two compressor assemblies, DFM reduced the number of parts by 64%, reduced the number of fasteners by 47%, and reduced assembly operations by 75%, which cut assembly time by 60% (30).

Major shipbuilding programs such as the DDG 51 class destroyer program (32) and the SEAWOLF submarine program (33) involved concurrent engineering efforts. They demonstrated applications of model-data communication and CAD/CAM solutions.

CAD/CAM Systems

CAD/CAM is not new to shipbuilding. A variety of CAD and CAD\CAM systems have been used (1,34-39). The level of technology and the level of integration varies from shipyard to shipyard.

To increase world market share, manufacturers are aware that "rapid responsiveness" to change is critical, and depends upon accelerating the concept-to-manufacture cycle. Conventional CAD/CAM is an obstacle to this acceleration. The characteristics that enabled CAD/CAM to replace drafting and manual part programming now limit its productivity. CAD\CAM systems require numerous interactive

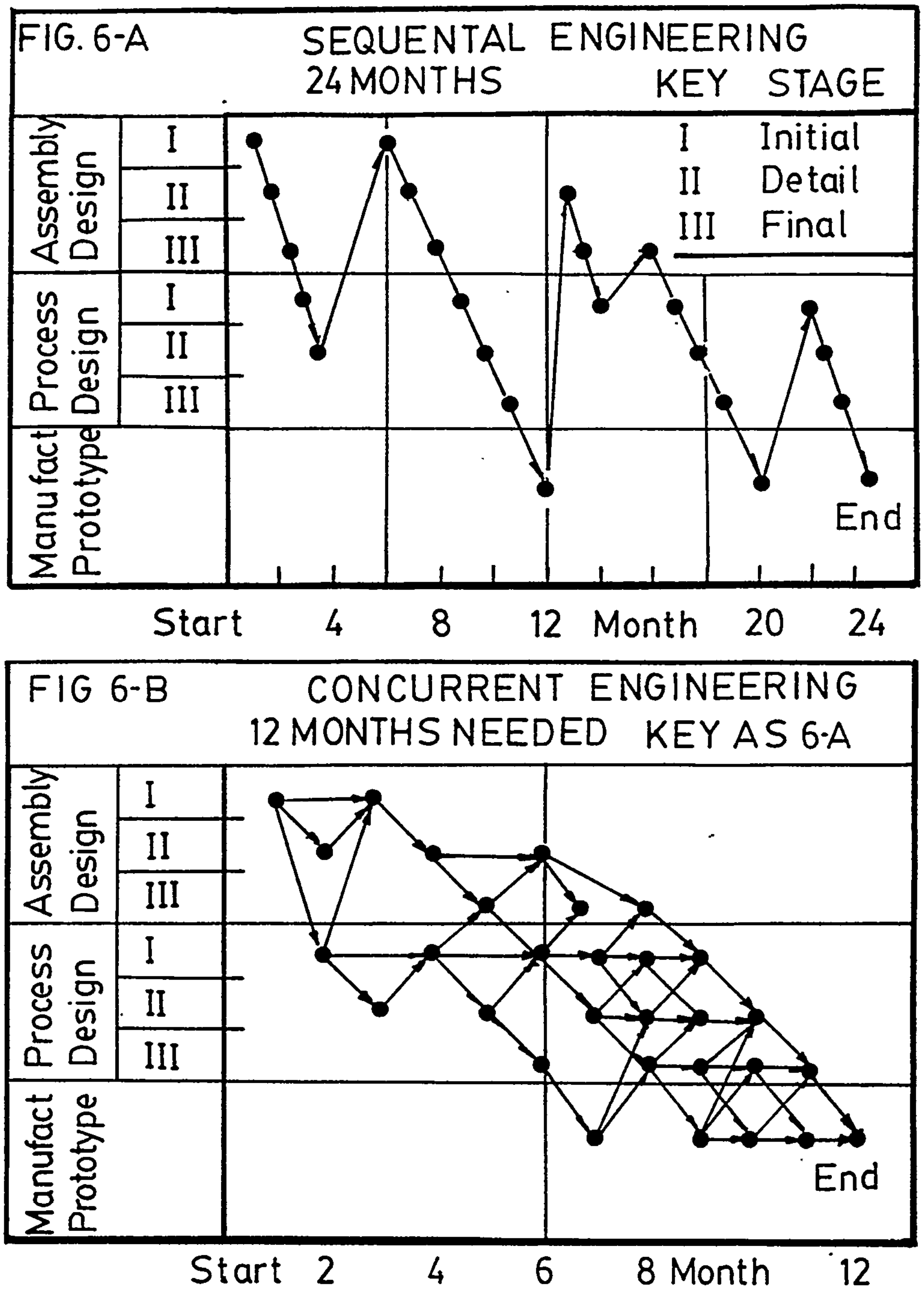

Figure 6. Comparison of Start-End Time for Sequential and Concurrent Engineering.

steps or "seams" which prevent rapid responsiveness. While CAD systems produce only a CAD drawing, the major interface or seam in CAD\CAM systems exists between CAD and CAM, which are employed sequentially. First an item is designed in CAD and then the manufacturing process is developed in CAM. In conventional CAD/CAM systems, assembly design changes require redoing the CAM work. This makes such systems inflexible to changes. Conventional CAD/CAM systems do not address conceptual assembly and process design. They assume that the engineer does the conceptual assembly and process design on paper.

Seamless- Design-to-Manufacture (SDTM) is a post-CAD/CAM technology that offers rapid responsiveness by eliminating many interactive seams and by automating others (40). Figure 7 compares STDM and traditional CAD/CAM systems. SDTM systems consist of an interactive conceptual assembly- and

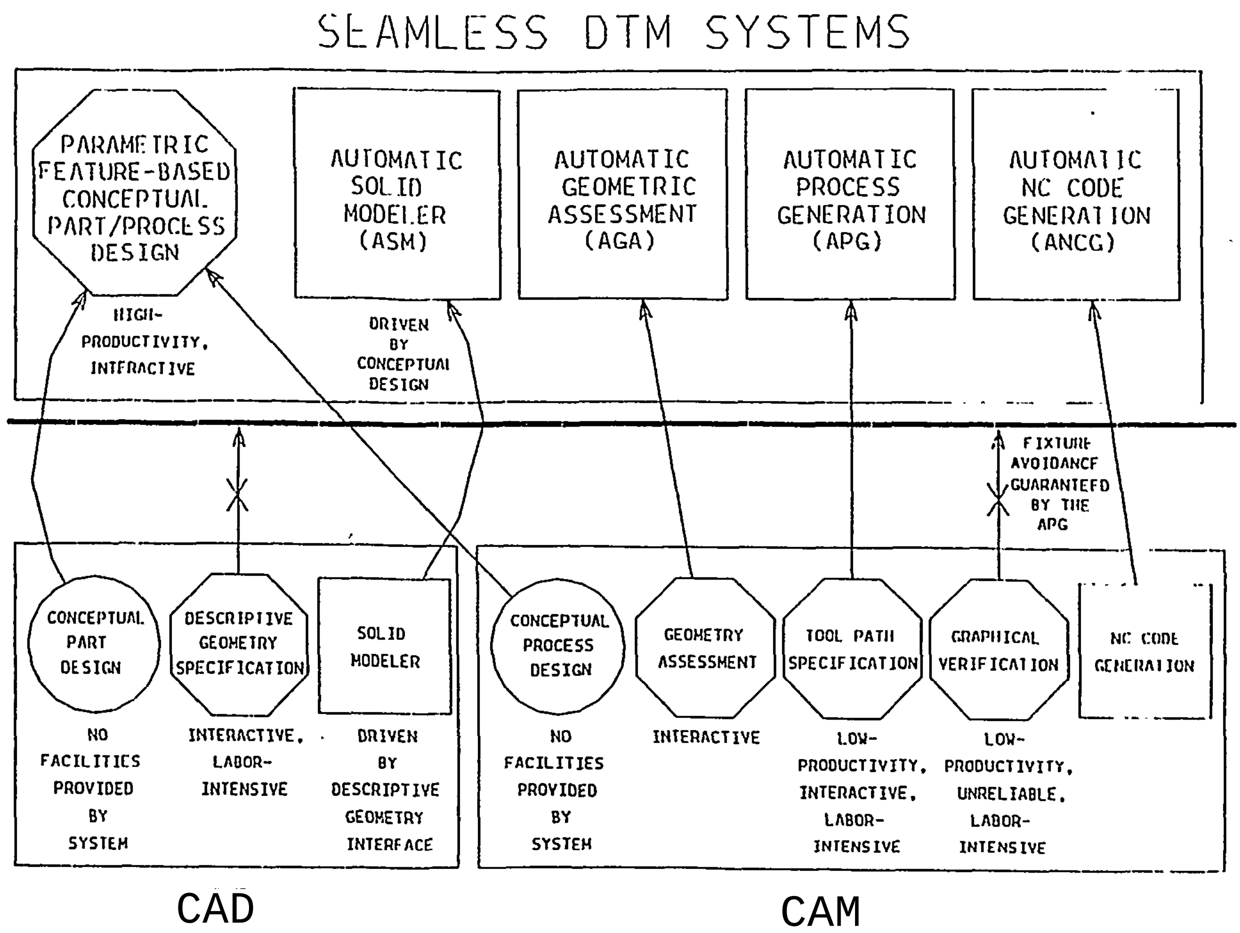

Figure 7. Illustration of Seamless DTM Systems.

process-design component, a set of Automatic Geometry Generators (AGG), and a set of Automatic Process Generators (APG) (41). The feature-based assembly- and process-design components are customized for a Group Technology (GT) family of similar assemblies. CAD/CAM's most serious flaw is overcome by SDTM's rapid responsiveness to product and process change. SDTM uses new or traditional manufacturing processes, and rapidly introduces engineering changes into production. An APG system generates process geometry and either numerical control (NC) code for manufacture, or production schedules, work assignments, production diagrams and material requirements for production, using the family of assemblies* shared process similarity. CAD/CAM is in a poor position to use reduced computer cost and higher speed to improve its responsiveness to change. SDTM is suited intensive and well- to benefit from distributed cooperative processing.

computer and communication hardware technology developments have continued to improve computer processor and communication speeds. However, software-development productivity has made comparatively little progress. Conventional CAD/CAM systems development has been slow and costly due to the traditional low-productivity methods employed. To distribute this development cost over the largest possible market, generic CAD/CAM systems are marketed to design a wide range of products. Unfortunately, they are not responsive to change. Due to new high-productivity software-development methods (28), customized SDTM systems have been created quickly, at relatively low cost. These high-productivity methods make it economical to customize SDTM systems for similar GT families of assemblies. SDTM systems utilize these similarities, elevating design interaction to a highly productive parametric feature-based conceptual level. Although some companies pursued proprietary efforts to customize their CAD/CAM systems in the 1980's, those efforts have been costly and have subsequently involved those companies in more-costly customized upgrades. By devoting their resources to CAD/CAM customization, these companies have missed opportunities to benefit from many advances in technology. High-productivity software-development methods used to build and customize SDTM systems avoid these costs and enable the introduction of new technology.

Unlike conventional CAD/CAM systems, SDTM Automatic Geometry Generators employs "geometric integrity" to generate solid models automatically from assembly-design parameters (42). With SDTM, unlike conventional CAD/CAM, feature-based geometric assembly design, parameterization, and automatic generation of a solid model exhibiting geometric integrity are feasible.

Each SDTM system is built around a flexible process plan that suits the entire GT family of assemblies. A robust APG system is built for this flexible process plan and verified. Thereafter, the parametric design of a new assembly, in the family, produces an assembly automatically. APG eliminates the need for extensive pre-production verification for each assembly, to debug process geometry and either NC code or production schedules and material/work assignments. SDTM also eliminates the need for NC verification software included in many CAD/CAM systems, or sold separately (43). Graphical verification of NC toolpaths is imprecise, time consuming, and extremely costly, often more costly than the machining operation itself.

Within the shipbuilding industry, the SDTM concept-to-production approach can be employed to introduce CIM into shipbuilding without the adoption of NC processes, as explained further, later in this paper.

An FMS is a manufacturing system specifically designed to produce different GT families of parts together, without sacrificing efficiency, as compared with individual factories for each part. Shipbuilding and repair yards also use the same facilities and workforce to produce and repair different types of ships simultaneously. In this sense, they are tackling-the same generic problem as FMS. Enabling technologies of FMS must be examined to determine their applicability to shipbuilding and repair.

Some critics judge existing FMS implementations to be inflexible. They cite early FMS implementations developed in the 1980's, which manufactured a basic design with minor modifications. They also note that during economic downturns the company's capital is tied up in FMS that make unwanted quantities of products (45). These criticisms are directed to the degree of flexibility of FMS, rather than the advantages of FMS over normal automation. In manufacturing, machining centers and turning centers are recommended as being more flexible than FMS that use customized work cells (46,47).

Caterpillar Inc., East Peoria, Illinois, used an FMS to cut lead time and in-process inventory in half, and triple productivity. Parts for elevated sprocket tractors, previously experiencing a throughput of three weeks, now take only a few hours. The part family consists of 41 steel parts fitting within a 150 cm (5 foot) cube. The FMS system includes CNC machining centers with automatic tool changers and automatic work changers, and an automated storage/retrieval system (44).

A major California-based air conditioning manufacturer replaced its five separate batch lines, each producing five component types, by a flexible new line that eliminates work in process (WIP) inventory. This line can produce all five Component types as individual units in any sequence. Now, no tooling changes are required, and only one sixth the workforce is required (21).

<u>Rapid Prototyping Systems</u>

In adopting CIM in shipbuilding, it will become necessary to speed up manual activities like model making. This requires adopting "rapid prototyping" technologies. Recently, several rapid prototyping technologies have emerged [48,49]. These technologies have demonstrated the ability to create geometric models that roughly match part designs. However, for many applications they are unable to generate prototypes that can withstand physical testing and realistic thermal environments. Stereolithographic plastic models are suitable for judging aesthetics and fit of many consumer products. But these plastic models are inappropriate for applications such as instrumented water-tunnel testing of metal marine propulsers, to judge their structural, acoustic, and hydrodynamic response, or for engineering applications that involve appreciable heat. In addition, rapid prototyping speed and accuracy varies greatly from one geometry to another. Other problems include differential shrinkage and polymer toxicity.

Stereolithography and solid imaging selectively cure a liquid photopolymer to build a solid object slice by slice. Selective laser sintering selectively fuses powder, to build prototypes slice by slice. Other processes, based on material deposition. include laminated object manufacture (LOM), ballistic particle manufacture, and fused deposition modeling. Stereolithography has led rapid prototyping, dominating sales.

While most of these processes are driven from standard CAD data, the slice geometries must be fully closed. Most conventional CAD systems do not preserve geometric integrity (42), so CAD rework to close the slices is required for each part.

SDTM provides rapid prototyping using conventional machining processes and the intended part materials (40). SDTM produces prototypes which are both geometrically correct and can be evaluated in realistic physical and thermal test environments. These prototypes are also acceptable final products.

Virtual Reality

Virtual reality is an emerging technology that enables an observer to experience an environment or a task by means of visual, auditory, and sensory simulation (50). The equipment includes a helmet that features graphical screens as goggles, stereo sound, and a pair of gloves equipped with position and orientation sensors. A person moving their hands and arms sees graphical depictions of their hands and arms moving in the goggle screens. By walking on a treadmill, the operator can tour workplace or a designed environment such as a ship. A pilot may see a virtual cockpit dashboard with gages and knobs. As he reaches out to touch them, he sees the image of his arms doing so, and experiences the effects. This is an effective way to prototype instrument panels. The computational requirements of presenting realistic images and computing intersection of virtual objects, and the physical effects of exerting forces on these objects are enormous. Advances in computer hardware technology will supply the computational power to provide better and more convincing realistic Visual and auditory images. Less progress has been made on general-purpose tactile sensory response equipment.

Quasi-realistic graphical output has already helped in many design areas. It is possible with commercial packages to visualize the simulated interior of a ship cabin. Designers can check ergonomic issues such as head clearance, or the clearance for a crew member carrying equipment. These systems differ from virtual reality systems in the nature of their input devices or interfaces, and by the use of workstation screens.

In ship production, a tradesman wearing virtual reality equipment could see an overlayed image of the correct placement of the next component to be attached superimposed over the existing assembly. Ship designers could digitally explore the final assembly interferences of large system subassemblies. Maintenance requirements and difficulties could be assessed quickly during the design stage of engines and other complex intertwined 3-D assemblies using virtual reality [50].

WORKSHOP ON APPLYING CIM TO SHIPBUILDING/SHIP REPAIR

An NSF-sponsored workshop was held at the University of New Orleans on February 6th and 7th. The objectives of this workshop were:

- to expose U.S. shipbuilders to developments in CIM,
- to develop a consensus of what bottlenecks stand in the way of realizing CIM, and
- to develop research themes which address the problems facing introduction of CIM in U.S. shipyards.

Representatives of academia, from Boston University, the Massachussetts Institute of Technology, and the University of New Orleans were in attendance. Shipyard representatives of Avondale Industries, Beth Ship, Ingalls Shipbuilding, and Swiftships participated.

Workshop Observations

Substantial implementation of CIM in shipyards will change the traditional boundaries between engineering, production, and scheduling. It will shift the sequence of these activities (Fig. 1). It will also alter the scope and conceptual level of shipyard job responsibilities, and work force job skills. This will impact supervisors, planners, designers and engineers (everyone other than the workers actually performing shipbuilding trades). Routine work will be automated, saving time for conceptual planning and comparative decision-making.

Ship production planning involves a hierarchy of planning levels and different levels of detail. The lowest level involves the foreman who examines the job, its location and its accessibility, and then accurately specifies the detailed sequence of tradesmen, equipment and the time

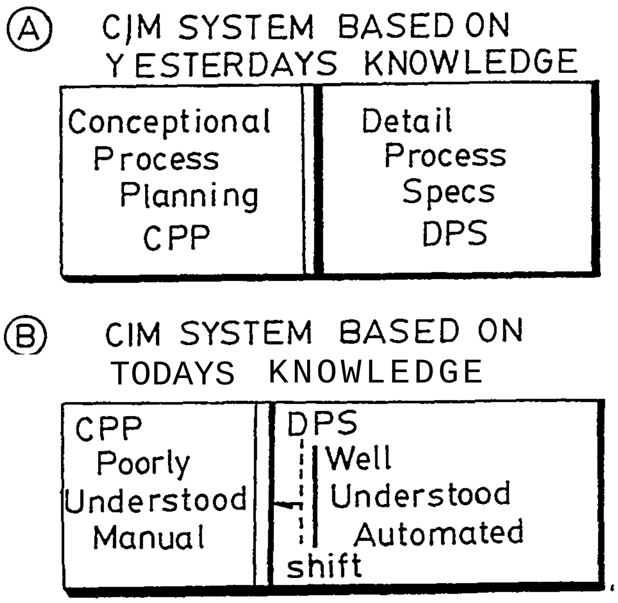

Figure 8. Illustration of DPS-CPP Shift

required for each outfitting process. Shipyard process planning consists of **two activities,** conceptual process planning and detailed process specification as shown in Fig. 8. The detailed process specification is the well-understood portion of process planning. It has become routine, and can be automated. Conceptual process Planning is the portion that is not understood well enough to be automated. The division between these two levels shifts gradually, as the employees learn and their understanding increases and as the shipyard technology base grows (Fig. 8).

The detailed design, planning, scheduling, purchasing, and cost-estimation of ship production is too massive, tightly coupled, and dynamic to afford the luxury of performing detailed process specification manually or even as a computer assisted activity (51). Detailed process specification must first be automated into CIM systems so that shipyard personnel can progress to conceptual process planning. This will allow a better capability to compare design alternatives, evaluate design changes, and understand the impact of delivery and work delays. The CIM Workshop attendees agreed that a shipyard CIM system must be able to respond to engineering change. This involves using the existing process plan, performing the detailed process specification automatically, and producing a budget and production schedule that conforms to current lead times and manpower/equipment constraints. This allows different engineering changes to be compared to select the best. Today's manually detailed process specification will be automated to achieve SDTM in ship production.

It was noted that attemps to fully automate shipyard process planning may not yield a successful shipyard CIM system. Since many of these process planning skills are poorly understood, they are not easy to capture. Most generative process planning systems are still at the research level. The few commercially available systems have not found widespread acceptance in industry because they require manual coding of part features, and the development and maintenance of extensive databases and decision logic that is unique to each manufacturing firm (52).

Rather than automating all of process planning, the detailed shipyard process specification of well understood tasks, such as welding or outfitting, should be automated first. Then, the foremen can deal with the next-highest assemblies. In doing so they can identify any errors in the planning software and later, they can add additional tasks not previously automated. In this way, shipyard supervisory expertise is available to improve the CIM system continuously. Rather than displacing skilled shipyard foremen, their job is expanded and improved as a result of shipyard CIM.

This approach to CIM differs from the call to mechanize, automate and numerically control shipbuilding processes. Although automation has been demonstrated to be effective in the Japanese shipbuilding industry, it is linked to the Japanese shipbuilding industry's division into specialized shipyards, each building a certain type of ship. Japan enjoys sufficient volume to make mechanized assembly processes effective. Presently, American shipbuilding has too small an order book to reorganize itself in this fashion.

Rather than automating shipbuilding, the approach to realizing CIM seeks to automate the process specification. Tradesmen are needed to build ships: however, as knowledge of shipbuilding grows, more and more complex process-specification tasks will be automated, freeing those workers to consider more important productivity issues, rather than repeatedly "fighting the same fires" throughout their careers.

CONCLUSION: RESEARCH RECOMMENDATIONS

The workshop attendees strongly endorsed the concept University-based Center for Advanced Marine Technology similar to an NSF Center of Excellence. In this university-affiliated center, advanced technologies would be developed and made accessible for ship production. It would be associated with a university program in naval architecture and be close to the shipyards.

The workshop attendees also indicated that the role of the Center should be focused on research and development in areas critical to the maintenance of the U. S. shipbuilding base. They suggested that the Center should conduct research in four areas that would accelerate the adoption of U. S. ship production and repair. These four research areas are summarized below.

Development of Quantitative Index of CIM-Related Improvements in Ship production/Repair

The cost for a shipyard to adopt CIM must be balanced with the projected improvements. This raises several issues which must be addressed for the CIM system to be adopted. The scope of this research would include the areas listed below.

- Identification of areas which will see:
  a. significant improvement,
  b. moderate improvement, and
  c. long-term improvement (initially small improvement).
- Development of an index to assess these gains. This index would include improvement in costs, schedule, and profitability in shipyard production.
- Application of this index to a cross-section of ships and offshore structures to identify where the highest gains will occur.

This research will also clarify the extent of benefits from incremental adoption of CIM, versus a complete switchover to CIM.

Characterization of Shin Production Activity and Manpower Shift with CIM Adoption

The introduction of CIM into shipyards will have far-reaching implications on present and future shipyard staff. Implications which should be explored will include:

- their required skills,
- their training,
- how their expertise will be incorporated into CIM systems,
- how they will use and supervise these CIM systems,
- what new opportunities for career growth paths are presented by their use of these CIM systems, and ultimately
- who will seize the opportunity to advance and grow with the technology or be made obsolete by it.

In the long term, shipyard jobs (above the level of tradesmen actually performing shipbuilding processes) will be integrally tied to the use of CIM systems.

This shift in personnel requirements can only be accomplished in an evolutionary manner. Many obstacles, both technical and social, obstruct the transition from present shipyard structures to CIM based shipyard. Cooperation of process-planning experts is necessary, although unlikely unless shipyard management can take serious steps to prove that their goal for CIM automation is not to displace workers.

Development of Shipyard Production Testbed for CIM Development and Training

Emerging CIM technologies are rarely presented in the ontext of shipbuilding. Due to differences between shipbuilding and other manufacturing industries, some of these technologies are inappropriate for use in ship production, while others are quite effective. Because of the high cost of. implementing large corporate CIM efforts, the shipbuilding industry will either duplicate efforts in testing emerging CIM technologies or choose to ignore them. A computer-based ship production testbed can provide a prototyping environment to test emerging CIM technologies and demonstrate their relevance to ship production. Specific examples of individual shipyard production methods can be used to customize the application of these technologies to production activities at specific yards, helping member yards to gauge the detailed performance of the technologies on their own work, through their own evaluation criteria. Once technologies have been demonstrated using the testbed, better decisions can be made regarding their benefits, costs of scale-up, expected difficulties, and technology transfer into the shipyards

Characterization of the Costs and Scope of Engineering Changes Throughout the Production Cycle

To achieve low costs, quick delivery, and high quality, the costs and delays from engineering changes must be minimized. The CIM system provides a mechanism with which to make frequent changes easily, however, once production begins, these changes can have costs that are not readily discernible. These costs can involve not only material and services that have already been ordered, but by delaying other work, engineering changes can affect tasks along the critical path and cause delays which add significant costs. Other engineering changes actually reduce costs and positively impact the schedule.

It is imperative that the CIM system determine these cost increases/decreases and schedule improvements/delays so that decisions can be made by the production managers Other alternatives involve 1) strictly limiting all engineering changes, with no knowledge of their implications, or 2) freely permitting all engineering changes, blindly hoping that the implications will be positive or minimal. Neither of these two alternatives is acceptable. Instead, shipyard planners must have the information with which to gauge the impact of their proposed changes, so that alternative changes can be compared to build the best ship at the lowest cost in the shortest time.

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The Effective Use of CAD in Shipyards

No. 2B-2

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ABSTRACT

In the current severely competitive climate that is challenging shipbuilders everywhere, how information is managed is taking on extraordinary importance. Existing computer aided design (CAD) systems have not been focused on the most critical information needs, for example, information to serve marketing. This limitation is the result of concentrating primarily on aspects of design and manufacturing without regard for impact on an overall manufacturing system. In this paper the need to extend CAD systems is identified so that they would more fully provide critical-data to everyone who has to have understanding of a manufacturing system's capability and availability.

INTRODUCTION

This paper is an attempt by the authors to provide a thought provoking preview of shipyard CAD systems for the next decade. It is based-on interviews, visits, and/or discussions with shipyard representatives from the U.S., Europe and Japan concerning current CAD capabilities and practices. It also reflects a review of pertinent CAD literature, in the marine and other industries. Finally, it considers CAD utilization and implementation issues in conjunction with the application of a modern, product oriented shipbuilding system which constantly improves while serving commercial-ship and other customers, in a worldwide competitive market.

Evidence is continuing to accumulate which indicates that even the most impressive CAD capabilities will never achieve their maximum potential if future such developments proceed as they have thus far. Most people who are responsible for funding existing and future CAD systems, still do not have sufficient understanding that the computerization of design, in what is now being called the information age, cannot proceed isolated from all other aspects of a manufacturing system per se.

Where such understanding exists, shipyard managers oversee rationalized work, exploit statistical analyses, provide information to workers about how their work is performing (especially regarding schedule, man-hour budget, and quality adherence), and rely on decentralized decision making. As top priority measures they insure that their manufacturing systems capture the many small-scope productivity improvement-ideas that-informed workers make. "At Ishikawajima-Harima Heavy Industries (IHI) each-employee submits an average of 18 suggestions for improvement per year." (1)

Thus in a shipyard which employs 1500 workers, 27,000 suggestions per year or about 120 per workday are considered. Collectively they are the "backbone" of the yard's constantly improving manufacturing system. But there would be no backbone if the impacts of accepted suggestions were not captured as corporate data, summarized at various levels, and instantly made available to managers, supervisors, and workers commensurate with their responsibilities. All are dependent upon knowledge of how their manufacturing system currently performs. Prominent among them are the marketing and estimating people who regularly project the rate of improvement and discount bids for contemplated projects accordingly. Emphatically, for world-class performance, CAD system developers have to address how to automatically assimilate the consequences of every design and manufacturing method change regardless of its size. Furthermore, the information age requires CAD system developers to regard marketing as part of the manufacturing system because it is vital for marketing people to be precisely up to date about the system's capability and availability.

As shown in Figure 1 the feedback paths to marketing from the other basic management functions (planning, scheduling, executing, and evaluating), constantly update knowledge of the manufacturing system's capability and availability. Estimating is an aspect of marketing. Design is an aspect of planning. Executing includes both material marshaling and producing.

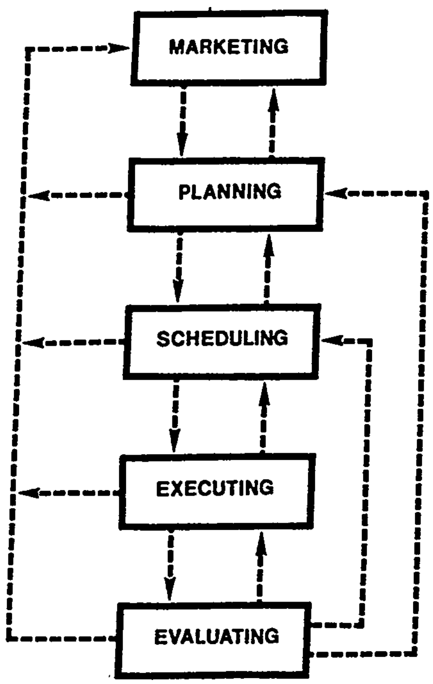

FIGURE 1: FEEDBACK PATHS TO MARKETING.

MARKETING NEEDS

No one will disagree that marketing is important, but because it is not generally recognized as part of the shipbuilding system, it has not benefited from marine industry related research and development efforts. Unfortunately, good advice was ignored. In the mid seventies when the National Shipbuilding Research Program (NSRP) was recognized in a Rand Corporation report as one of the most effective research programs funded by government, Marvin Pitkin, then a deputy administrator for the U.S. Maritime Administration and someone having significant experience in high-tech industry, advised, "The NSRP is doing a great job on half the equation, that is, the half that involves cost reduction." He went on to describe the need to also invest in developing marketing and, with Figure 2, emphasized that the NSRP should measure its success by monitoring the difference between shipyard revenue generated and cost incurred. This difference is a true measure of the success of a manufacturing system. Thus, marketing, which uniquely concentrates on increasing revenue, is critical.

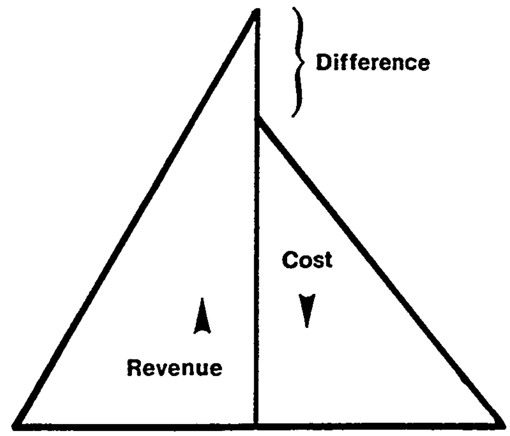

FIGURE 2: DIFFERENCE BETWEEN REVENUE AND COST.

The few in the U.S. shipbuilding industry who appreciated the need to support marketing, were soon diverted to lobbying for part of the program to build a 600-ship navy. At that time building warships was not compatible with development of a modern flexible manufacturing system which could manifestly self improve during each construction effort, and which could construct both naval and commercial ships and other entities, such as, processing and toxic-waste incineration plants. Work for customers with such understanding is essential for developing a modern manufacturing system, which in turn is essential for generating and constantly updating information that marketing people need in the information age.

Information that serves marketing that depends on input from design includes:

o how hull construction man-hours vary with block coefficient,

o how outfitting man-hours vary with block coefficient,

o how hull construction, outfitting, and painting man-hours vary with design and production innovations, and accuracy expressed in statistical terms that the yard's manufacturing system normally achieves for various structural details.

Regarding block coefficient, hull construction man-hours reduce and accuracy improves as line heating is perfected for curving hull plates and structural shapes. Also, the engine rooms of high-speed container ships are more difficult to assemble than those in tankers. An innovation, already implemented by a Japanese shipyard, features container-size outfit modules for the assembly of engine rooms. The yard specializes in production of the modules and transports them in container ships to other yards, in Japan and elsewhere, for blue-sky outfitting. When the accuracy normally achieved is referenced in contracts, enlightened owners who understand the link between productivity and quality are thus assured that critical dimensional requirements, as in container *and* liquid natural gas ships, will be met. Also, regulatory agencies are assured before work starts of structural integrity that is related to accuracy, for example, the alignment of longitudinal butts.

Keeping marketing people up to date about such relationships is very important because even the slightest edge in a market that includes constantly-improving competitors, is vital.

There is more information that marketing people need which should be the subject of development at least equivalent to that which has been applied for CAD in the last decade. Some needs were identified by Sarabia and Gutierrez in their description of the process of recovery which enabled Astilleros Espanoles, S.A. to reenter the global shipbuilding arena. (2) They described a strong marketing effort consisting of: training a large specialized sales force to canvass the world, sophisticated media and image campaigns, untiring travel for contacts with brokers and customers, and, as very important, "financial engineering teams that were brought in to prepare competitive offers, making the best of Spain's currency, exchange rates and credit schemes." Regardless of what computerization in shipbuilding is called, CAD extended or preferably, computer integrated manufacturing (CIM), financial matters, including ways to evaluate the quality of a prospective customer's fiscal responsibility, is the area that should now be targeted for highest-priority computer-application development.

While it may seem mundane to some, it is also critically important that CAD systems address many indicators of productivity that are not now being monitored, particularly in yards that have been favored with large naval shipbuilding programs. While their managers often cite learning curves that reflect the decrease in overall man-hours required per ship during series construction, and even by man-hours per ship's functional system, that information is not sufficiently detailed for practical management by target. When world-class shipbuilders shifted to product orientation, they reorganized people so that each group of designers has a counterpart group in production with whom they share responsibility for the cost of specific interim products. Thus both are immediately interested in monitoring many things for which design input is required and which are readily counted or calculated by simple computer routines; see Figure 3 for examples.

EARLY CAD DEVELOPMENT

Why didn't development of computer-applied management information systems in the 1960s direct CAD developers in the West to anticipate more than design needs? In the late 1970s when the first descriptions of a Japanese developed product work breakdown structure (PWBS) for shipbuilding were published by the NSRP, archaic system-by-system work breakdowns for implementation by inadequately-coordinated functional crafts, were in general use. The concept of a rationalized manufacturing system featuring integrated structural, outfitting, and painting work, was unknown as was the concept of collecting cost per (interim) product regardless of the mix of systems represented. Computerization of management information needs reflected the status quo. Even now, more than a decade later, only two U.S. shipyards demonstrated with completed shipbuilding projects that they organized information, people, and work, with sharp focus on cost per product.

Without such demand from managers, design oriented people a0 not understand that the effective use of CAD is not limited to improving the effectiveness and efficiency of the design process. With such demand they will understand that they can significantly contribute to improving the effectiveness and efficiency of the entire shipbuilding process which includes all design activities. Furthermore they will readily accept that for building a typical merchant ship, basic designers, those who interact the most with marketing people, only contribute 3% to direct costs, whereas by a wide margin,

a. ratio of net steel weight to invoiced weight,
b. number of hull plates and percentage of curved plates,
c. ratio of penetrations NC cut to total number of penetrations required,
d. total lineal meters of hull erection butts and seams,
e. total lineal meters and locations of erection butt and seam edges that were not neat cut,
f. total lineal meters and locations of erection butts and seams that required rework by gas cutting and, separately, that required rework by back-strip welding,
g. accuracy in terms of mean values and standard deviations for hull parts, sub-blocks, blocks, and erection butts and seams,
h. number of temporary lifting pads required for hull construction,
i. number of scaffolding planks required separately for assembling bow blocks, midships blocks and stern blocks; for hull erection; and for outfitting separately by deck, accommodation, and machinery,
j. total lineal meters per size and type of welds for sub-block assembly and separately for block assembly,
k. total number of separate material items that must be manufactured or purchased, and the numbers that apply for each specialty, for example, deck, accommodation, machinery, weapons, etc.,
1. lineal footage of all pipe and separately for large, small and medium diameters, (This item and most which pertain to pipe that follows, also apply to vent-duct pieces.)
m. number of pipe pieces and percentage of field-run pipe pieces (The latter represents work out of control and is a particular target for reduction.),
n. average pipe piece length,
o. number of straight pipe pieces and pipe pieces that can be completely fabricated as straight and bent afterwards (these are the two least-cost categories),
p. number of bent pipe pieces having other than 90 and 45 degree bends (Allowing other degree bends impacts adversely on ability to employ statistical accuracy control.),
q. number of bent pipe pieces which require less than "3-diameter" radius bends (Smaller radii impact adversely on ability to employ statistical accuracy control.),
r. number of pipe pieces fitted on unit, number fitted on block, and number fitted on board.
s. number of pipe pieces that must be fitted on board of such weight and/or length that exceed limits determined from what one worker can handle safely.
t. regarding pipe-piece precision, ratio of total number of mock, loose flange, reworked, etc. pipe pieces to total number of pipe pieces (This too is a particular target for reduction.),
u. accuracy in terms of mean values and standard deviations for pipe pieces,
v. footage of all electric cable and separately for small, medium and large diameters,
w. footage of electric cable pulled on block and separately for small, medium and large diameters,
x. number of electric-cable runs and separately for small, medium and large diameters,
y. number of electric-cable runs precut and separately for small, medium and large diameters,
2. number of electric-cable runs pulled on block and separately for small, medium and large diameters,
aa. number of precut electric cable runs provided with distance from the pulling end to a reference mark to facilitate installation (This also requires, dimensions for corresponding reference marks on-block or on-board.) and separately for small, medium and large diameters,
bb. percentage of electric cable pulled on block relative to total footage of cable required,
cc. percentage of cable ends connected on block relative to total cable ends connected,
dd. average length of remnants from precut cables separately for small, medium and large diameters,
ee. total number of supports for walkways, pipes, vent ducts, electric-cable trays, etc., and
ff. regarding material pallets, ratio of missing line items to total number of line items.

FIGURE 3: EXAMPLES OF PRODUCTIVITY INDICATORS THAT SERVE MANAGEMENT BY TARGET.

they have the greatest influence on ship total cost. Thus, compared to traditionalists, the world's most effective shipbuilders invest more in basic designs and insure that each design is implemented as an aspect of planning. When shown Figure 4, which illustrates that basic designers have the greatest influence on ship cost, a former managing director of Australian Defense Industries said, "When a project is behind schedule and/or over budget, do not blame production. First ask, 'Who is responsible for the planning?'"

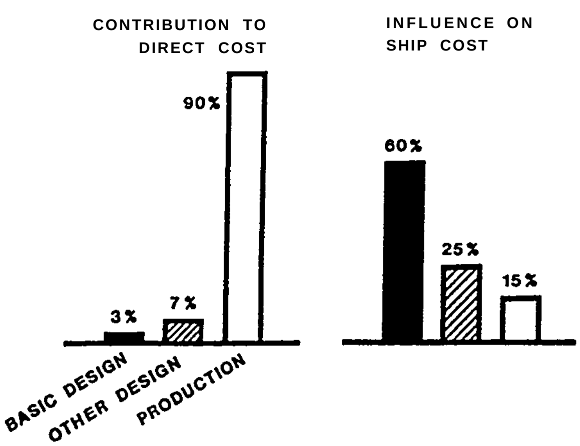

FIGURE 4: IMPACT OF DIRECT-COST ON SHIP COST.

Most shipyard CAD systems evolved over a number of years, forcing managers to decide between upgrades to existing hardware/software or total revamping of an outmoded system. Rarely did shipyard managers choose the later approach. Consequently, most CAD systems are the outgrowth and extension of earlier systems. In shipbuilding, the initial application of CAD systems was for computer lofting. There are a number of systems that fit this description. Originally, design/lofting contractors provided numerical control (NC) tapes for the shipyard to use for automatic control of cutting machines. The next upgrade involved the direct generation of the NC tapes at the shipyard, and thus involved the installation of a CAD system that was capable of producing information to generate the NC tapes. Systems are also currently in operation that electronically transfer NC cutting instructions to the cutting machines without generating tapes. The early literature (from 1975) about CAD systems reflects the concentration on steel parts cutting. (3,4) Eight years later, in 1983, although computer hardware had significantly improved, the concentration was still on steel parts design and production, with additional emphasis on structural computations. (5,6)

Had hull construction processes in Western shipyards been rationalized before computerization, per the Pareto principle, initial developmental efforts would have been directed at subassembly, block assembly and hull erection work. That would have addressed about 90% of hull construction man-hours as compared to parts production (10%). This different focus would have established identification of process control through statistical analysis of accuracy variations as far more important than just improving parts production. Something as simple as a fish-bone (cause-and-effect or Ishikawa) chart applied for improving any assembly work, would have shown that the need for improving the accuracy of parts did not make sense if not compatible with fitting and welding capabilities for subassembly, assembly and erection work. Why improve parts "accuracy" if no compensation is made for shrinkages caused by gas cutting and if margins of excess material (commitments to rework) are routinely employed? Thus 25-years ago, computerization of hull construction processes in Japan lagged relative to that in the West while the statistical approach, very much of which was performed manually, permitted Japanese shipbuilders to eliminate virtually all margins and to constantly establish the latest criteria, in statistical terms, for further automation of welding. Computer applications independent of a unified CIM system were developed in support of these narrower, but higher-priority needs, such as statistical accuracy control. (7,8)

In the West, simultaneously with the development of NC for parts cutting, CAD capabilities that were primarily useful-for drafting were being developed. These systems provided the opportunity to develop high quality, preliminary design drawings, such as outboard profiles, general arrangements and machinery arrangements. Additionally, CAD drafting capability was used to do on-screen detail design, permitting uniformly high quality drawings to be produced. Similarly, CAD development in Japan focussed on software modules for specific detail design applications. Shipbuilders developed internal systems for design of Structure, piping, accommodations, etc. **(9,10)**

CONTROL THROUGH CONTROL OF MATERIAL

In the absence of a PWBS with its sharp focus on cost per interim product, most computer applications in the West were developed in the mold of traditionalism leading one wit to note, "A computer lets you make more mistakes faster than any other invention in human history, with the possible exceptions of handguns and tequila." (11) The computerization of cost/ schedule control based on collection of data by ships' functional systems is the most profound example. In order to postpone hassles, supervisors in such traditional environments regularly mischarge man-hours and/or report progress, as a crisis deepens, through increasingly-darker rose-colored glasses. Of course, computer prepared summaries of such data misinform managers faster than they have been misinformed before computers were introduced.

But with product orientation as developed in Japan, first priority was assigned to employing computers for production control through control of material. Monitoring material definition from establishment of a material budget during marketing to producing structured material lists down to the level of the smallest assemblies (as for pipe pieces) started many years ago and is still regarded by the world's most effective shipyard managers as their most important computer application. The man-hours needed for processing materials are, as a consequence of corporate experience, related to physical characteristics of material. Thus basic man-hour budgets, and therefore basic schedules, are computer produced. As the material is further defined during each design stage which follows a marketing effort, computers constantly monitor for the purpose of answering two questions. Compared to materials defined previously, have any new materials been defined? Has there been any change in quantity of any material item previously defined? Affirmative answers to one or both during any design phase automatically advises of the basic amounts to change the man-hour budget and the schedule.

Further, in accordance with a strategy provided and refined by production engineering functionaries, detail designers group information (arrangements and details and attendant material lists) to match what is to be assembled in a specific zone during a specific stage, such as for assembling an outfit unit or for a discreet amount of outfitting on block. The same parameters which relate materials to man-hours required for their processing are used in Japan, per U.S. Department of Defense parlance. for establishing budgeted cost of work scheduled, and when workers "shade in" material lists as materials are processed. for determining budgeted cost of work performed. For the bulk of the materials processed, no supervisor's assessment of work performed is required. Computerization of design in the most effective yards in Japan contributes significantly to cost/ schedule control!

With the extraordinary focus on grouping material to match interim products in Japanese shipyards, computer applications for material management were given extraordinary attention. The number of prospective suppliers for any one material requirement was limited in order to make practical the maintenance of required knowledge, that is, design details, regulatory approval status, timely delivery record, previous costs; vendor guarantee history. various material classifications, etc. Generally, twice the computer capacity required for design was devoted to material management matters. Further it made practical computer files of flexible standard arrangements and details that CAD operators could "plug in" and that production managers could use for collecting attendant cost and schedule adherence data.

Notice of this profound computer application was published fourteen years ago when Ichinose advised:

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

"Standards and modules show their greatest advantage when integrated with a comprehensive computer system." (12)

The modules described by Ichinose also applied to diagrammatics. (13)

Standards and modules were included in Future-Oriented Refined Engineering System for Shipbuilding Aided-by - Computer (FRESCO) as briefly described in a paper which was presented three-years ago. FRESCO is having a profound beneficial impact on the sponsoring company's overall manufacturing system. (14)

Also, computer capability makes it easy to enter changes and quickly produce updated high-quality drawings. While this CAD capability was extremely useful for marketing, in-general there was no capability to automatically extract and discuss previously used diagrammatics or standard arrangements.

As a matter of equal significance, the drawings from these systems used for contract design could not be electronically transferred in order to start the next design stage. In other words, links between the CAD drafting tools and the NC lofting tools did not exist.

A major area of development in CAD systems over the past decade has been the linking of structural design software packages with outfit design packages for piping and electrical distributive systems and for heating, ventilation, and air-conditioning systems (HVAC). Significant progress has been achieved, although the goal of most applications has been interference checking after sequential design has taken place (structure, piping, HVAC, and electrical in that-order):.Thus,. while CAD capabilities have continued to increase exponentially, Western shipbuilders have not had the benefit of system development focussed on the most critical needs of the overall shipbuilding system. (15,16,17)

Again, this lack of insight is due to not rationalizing shipbuilding work, which would have led to general adoption of PWBSs.

3D MODEL

Commonly, after CAD drafting tools are used in the contract design stage, a new, large scale effort must be started to develop a 3-dimensional (3D) model of the shell, major structure and major outfit components (including space reservations for distributive systems). The development of the 3D model can require about a 6 to 12 man month effort, for a basic model of a large ship. Today, many shipyards have separate systems for preliminary design and detail design. These systems are often totally incompatible, or can transfer data only with considerable effort.

In other words, the computer capabilities are not used to address the full management cycle from marketing (including estimating to evaluation. Furthermore, the incompatibility between systems commonly used for basic and sometimes system design and those used for transition and detail design impedes both the rapid progression of the design process and the availability of feedback from the later stages of design and more importantly the management cycle.

The key means of relating information at all stages of the management cycle is through interim products, i.e. material.

If a CAD system is intended to provide maximum benefit to a shipyard, it must effectively address the critical information needs of all facets in the yard's manufacturing process. Discussion of the need to consider total integration of the shipbuilding system began some time ago. These have focussed on the life cycle of the vessel or additional coordination with management information systems. No consideration of the need to include marketing decisions is commonly included. (18,19)

Since marketing is the initial stage, CAD capability must focus on generating information that is descriptive in terms of ship capability/cost tradeoffs. Since many iterations and options will commonly be considered, rapid, easy response is a key requirement. Even though the 3D model would provide more information at the initial stage, the cost for generating a 3D model for each product alternative under consideration, would not be justified. Thus, at the initial stage, 2D capability is the proper choice. This reflects existing practice in nearly all shipyards evaluated by the authors.

Although drawings based on 2D information are all that are required at the marketing stage, many systems exist that have the same rapid response and ease of use, but that also provide direct transfer of information for the 3D modeling required later. Thus. phasing out the use of strictly 2D systems in favor of systems that permit easy transition to 3D models is prudent. The primary reason for suggesting this is not the ease in generating the 3D model for later stages of design, however. Compatibility between marketing CAD tools and detail-design CAD tools is essential to permit electronic data feedback to provide marketing and estimating people with current information concerning actual cost, including cost comparisons between alternatives. Additionally, a key benefit to marketing and estimating people is the development of a data base of reusable designs. In particular, "standard" diagrammatics are valuable as a starting point for discussions with potential customers, and could be quickly developed to be included in contract design packages.

The timing for preparation of each 3D model is somewhat important, because it involves a significant investment. It is also an important initial step for the transition design process, and thus its early development-facilitates producing material lists for pallets sequenced by the specifically designated build strategy. Thus, rapid start of production depends on early development of a 3D model. While a 3D model can be developed at various locations within the design organization, it has a distinct tie in to marketing. Only marketing and contract negotiation people have direct contact with potential customers, and therefore should have a good feel for when a contract has a high probability of being signed. Additionally, they have more intimate knowledge of customers' needs and wants. Furthermore, the generation of a 3D model is likely to occur rather infrequently. Thus, centralization of this skill in close proximity to marketing will offer the advantages of good communication and coordination between marketing, design and material procurement functions.

BASIC SCHEDULING

A significant part of the feedback to marketing from design and production relates to current information regarding cost, and thus is useful for helping evaluate cost/capability tradeoffs. The second key piece of the equation, schedule, can also be addressed in a CAD system that has been designed to serve marketing through feedback of current information.

As previously mentioned, basic schedules can be computer produced as a part of the marketing effort, using the relationships of physical characteristics of material to man-hours and time durations normally experienced to process material. A second important type of feedback that could then be exploited is the current and anticipated utilization of the facility, by process lane. In this regard, production control data would indicate the progress of work by process lane for projects underway. Feedback to marketing resulting from reduction of information from a large-frame sense to small frame is shown in Figure 5. Both capability and availability information are included. (20)

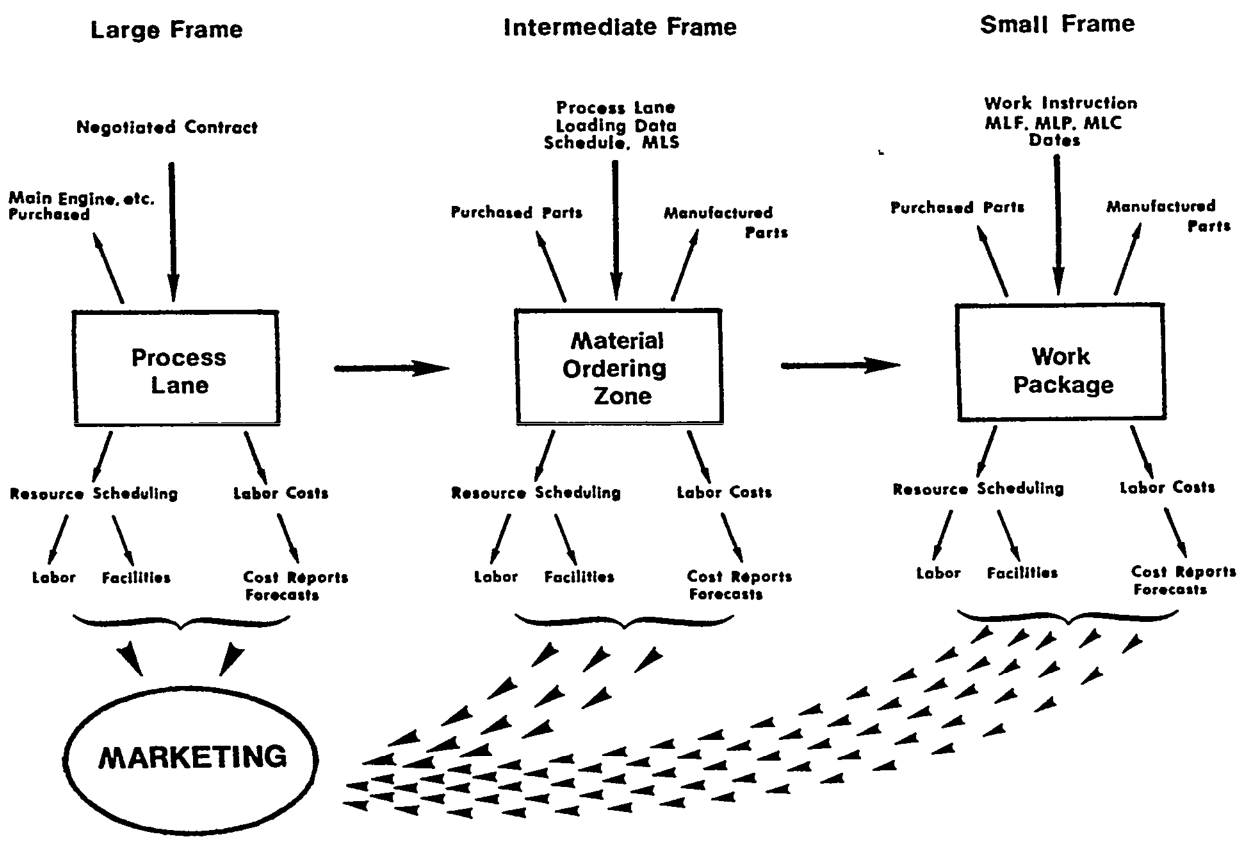

FIGURE 5: CONSTANT FEEDBACK TO MARKETING.

Projections of process lane utilization, using basic scheduling information, should be made in three categories. Firm commitments, for which contracts are in hand, should be treated as one category. A given percent utilization of a process lane for a given time period should be reserved for this work. A second category for high-probability work should be superimposed on the firm workload. This is for contracts being negotiated that have progressed to the point that 3D modeling is prudent. Finally, work that is-still uncertain, but being discussed should form the last category. Thus, prospective customers could readily be informed about the periods available in process lanes for their work.

The commercial airframe industry uses a similar reservation system, but needs only to consider one type of "process lane." the assembly line for a particular airplane model. A system like this would not be difficult to program, once a PWBS and the man-hours per material characteristic per process lane are in place and known. Note that the feedback from production and proauction control to marketing, and from different parts of the marketing organization, allow for a continual updating of actual practice. The feedback includes current productivity (such as man-hours/ton for flat block assembly), schedule adherence (such as actual status of process lane work), and process lane reservations (including probable work based upon negotiations with customers). This approach would provide an effective system that achieves some of the goals of a material requirements planning (MRP) system at the basic design/man-hour budget/schedule level, rather than at the detail level characteristic of commercial MRP applications.

CONCLUSION

Despite impressive development of computer hardware, CAD systems are not vet really addressing certain critical heeds. At-this time, successful marketing is the most important shipbuilding function. Consequently, in each shipyard, it is vital that a CAD system supports marketing with quick and accurate summaries of-the manufacturing system's current capability and availability to undertake various product alternatives that are of possible interest to customers.

Although computer capabilities exist to perform these functions, CAD systems built around traditional manufacturing approaches will not suffice. There is no alternative but to maintain (interim) product orientation with its focus on control through control of material. Thus, material, the only tangible entity, becomes the focal point for all data collection and feedback. Material volume equals work volume and thus ship cost/capability tradeoffs and facility utilization can be analyzed, evaluated and updated to provide-marketing functionaries with up-to-the-minute information. This information should be available regardless of the scope of any change in the manufacturing system.

Since there will always be another third-world country which will support its shipbuilding industry as a means to industrialize, from now on, the ability of other countries' shipbuilding industries to compete will be highly dependent on how well information is exploited. Thus the ability of CAD systems to constantly collect, process and distribute the right information to the right people is essential. Right now, CAD system developers should include data feedback to marketing as a high priority enhancement to current CAD capabilities.

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The SP-4 Workshop on Computer Aids for Shipyards

No. 2B-3

Daniel H. Thompson, Member, Coastal Technology Group

ABSTRACT

The shipbuilding industry in the United States stands at the crossroads of major changes in the global marketplace (1). The Society of Naval Architects and Marine Engineers Ship Production Committee Panel 4 (Design / Production Integration) is launching a major project to examine the best computer technology to assist yards to enter this new marketplace. This paper reports on the progress to date and especially the initiating national conference held in May 1992.

Participants at the conference were startled to find that the collective consensus clearly showed that no progress with better computer aids can be possible without a very significant breakthrough in the extent to which yards, suppliers, designers, and customers cooperate (2). The information captured from the participants indicates that there is a major barrier to moving critical objectives from implementation to production. Twelve objectives with 83 initiatives resulted from the conference. These depend upon short term and long term actions and continuous support from the National Shipbuilding Research Program (NSRP) over the next few years.

BACKGROUND

The idea for the SNAME Panel SP-4 initiative on computer aids came from Panel discussions regarding a series of projects to assess the status and scope of computer aids in shipyards worldwide with potential application to United States and Canadian shipyards. A five year program was discussed and the first year project (N4-91-5) was awarded to Coastal Group Technology in late 1991. CGT in turn prepared for and held an initiating national workshop conference in May 1992 with representatives of the shipbuilding, ship design. supplier, and government communities.

The workshop on computer aids was formed to create a vision of the best trends in computer aids through the next decade while at the same time providing a future business vision for the U.S. shipbuilding industry and sharing views on how U.S. shipbuilding might best provide products and services to fulfill the recommended vision.

THE PARTICIPANTS

Participants in this workshop conference were chosen for their ability to represent and articulate the needs and values of U.S. and Canadian ship construction endeavors. Of the twenty one participants the great majority were leading engineering or system executives. Several were consultants in the field and others represented major suppliers to the industry. Some correspondence from the participants modified the agenda of the workshop (3). The participants are listed in the Appendix.

THE FACILITATOR

Michael Kelly, Ph.D., and Neil Cambridge of Coastal Group Technology pioneered the procedure used to guide the participants to a focused statement of vision and policy objectives for the project. Dr. Kelly, the creator of the Advanced Management Catalyst System (AMCat) at the heart of the strategy verification method. has worked with management in companies such as Xerox Corporation, Citibank, and Asa Brown Boveri to catalyze the development and implementation of the corporate vision and new operating plans. This strategy verification procedure now has been computerized to elicit, record, process, and analyze collaborative group input. Strategy verification enables the participants to develop a road map to decision making, to integrate information in ways that are innovative and extremely powerful, and to establish a strategic vision down to tactical steps for accomplishment and evaluation. The prerequisite impetus for this approach has been presented several times before NSRP (1,4,5).

THE STRATEGY VERIFICATION PROCESS

Successful Action

Successful action requires total knowledge, cooperation, and capacity. The strategy verification method used to facilitate the SP-4 workshop follows a process designed to continually increase the quality of action toward such perfection.

Research at Boeing Company using a similar, though less integrated system, has shown that the calendar time for projects which require team meetings can be reduced typically 91 percent. Overall meeting time can be reduced as much as 7 1 percent (6).

So many ideas are created by so many people during an advanced management catalyst workshop (AMCat) that using marker pens and flip charts is prohibitively cumbersome and time-consuming. With a skilled operator handling a system consisting of a personal computer, printer, and projector; however, three major benefits can be derived:

The facilitator is able to concentrate on eliciting the maximum participation from each member of the group

All contributions are recorded and analyzed with great precision

Statements, lists, and matrices are clearly and quickly displayed and changed, leading to more rapid audience understanding and reaction.

What happens is that the technology, combined with the advanced management workshop process, actually begins to create knowledge, unlike simple data processing which can only create information. It then makes that knowledge immediately available so that a bridge is built between the formulation of strategy and its implementation. It becomes catalytic. Figure 1 illustrates the principle which makes this possible.

This figure illustrates the inter-relationship between knowledge, society, and actions which create net positive value. As knowledge increases in validity, precision and availability, it gains leverage. Knowledge is valid when it is understood in a common context (3). It is precise when it is relevant and sufficient to describe the subject. It is available when it is at hand "just in time."

Decision Systems Can Create Value

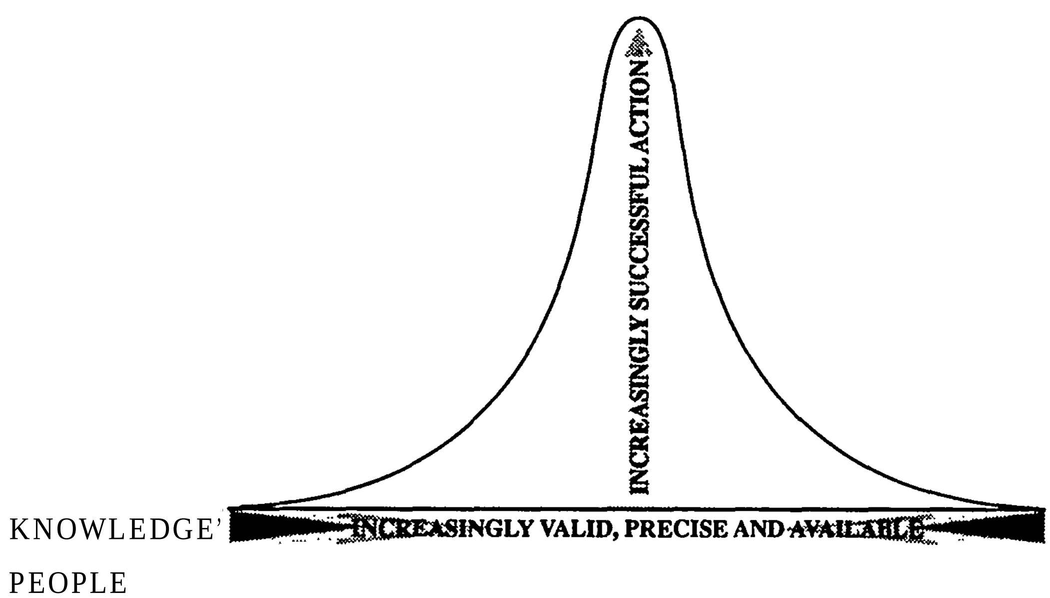

Fig. 1 Increase value to society by developing decision systems which use valid knowledge to complete appropriate action.

Knowledge, cooperation, and capacity are terms meaningful in a systems context, but they are inoperative without people. People supply knowledge and capacity. The success of action depends on the extent to which people cooperate to provide knowledge and capacity to their endeavors. Adversaries do not contribute to each other, but instead limit knowledge and the capacity of the system.

All in the shipbuilding industry are in the same boat. The total American shipbuilding system includes all knowledge and all concerned with this knowledge. Once this fact is realized by all, they become less adversarial and more willing to include new ideas from others. With valid knowledge the industry can become not only increasingly successful but also can increase its value to our whole society.

Understanding the potential of group decision systems, we were ready to work toward our first goal of assessing computer aids for shipyards. The process was carefully planned and then carried out in an intense period of time: the workshop itself.

The Event

The SP4 workshop on computer aids convened for three days, May 14-16, 1992, in Brunswick, Maine. Day one started with a demanding, non-stop brainstorming session with shared lunches and work into the evening. The second day was equally intense but focused on how to reach and realize the vision through actual actions to be taken now and in the future. On the last day each of the participants was privately interviewed for one hour to expand on the meaning of each of the action initiatives as well as on general observations.

Well ahead of the actual workshop prospective participants were sent material on the advanced management workshop facilitation process.

Dr. Kelly set the stage for the first session by asking each participant to take the role of a member of the Board of Directors of the U.S. shipbuilding industry. Each panelist was instructed to assume responsibility for setting the strategic direction for a major company whose corporate and product identity commands world wide recognition. It was left to each participant to bring his or her own set of values and perspectives into the role. The stage was further defined by stating that the group was now engaged in a three day session with management to determine the most profitable and productive future direction of the industry by providing the most appropriate computer technologies available or becoming available.

A STRATEGIC VISION FOR THE U.S. SHIPBUILDING INDUSTRY

The participants' brainstorming was launched by asking each participant to read the following statement of purpose (A) and a common, agreed upon definition of "Strategic Vision" (B):

(A) Why We've Been Brought Together

For the purpose of determining the direction of effort the shipbuilding industry will take over the course of the next decade, we invite you to assume the persona of a member of the board of directors of The shipbuilding industry. Please regard this position as an opportunity to create the future as much as it is an opportunity to respond to it.

Toward achieving this end, our first task will be to describe what the shipbuilding industry's world of customers, technology, and organizational strategy will be over the course of the next (ten) years. We will call this the shipbuilding industry's strategic vision.

At the conclusion of the two day process we are now undertaking together, we will have created a strategic vision; brain stormed every option, resource, and step we can imagine to fulfil our (The shipbuilding industry's) vision; refined those options and resources into a set of policy objectives: and mapped a general course for their implementation. We will use a procedure called the Advanced Management Catalyst (advanced management workshop) to orchestrate this process.

(B) What is Strategic Vision?

- A statement of purpose that is broad enough to involve people at every level within the industry, and inspiring enough to encourage the emotional involvement of all participants

- An announcement to internal and external customers of what can be expected from this group

- A challenge to all ship builders based on where technology is headed

- The projection of future accomplishment that promises to extend the U.S. ship building industry's domain of influence in terms of both strategy and tactics

- The written description of this group's dream for the future.

Using this definition of strategic vision, the participants created the following strategic vision for The U.S. shipbuilding industry to be implemented over the next decade.

The Participants' Vision for the U.S. Shipbuilding Industry

We market, design, produce and support ships and other products that utilize similar processes, profitably, with greater value to our customers and in less time than anybody else in the world.

The industry has achieved a significant share of the global market and hence is recognized as a key sector of the U.S. national economy.

This industry recognizes that in order to ensure long term growth it must build better and better products at lower and lower prices and create opportunities for customers, owners, employees and suppliers.

We are:
A world leader in innovation and implementation of information, process and people management. We consistently achieve cycle times at least 10% better than the best in the international market place.

We are:
An industry which prudently reinvests in itself to support continuous improvement in process and capability.

We are:
Enterprises and business units where management and operating teams continually reconcile their processes and products within this vision.

We are:
An industry that creates an environment which supports cooperation among customers, owners, employees, suppliers, and within itself.

We are:
Proactive in applying technology to improve our products and processes.

We are:
A self sustaining. non-subsidized industrial base.

We are:
An industry which attracts, retains and motivates talented people.

We are:
An industry which delivers what it promises.

We are:
Constantly sharing knowledge with other industries to our mutual benefit.

We are:
Committed to constructing a single ship as cost effectively as multiples.

We are:
An industry that competitively services ships regardless of where they were built.

We are:
An industry which is continually re-inspired by its heritage.

Creation of a Strategic Vision for the U.S. shipbuilding industry was the most ambitious, debated, analyzed, and creative portion of the participants' activity. Under the non-interventionary guidance of the facilitators, the panel members covered every conceivable aspect of the future direction of marine production, management, and competition; debated every possible strategic scenario that might catapult the industry into a position of leadership in providing customer solutions in the future; weighed multiple approaches that might ensure capturing the majority of the participants' predictions of where customer values, technologies, economics, and marketing requirements and opportunities are leading. On almost every point, there was a minority view but rarely an unresolved conflict. Thus, the Strategic Vision was adopted and 'bought into" by the participants.

The next step in the project brought the participants from visionary definition to specific recommendations. After creating their strategic vision for the shipbuilding industry, the participants identified well over 200 specific options including options for yard aids which could be pursued to fulfill it. After culling, 83 specific initiatives to be undertaken were recommended. These were organized into 12 policy objectives and then put in priority order.

This process forced a "bottoms up approach" on the participants in arriving at these policy objectives. Through vigorous use of brainstorming, the participants offered every conceivable action that they could think of that might be essential to implement the strategic vision and every possible support action that might be useful in implementing that vision. As evidenced in the final output, these recommended actions are sound, pragmatic, hard-hitting activities, actions, organizational adjustments, and strategic changes that, if implemented, ensure that the U.S. shipbuilding industry will "win" by fulfilling the strategic vision.

Once the participants had exhausted every possible required action for vision implementation, these actions were then grouped into objectives. The objectives were not labeled until a common thread was found whereby several recommended initiatives suggested an objective. By clustering to derive objectives rather than determining objectives and then assigning actions, the workshop's thinking was not constrained by form. Any possible action that a participant thought essential for American shipbuilders to claim and fulfill the strategic vision came out on the table and was woven into the policy objectives. The grouping of these initiatives into objectives then helped to integrate the initiatives around common mission style goals. The participants then weighed the various views of their strategic importance based on priority/urgency and feasibility in order to produce a "feasibility matrix." Then they assessed the stage of accomplishment of each objective industry-wide in order to produce a "diagnostic matrix." Both matrices are presented later.

The objectives and initiatives are first presented here as the workshop weighted them. The labels given to the objectives are purposefully brief and self explanatory. The initiatives following each objective are specific and able to be acted on - these actions are each considered necessary to fulfilling the stated objective but may not be all inclusive. See Table 1 for a brief characterization of objectives and initiatives:

Table I. Numbers of Initiatives per Objective

I	Process Definition	I5
II	Integration	8
III	Product Model Exchange	5
IV	Product/Process Model	5
V	Computer-Aided Acquisition and Logistic Support (CALS) Implementation	II
VI	Human Resources Innovation	7
VII	Follow Up	5
VIII	Industry Cooperation	9
IX	Expert Systems	5
X	Configuration Management	3
XI	Generic Modular Ship	5
XII	Service Life Support	5
	Total:	83

OBJECTIVES IN PRIORITY ORDER

I. Process Definition

Our objective is to identify the best processes, tools and measurements which support our vision. We define processes as combinations of people, equipment, raw materials, methods, and environment our industry is striving to bring together to produce our products or services.

It is pointless for us to automate existing processes which perpetuate the current inadequate state of our industry in world competition. Instead, we need to document and analyze current practices to define new processes which will lead to our vision.

For example, money should be invested first in systems that improve the competitive position of shipbuilding in the United States. Benchmarking our competitors overseas represents such a system. Then priorities need to be set based on which processes are on the critical path toward that end.

II. Integration

We can and must bring the improved processes together in a very connected way. This integrated approach will flow from design to implementation through a computer simulation of our ship as a product. The approach treats process and product as system elements and management tools. This computer simulation model must be accessible to all concerned. The complete picture of our processes must include:

- concurrent engineering

- business operations
- overall planning
- yard personnel
- all relevant databases
- proposal and detailed estimates
- work accomplished and reported.

III. Product Model Exchange

For integration to work, information must flow freely throughout our industry. Suppliers to shipyards must have access to project data promoted by good interchange standards and organizations dedicated to maintaining them.

IV. Product/Process Model

Standardized definitions and information shared by the industry must be captured to document the information required to manage.

V. CALS Implementation

Such integration and clarity of definition lead to the replacement of conventional drawings with digital product models, which provide customers with on-line access to product data and encourages vendors to supply product data with their products. Thus customers, suppliers, and life cycle needs are brought together effectively and efficiently.

Note: Concurrent with this workshop, a relevant systems analysis of U.S. commercial shipbuilding practices was published (7).

VI. Human Resource

Best processes and product models cannot effect the continuous improvement needed to realize our vision. All of us in the system must be empowered by a new philosophy and understanding of computer aids, concurrent engineering, and team building.

Per his statements on public radio, research by Lester C. Thurow, Dean of M.I.T.'s Sloan School, indicates that by the end of this century people and their skills will *be the only significant source of competitive advantage in global competition.*

VII. Follow Up

We must conduct additional workshops like this one with senior management to build in follow up to this action plan. Also we must develop critical experiments and an industry wide project for reaching our goals.

VIII. Industry Cooperation

In spite of the self destructive intensity of competition between and among our organizations forced by the narrow pursuit of a single and "impoverished" customer, we must create:

- a national consortium for software
- databases of valid knowledge
- customer/producer councils
- leadership forums
- mechanisms for sharing information
- centers of excellence
- assessment and communications nets.

IX. Expert Systems

Computer systems which capture the experience of ship designers and shipyard managers can and should be developed. Parametric ship design concepts and management decision modeling tools can greatly facilitate our planning and manufacturing.

X. Configuration Management

We must apply the methods of configuration management to our industry. We must both understand and design computer systems which clearly document and maintain valid knowledge of our processes.

XI. Generic Modular Ship

We need to build a national library of reusable design modules to the parts level of detail. This may require consortiums of Navy and private shipbuilders for commercial ship production with modular designs for both military and commercial ships possibly being produced in the same facility.

XII. Service Life Support

We must develop a new ship repair strategy using advanced technology. New construction methods must be extrapolated to fulfill lifetime support applications including automated crew training aids and shipboard computer aids for at sea operations.

FEASIBILITIES

The Feasibility Matrix was one of the most revealing products of the advanced management workshop process at the workshop. Participants were asked to rate the feasibility of each objective according to the following scale:

0 Conceivable
1 Theoretically possible
2 Technically achievable
3 Innovative
4 Producible
5 Risk worthy
6 Unfamiliar process
7 Early Adopters
8 Organizationally viable
9 Widespread acceptance
10 Routine.

The feasibility rating is displayed on the horizontal axis and the priority/urgency is displayed vertically.

The matrix below (figure 2) startled the participants as it gave a shocking picture of the condition of our industry. The information captured from the participants indicates that there is a major barrier to moving critical objectives from implementation to production. The industry has little difficulty developing and demonstrating new methods and technologies; it just can not incorporate them readily! This "wall" represents a management mind set reluctant to embrace emerging team building strategies. This barrier is holding back not only applications of better computer systems to the industry but also the whole industry's effectiveness and efficiency as a whole.

Half of the objective critical to the advancement of our industry are blocked by this wall:

- Process Definition
- Product Model Exchange
- Product/Process Model
- Industry Cooperation
- Configuration Management
- Service Life Support.

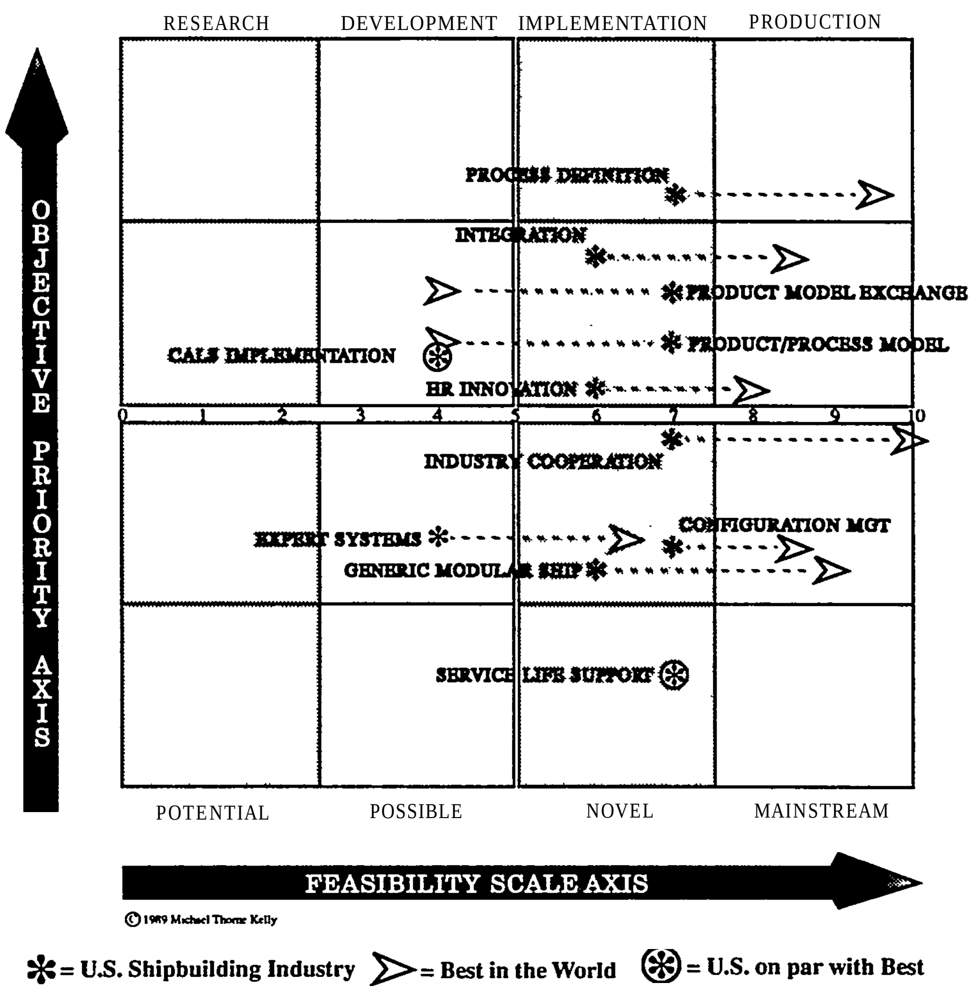

Figure 2 Feasibility Matrix

The first three of these are of the top four in priority!

All 12 objectives are portrayed on Figure 2. Behind each of the objectives are detailed initiative action items. When this conference is reported in final form, the first year of research will be published in the standard report format for NSRP. At that time each of the 83 initiatives will be detailed together with all of the pertinent interviews of participants.

DIAGNOSTIC

The workshop participants were asked to focus on the current stage of performance of the objectives within the whole industry using the performance stage scale illustrated below. The priority axis is the same as for the feasibility matrix.

The diagnostic matrix illustrates the optimum path for accomplishment. It shows the relationships between objectives as they contribute to fulfilling the vision and how well these priorities are managed.

Figure 3 below shows the priority order of action necessary to move the U.S. shipbuilding industry into viable global competition through computer technology and changes in management practices. It graphically illustrates the fit between priorities and actual use.

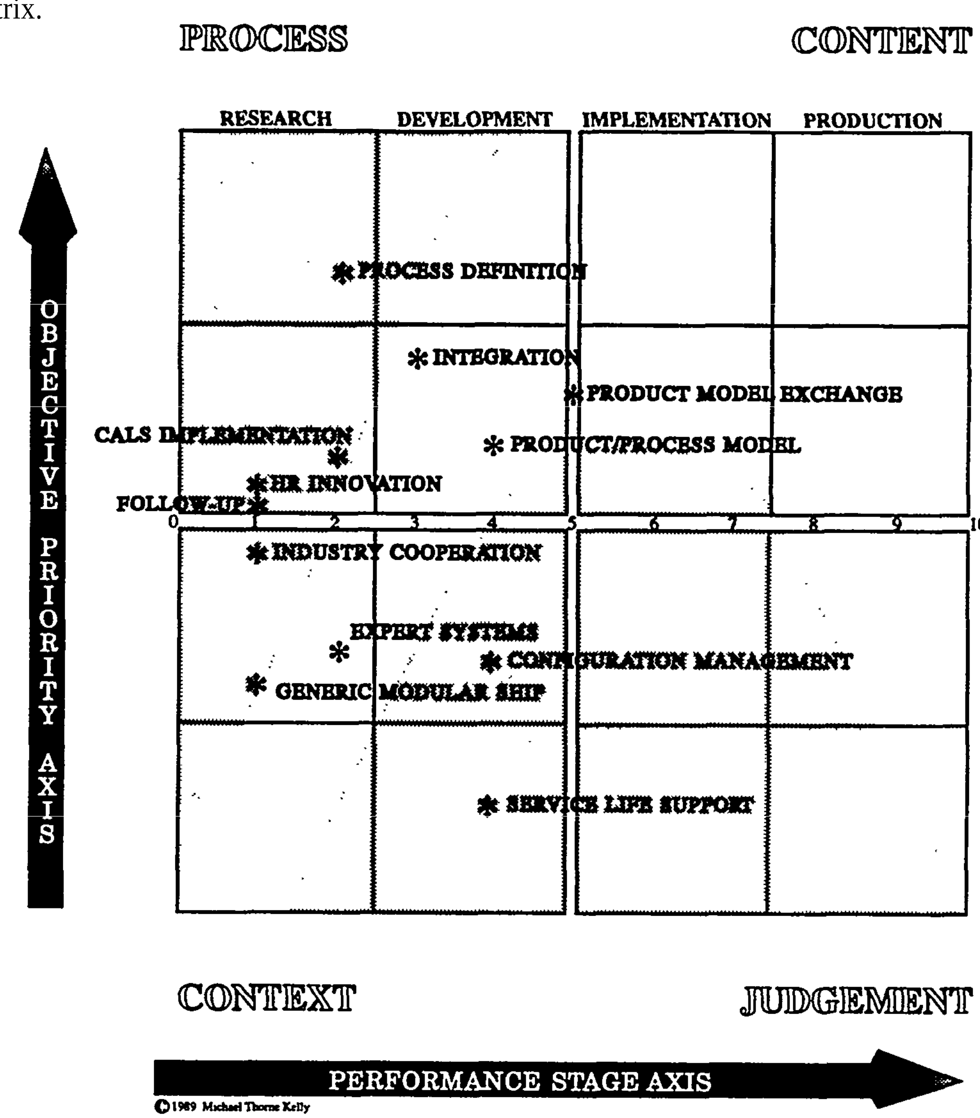

Figure 3 Diagnostic Matrix

The meaning of the performance stages is described below as presented to the participants.

Performance Stages

0 -----YOU HADNT THOUGHT OF IT UNTIL NOW.

---YOU ARE THINKING ABOUT IT: WONDERING IF IT WILL ACCOMPLISH WHAT YOU INTEND.

2 -----YOU ARE THINKING SERIOUSLY ABOUT IT; EXAMINING ITS IMPLICATIONS AND FEASIBILITY.

3 -----YOU HAVE BEGUN PLANNING. IF THIS WERE A BUILDING IT WOULD BE LIKE HAVING THE ARCHITECT BEGIN THE DESIGN.

4 ---YOU ARE OPERATIONALIZING IT. AGAIN USING THE BUILDING ANALOGY, YOU NOW HAVE YOUR PLANS, SO YOU ARE CALLING THE CONTRACTOR, THE CEMENT COMPANY, AND ETC. AND ARRANGING TO HAVE THEM CARRY OUT THEIR TASKS AS REQUIRED BY THE PLAN.

5 -YOU ARE READY TO INITIATE IMPLEMENTATION.

---THE PLAN IS BEING IMPLEMENTED BUT AS YET YOU HAVE NO FEEDBACK ABOUT WHETHER OR NOT IT IS PROGRESSING SUCCESSFULLY.

7 ----THE PLAN IS BEING IMPLEMENTED AND YOU ARE GETTING POSITIVE RESULTS BUT AS YET YOU ARE STILL INVESTING MORE THAN YOU ARE GETTING.

----IMPLEMENTATION HAS ACHIEVED INDEPENDENT MOMENTUM you HAVE PASSED THE BREAK-EVEN POINT.

9 ----YOU ARE MANAGING IMPLEMENTATION. YOU HAVE CREATED AN EFFECTIVE, EFFICIENT SYSTEM THAT REQUIRES THAT YOU Do NOTHING MORE THAN OVERSEE ITS OPERATION.

10----PRODUCTION PROCEEDS EFFORTLESSLY ALL OF THE IMPLEMENTATION IS DELEGATED LEAVING YOU READY TO UNDERTAKE YOUR NEXT PROJECT.

The lighter area on the matrix is the path of optimum accomplishment. When activity and resources are properly aligned with priorities, objectives fall on this path. According to the consensus of all participants in this advanced management workshop, the U.S. shipbuilding industry has fully 75% of its activity off the path for achieving the strategic vision.

When objectives are behind the path, like Process Definition and five others, it means that there has been insufficient assessment of the risks, rewards and demands involved relative to achieving the strategic vision. When things are ahead of the path, Service Life Support and Configuration Management in this case, resources have been prematurely allocated.

According to the facilitator, this is the graph of an industry which will be repeatedly blind sided in its attempts to fulfil the strategic vision unless crisis measures are taken to thoroughly assess the effectiveness of the objectives that are behind the path and clear the way for developing them. It will also waste resources on efforts that, though perhaps successful in themselves, will hit a glass ceiling and fail to contribute to accomplishing the vision.

His comment was that “This is a catastrophe in the making. This is the graph of a start-up industry where no one really knows what they are doing or why. The fact that the shipbuilding industry in this country is two hundred years old and encumbered with all the unforgiven sins of the past foreshadows a repeat of the U.S. steel industry’s staggered pattern of collapse.”

COMMENTARY FROM PARTICIPANTS

As indicated in the discussion of the feasibility matrix, all participant comments on initiatives have been recorded. A synopsis of their comments follow.

1. What is your assessment of the vision relative to where we are today?

Everyone agreed that the vision represents a worthy goal for the industry and is based on a relatively accurate overall assessment of the industry.

Repair and ship overhaul is the near term future of the industry, not new construction.

Unless there is general cooperation to support this vision as a Computer-Aided Acquisition and Logistic Support effort the industry is doomed.

It is a great vision but culturally the industry is not prepared to understand it much less implement it. Moreover there are concrete structural impediments to realizing it.

Perhaps the industry can make progress in its thinking if the industry is considered now to be simply one of many defense contracting industries tailor making ships for the Navy.

The vision is an affirmative vision, an aggressive one without question, but when you recognize that there are people in the industry capable of supporting steps toward it right now, it is not impossible at all, more a question of will than substance.

2. How can our strategic plan strengthen the Computer-Aided Acquisition and Logistic Support (CALS) initiatives?

The CALS initiatives could use a lot of strengthening. After six years we do not even have a plan.

"It appears to me that what is planned and will be planned as a result of this workshop will feed right into that [CALS]."

Some questioned the relevance of CALS to commercial shipbuilding: however most agreed that it is relevant to government regulation. It is certainly relevant to the computer tools because it makes the data exchange and makes sure the government does not ask for stuff they really do not need or will not use, as they have a tendency to do.

Implementation of CALS is a means to achieve some strategic notions that we discussed. In addition I think the strategic plan probably would be a help to implementing CALS because it tends to address the issues that CALS does not deal with. It establishes a context for CALS.

The strategic plan could function like a bridge between CALS as technology and shipbuilding as business. "There might be some commercial experience that might trim some stuff out of CALS. The proof of that pudding is interest in buying CALS."

3. What constraints need to be eliminated to strengthen the industry?

"The main thing that I think is holding us back is a lack of understanding of what the potential is that is at hand right now. The potential is to eliminate the false work, the retrieval effort, the transformation effort that occupies so much of our everyday working efforts."

We are constrained by lack of training, lack of enthusiasm among a gutted user community and by lack of management support.

There is a concern that unless progress is made on a broad front one area will advance at the expense of other areas.

The industry is locked into a drawing with pencil and paper mind set which dictates that you haven't finished the design process until you have a drawing to use as the essential basis for activity. We have to break out of that mold and accept a digital mode for product models. We need to see the drawing as something that needs to exist only in the computer.

The functional similarities across companies are much greater than our differences, but our perceptions of self interest drives us to block the progress possible through collective agreement. The government is maintaining segments of our industry but not supporting the industry as a whole to make substantial leaps forward.

It is difficult for us to relate to each other because we lack a common terminology.

The industry thinks that the Navy is the only game in town and consequently is starving in the midst of global abundance. We need an Apollo style program to build commercial ships for the world.

4. What management attitudes need to be changed?

"Everyone must realize that information technology is no longer the domain of specialists. It is having a pervasive effect on all aspects of NAVSEA's business. Because of the current fiscal environment, the rate of change is becoming revolutionary. Everyone is involved!" (8).

"The old 'theory x' management style where a manager manages by intimidation is still prevalent."

"We have too many layers of management."

"I'm pretty optimistic about the way our unit is transforming itself - I just hope we can do it in time."

"I would focus on changing the attitudes of middle management rather than senior. Many of our middle managers, especially the ones who am real good at their job, because that is what they have been doing for along time, are hung up on the notion that that is the way God intended it to be done. I see that as our shipyard's biggest impediment. I would focus on middle management attitudes and there is no specific attitude that needs to be changed other than a willingness to change."

The industry is caught up in the attitude that all workers need a crisis to promote productivity. This palpable lie is worn out.

Management has to take the attitude of "What does it take to be profitable in the commercial business?" The question then is, "What are the appropriate computer tools for profitable commercial shipbuilding?"

5. What management methods hold the greatest promise for implementing this plan?

Total Quality Management provides an opportunity to create solutions as long as it is not presumed to be the solution itself. "The operating philosophy should be one of continuous improvement."

We need employee empowerment including trust in the knowledge of the worker to accomplish positive changes in the processes they know well.

Self directed teamwork leads to the kind of employee empowerment (at the process level) and motivation necessary to global competitiveness.

We need to identify and implement management methods which support faster cycle times, continuous improvement and more efficient use of resources.

Leadership needs to be taught at all levels of our business. Senior management does not understand the nature of leadership confusing it with authority. People on the shop floor are not training in leadership because they are expected to be followers.

6. What is the best approach to standards development for the industry?

"I have been involved with the data exchange standards and they sure have been painful. There has to be a better way."

Were the industry participants to collaborate on and finance standards the outcome would be positive.

"I think our strategic plan has to get the vision right first, we have to know where we are going. I think we have the foundation in the vision. Then we complete the analysis of best practice for a world class competitive commercial yard including identifying what tools are in that yard; informational, structural or physical tools. After that we decide which of those tools would be used across the industry. Then we standardize the tools that are in this new commercial / military shipyard. These are the tools, especially those tools that help, which are capable of migrating and communicating across shipyards."

Electronic Data Interchange is a viable approach to promoting standards in the industry.

CONCLUSIONS

So let's do it! Let us implement this action plan, because it leads us to take both short term and long term steps toward industry viability. Ultimately you cannot control what you cannot produce; therefore, production of many kinds of products is needed to not only sustain our economy but also to provide our children and grandchildren with options, Although shipbuilding represents a small part of the United States economy, it is a bell weather for complex heavy and high technology industry. Shipbuilding combines both factory line production and outdoor construction. Consequently and potentially our industry can combine the best practices of flexible computer integrated manufacturing with the best practices of complex outdoor projects.

We are not talking here about top managers alone. Middle management can be either a barrier to success or a powerful support in attitude and successful application of new approaches and technologies to this very old industry. Let us involve all levels of management in the process of keeping the ball rolling!

We can conclude that the participants in this initial study represent the problem in a most realistic manner. The message that stands out clearly from the knowledge bases assembled at the workshop: change the thinking of the shipbuilding industry and change it fast.

RECOMMENDATIONS

Let us get funded to do it! We have sounded this alarm and proposed 83 concrete steps toward improvement, but this is only a beginning. The Executive Control Board and the SP-4 Panel must keep the momentum of this project going. Without such support the follow up to the action items will be weak or lacking altogether. With support the action plan will lead to more persons committing to more effective actions to save American shipbuilding.

ACKNOWLEDGEMENTS

We wish all suppliers, designs, repairers, and producers of ships in the United States and Canada had contributed to this interim report: many have, however, and we hope all are included in the near future.

The -author especially thanks the David Taylor Research Center, the Panel chairs, and Newport News Shipbuilding for their crucial support and encouragement of this project. Heartfelt thanks to Dr. Michael Kelly, our skilled facilitator. The author also thanks the innkeepers at the Captain Daniel Stone Inn of Brunswick, Maine, for their patience and understanding: (Why does Dr. Kelly carry a bull whip?). And finally, great thanks to the participants and their bosses who worked so hard to arrange to be them amidst busy schedules and who worked so hard at the workshop itself.

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Microbial Biofilm Effects on Drag -Lab and Field

No. 3A-1

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ABSTRACT

Marine fouling on US Navy hulls causes increased propulsive fuel use and refueling frequency, and decreases ship range and speed. Modern antifouling (AF) coatings are effective against hard fouling for relatively long periods, but do accumulate marine microbial biofilms. Therefore, with respect to drag, the focus has recently shifted from hard fouling to microbial biofilms since even thin films can contribute significantly to drag.

Antifouling paints are being evaluated in the laboratory for drag minimization and are ranked based on drag performance with and without biofilm. All paints experienced increased drag after accumulating biofilm. Significant variations in drag and resistance to biofilm accumulation were noted.

Two full scale ship trials were also conducted on U.S. Navy ships to determine the effect of microbial biofilms on ship power and fuel consumption. A significant change in power consumption, ranging from 8 to 18%. was measured by power trials before and-after underwater cleaning to remove microbial biofilms from the hull. These data were compared to laboratory experiments.

BACKGROUND

The microbial biofilm, or slime layer, has been shown to increase hydrodynamic drag and therefore fuel consumption (1,21). About $500M is spent annually propulsive fuel for the United States Navy Fleet, of which about $75-100M is spent to overcome the hydrodynamic drag due to fouling.

Since the 1940's, the Navy standard antifouling (AF) paint has been Navy Formula 121 (F-121). This coating is 70% by weight cuprous oxide in a vinyl rosin matrix. F-121 has a widely varying service life prior to initial colonization by macrofouling organisms, generally considered to be from 7 to 30 months. This inconsistent performance is due to variability in coating quality, the many geographical locations where the ships are located, the seasonality of the marine fouling, and the pierside vs. at-sea schedules of the various units. The Navy found the F-121 service life was not compatible with the normal 4-6 year period between ship overhauls. In order to reduce the negative effects of marine macrofouling, the Navy has been conducting underwater hull cleaning since 1978 on all ships. In general a cleaning is ordered when the underwater hull is greater than 10% covered with macrofouling This operation utilizes Scamp a diver operated underwater cleaning machine which scrubs the hull with 3 rotating brushes. It is estimated that underwater hull cleaning saves about 6% of the Navy's fuel bill, or about $30M of the annual propulsive fuel loss due to fouling. More recently, however, research and development has responded to the Navy's need for a 5-7 year paint with the development of ablative AF paints. These materials were the first significant performance improvement over F-121 and were first applied to the entire hull of a Navy ship in 1981. The first ablative paints contained tri-organotin compounds as their primary antifouling toxicant. The organotin paints generally provided excellent performance, giving greater than 5 years macrofouling protection in most cases. However, environmental concerns and associated costs have discouraged the use of organotin *AF* paints by the Navy. Therefore, cuprous oxide containing ablative paints were developed and are now the materials of choice, having been applied to over 130 ships. Based on currently available Fleet data, about 70% of the cuprous oxide ablative AF paints in service are free of serious calcareous fouling.

Although modern AF paints successfully control hard fouling over long periods, it appears that all AF paints permit the attachment and growth of some microbial forms to ship hulls. Therefore, focus has recently shifted from the well-established negative effects of hard fouling to less severe but significant effects of microbial biofilms on drag. Loeb et al. (1) showed the significant contribution to drag of even very thin microbial films. It is thought that the increased surface profile and viscoelastic nature of microbial biofilms increase drag with respect to a smooth painted surface (3).

The exact relationship between microbial biofilms and drag remains to be defined, yet reducing their deleterious effects has become more important with the introduction of advanced AF paint technology. Some unanswered questions remain such as when and if microbial biofilms should be removed from AF paints, how to predict the drag characteristics of an AF paint, and how much an AF paint can contribute to drag minimization. This paper demonstrates through full-scale power trials and laboratory tests the degree to which marine microbial biofilms contribute to drag, and provides insight into potential solutions to the problems they cause.

MATERIALS AND METHODS - LABORATORY EVALUATION

Twenty-four candidate AF paint systems have been evaluated over a three year period (Table I). Each was applied to 3 duplicate 22.86 cm (9 in.) diameter, 0.3 cm (0.125 in.) thick steel disks. Surface preparation was accomplished by abrasive blasting with 90 mesh aluminum oxide grit with which a 50-75 micron (2-3 mil) profile was obtained. The disks were then either painted in-house or protected from corrosion and sent out to companies to be coated with candidate materials. The AF paints were applied as per manufacturer's specifications. If anticorrosion protection was necessary, formula 150 polyamide epoxy paint, MIL-P-24441, type 1 was used. Paint dry film thickness was measured with an Elcometer 256 gauge.

A friction disk machine (FDM) was used to evaluate disk drag (Fig. 1).

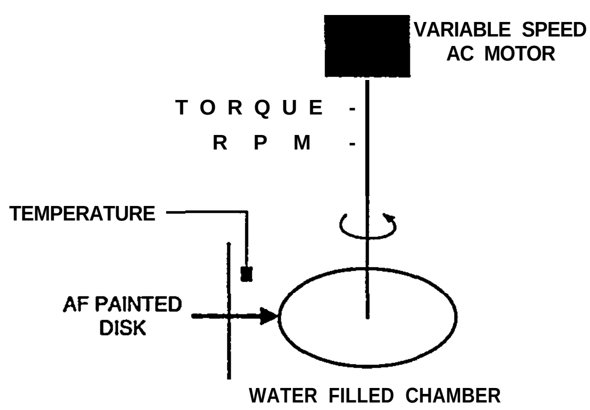

Fig. 1. Friction disk machine (FDM).

The FDM was powered by a variable speed alternating current motor which drove a shaft onto which a disk was mounted. Disks were immersed in a tap Water filled chamber during testing. A precision dynamometer installed on the motor shaft measured torque. The disks were evaluated in three conditions: 1) when freshly painted, when the paint was dry, 2) after 4-5 months exposure in brackish water, while slimed, and 3) after removing the remaining slime layer by gentle scraping with a rubber squeegee. Values of temperature, torque, and RPM were recorded for each disk at increments of 200 RPM from 700 to 1500 RPM and then at 200 RPM decrements to 700 RPM to complete the cycle. For each condition tested the disk was taken through this cycle one time except the post-exposure condition. At this stage the spinning action caused some debris and loosely attached biofilm to wash off the post-exposure disks, therefore these disks were taken through the cycle 700-1500-700 RPM two times to ensure equilibrium had been reached. In this case, only data from the second cycle was used in the final data analysis. Disks with significant amounts of macrofouling created too much turbulence in the FDM chamber. Therefore, these disks were considered to have failed and were not evaluated further.

After drag evaluation of the post-exposure condition, a light section microscope (Fig. 2) was used to determine the thickness of the remaining biofilm layer. A microscope coverslip was placed over the wet biofilm before taking a measurement.

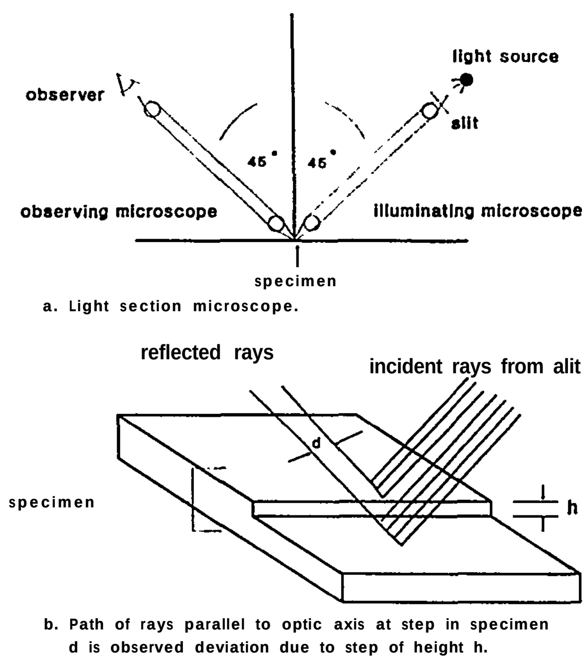

Fig. 2. a. Schematic of light section microscope.
b. Detail of light path at specimen.

Prior to and following the spinning of each set of three disks, a standard disk was run to ensure stable operation of the FDM and to correct for bearing drag. The standard disk was made of a titanium 6Al-4Va alloy with a known roughness (Fig. 3).

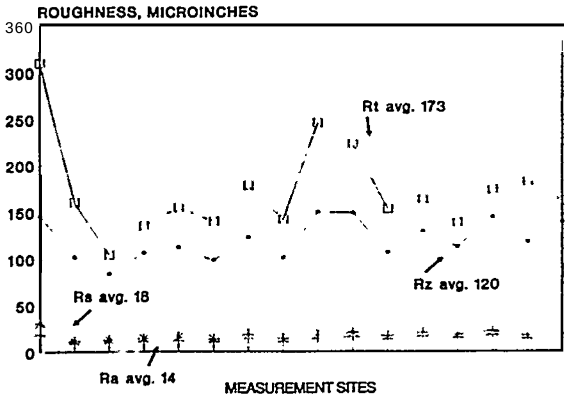

Fig. 3. Surface roughness of titanium disk number T-10.

MATERIALS AND METHODS - SHIPTRIAL

A full scale ship trial was proposed in an attempt to determine the effect of marine microbial biofilms on ship propulsive power and fuel consumption. It was desirable to identify a surface ship that was scheduled to receive an ablative antifouling paint in drydock, and to monitor the newly coated ship until a biofilm layer had been established. USS BREWTON, *(FF* 1071), a single screw frigate of the KNOX class, was nominated to be the test ship for the trial.

BREWTON, which is homeported in Pearl Harbor, Hawaii, was painted with an ablative AF paint containing both cuprous oxide and tributyltin oxide in October 1987. The ship had a 22 month biofilm on the hull at the time of the power trial. An initial underwater inspection by divers revealed the presence of a visible layer of microbial biofilm over the entire hull. In addition, there was barnacle fouling evident on the keel blocks and side blocks unpainted at the last dry docking, as well as on scattered small areas at the waterline. However, the vast majority of the hull was free of calcareous fouling.

The following sequence was conducted for the full scale power trial to determine the effect of biofilms on ship performance.

1. Initial installation of trial equipment. An Accurex™ shaft torsion meter was installed to measure shaft torque, from which shaft horsepower would be calculated. An RPM indicator was also installed. Various outputs from ship instrumentation including rudder angle, wind speed, turbine first stage shell pressure and ship speed from the electromagnetic log were to be recorded. The trial was performed on a "measured mile" course off the west coast of the island of Oahu. Motorola MiniRanger™ tracking equipment was used on both the tracking range and the ship in order to read ship speed to 0.1 knots and establish location.
2. Diver inspection of the underwater hull A Navy dive team conducted an inspection of the hull using color video and still photography to record the type and extent of marine fouling. In addition, a hull roughness survey was conducted with a British Maritime Technology (BMT) Hull Roughness Analyzer (HRA) at 50 locations on the hull. Also, the propeller was cleaned and polished to eliminate the effects of propeller fouling on the trial.
3. The initial power trial, The ship transited to the tracking range at high speed to assure that any-loosely attached biofilm and/or debris would wash off the hull. During the trial itself BREWTON was operated at speeds from 12 knots to full power, in 3 knot increments. Three reciprocal runs were made at each speed to negate the effects of wind and current. Williamson turns were made at the end of each run, so that ship rudder angle and heading had stabilized prior to the commencement of each run. Shaft torque, shaft RPM and ship speed were continually recorded for each trial run.
4. The underwater hull cleaning. The SCAMP™ machine was used to remove the microbial biofilm from the hull. Unlike a routine hull cleaning, the standard cleaning brushes constructed of wire rope were not used. Instead, brushes constructed of polypropylene bristles were used so as to, as far as possible, remove only the microbial biofilm and leave any calcareous forms on the hull. While some small barnacles may have been removed, a post-cleaned inspection showed that the majority remained on the hull.
5. The post-cleaned power trial. The post-cleaned power trial was conducted in an identical manner to the pre-cleaned trial.
6. The post-cleaned inspection. A post-cleaning diver inspection was conducted. Navy divers were utilized to inspect and photograph the hull and to record the hull roughness with the HRA.

DRAG CALCULATIONS - LABORATORY EXPERIMENT

The data indicated that microfouling has a measurable deleterious effect upon hydrodynamic skin friction, but *its* quantitative significance was not evident from data on systems as far removed from ships as spinning disks. In order to bridge this gap, the treatment of Granville (4) was applied to the data, which allowed interconversion of drag estimates among spinning disk flow and flat plate flow. The assumption was made that a long flat plate will generate a boundary layer similar to that of an actual ship. On this basis, ship drag over a range of speeds corresponding to the Reynolds number range achieved in the friction disk machine was estimated. The calculation proceeded by characterizing the drag increment of the experimental surface in terms of the quantity Delta B, which expresses the deviation of the frictional drag from that of a smooth rigid surface. Using this theory, the drag effects of microfouling observed with the friction disk machine have been transformed to the expected effects on a flat plate and are expressed *in* terms of Reynolds number (Re) and moment coefficient (Cm).

The values of kinematic viscosity and density of the tap water used *in* the chamber were interpolated from data taken from Saunders (5) and Weast (6) respectively. The confinement by the FDM tank walls reduced the measured Cm as compared to that of an unconfined disk. Both the Cm and Re were affected and were therefore multiplied by an appropriate correction factor to account for the confined chamber. A plate length of l00m (361 ft), which is representative of a real ship, was used for the flat plate conversion.

The final evaluation, therefore, compares the three treatments to the reference titanium: pre-exposed (painted), post-exposed (with microbial biofilm), and post-cleaned (with microbial biofilm removed). Relative increases in drag on a given paint system were converted to percent increase in drag and were used to rank coating performance.

RESULTS - LABORATORY EXPERIMENT

These experiments were conducted over three fouling seasons, with approximately 8 coatings tested per year. However, appropriate controls were included each year to correct for differences in biology and instrument variations. A reference disk was used frequently and controlled for changes in bearing drag and instrument variability. Overall variability in reference data was less than 2 percent over the three year period. In addition, a set of F-121 (standard Navy free association cuprous oxide coating) control disks was included each year and results were similar over the range of speeds tested each of the three years (year 1 (ll-13%); year 2 (14-21%); year 3 (15-17%).

Three replicate disks were prepared and tested for each coating. Within *any* one year the three replicate disks performed similarly (+/- 3% or less). Therefore, the data for the three was averaged. The graphs presented *in Fig.* 4 show the relation between rotational velocity, as expressed by (log) rotational Reynolds number (Re), and the drag coefficient (Cm) and are representative of the treatment applied to all disks. Coatings are ranked, however, based on a transformation of this data *into* percent increase *in drag* from the pre-exposed painted state to the post-exposed fouled state, therefore taking into account the initial drag contribution of the painted, un-exposed disk. The presence of microbial biofilms was shown to increase drag significantly in all cases. The range of drag increases is fairly broad. The rankings are presented in Table I, and represent data taken at about 25 knots.

Prediction of drag on 110m flat plote

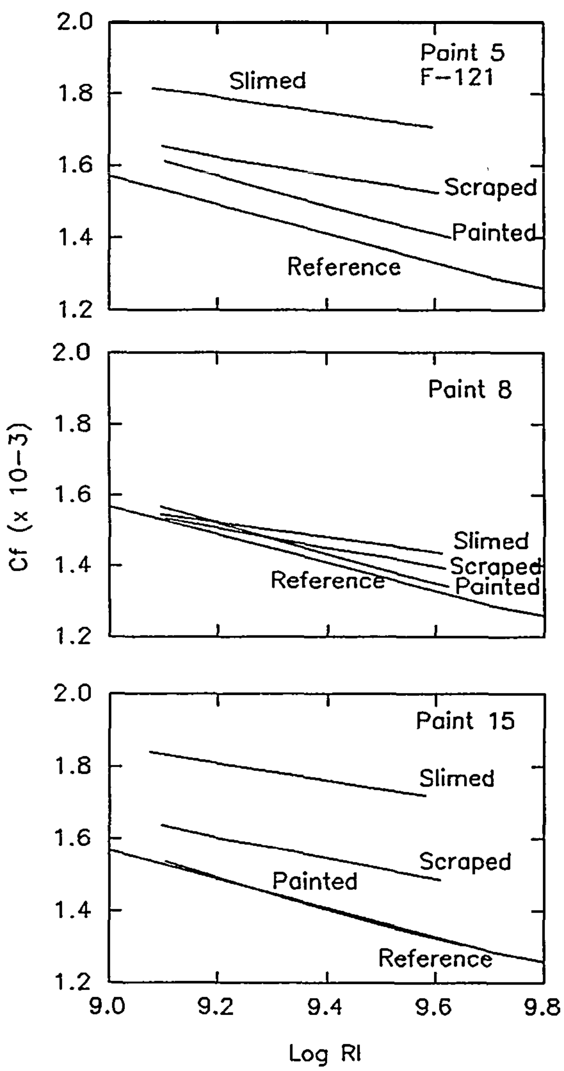

Fig. 4. Prediction of drag on 110 m flat plate.

Table I. AF Paint Systems Tested to Date

Pnt #	Description	Prf	Rank
1	Organotin copolymer	G	9
2	Organotin copolymer	G	6/7
3	Organotin	G	10/11/12
4	Cuprous oxide, non-ablative (F-121 A)	G	6/7
5	Cuprous oxide, non-ablative (F-121 B)	G	10/11/12
6	Cuprous oxide, non-ablative (F-121 C)	G	13
7	Cuprous oxide, ablative	G/P	17
8	Cuprous oxide, ablative	VG	1
9	Cuprous oxide, ablative	G	5
10	Cuprous oxide, ablative	G/P	19
11	Cuprous oxide, ablative	VG	2
12	Cuprous oxide, ablative	G/P	15
13	Cuprous oxide, ablative	G	14
14	Cuprous oxide, ablative	G	10/11/12
15	Cuprous oxide, ablative and booster	P	21
16	Cuprous oxide, ablative	G/P	18
17	Cuprous oxide, ablative	P	20
18	Cuprous oxide, ablative and booster	VG/G	4
19	Cuprous oxide, ablative and booster	P	22
20	Cuprous oxide, ablative and booster	VG	3
21	Cuprous oxide + ammonium sulfate	G	8
22	Copper flake	G/P	16
23	Copper flake + booster	F	23
24	Both copper and tin free	F	24

Based on percent drag increment, paints 8, 11, and 20 were the top three performers and paint 15 was the worst performer. The best three coatings showed only a 0-9% increase in drag over the range of speeds tested whereas the worst coating experienced 21-30% increase in drag over the same range of speeds.

Coatings were also placed into performance categories. Coatings which experienced 0-9% increase in drag were considered very good, 10-19% were termed good, and over 20% were poor coatings. In most cases, higher speeds coincided with larger percent increases in drag. Therefore, in some cases coatings fell into more than one performance category over the range of speeds tested (Table I). The majority of coatings tested fit into the good category with 10-19% increase in drag at about 25 knots.

The majority of coatings performed at about the same level as the Navy standard F-121. However, several coatings out-performed F-121 with respect to drag increment at about 25 knots. Although the majority of coatings experienced a drag increase of about 10-19%, there is room for improvement as evidenced by the top performers. It is expected, therefore, that future coatings development will take into consideration contribution of biofilm to drag.

Biofilm thickness measurements were inconsistent with coatings rankings. However, two of the top three performers did accumulate the thinnest biofilms. Overall, biofilm thickness ranged from about 1.2 mils to 2.7 mils, but there was a relatively large amount of variability within the three replicate disks for any given coating. This parameter, therefore, cannot be used to make significant performance characterizations.

Use of a rubber squeegee to remove remaining biofilm after evaluation in the post-exposure state reduced drag in all cases. In one case a paint returned to the pre-exposed level of drag after cleaning. This data may provide valuable data to ship operators when considerating cost effectiveness of underwater hull cleanings and lend insight into their effectiveness.

RESULTS - SHIP TRIAL

There was a significant change in BREWTON's powering characteristics after the underwater hull cleaning to remove the microbial biofilm. Fig. 5 shows a plot of ship speed vs. percent decrease in shaft horsepower required to achieve a given speed as compared to the pre-cleaned condition. There was an 8 to 18 percent decrease in power required to achieve a given speed after the microbial biofilm was removed. The ship's maximum speed increased after cleaning by about 1 knot. The hull roughness, as measured by the HRA, which is a peak to valley measurement over 50mm (2 inches), changed very slightly

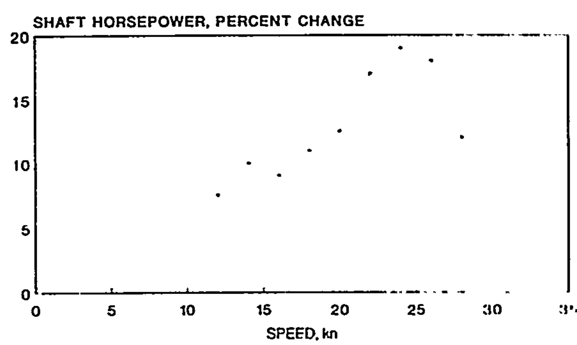

Fig. 5. USS *Brewton* power trial; percent change in shaft horsepower after removal of microbial biofilm.

(Fig. 6), with the mode of the population distribution changing the most.

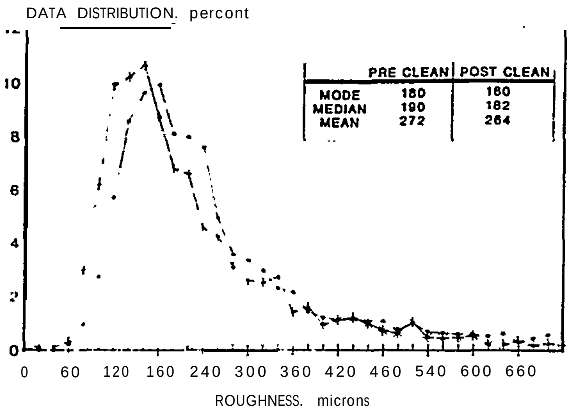

Fig. 6. USS *Brewton* hull roughness comparison pre-clean and post-clean.

When the ship trial data is compared to the laboratory data for the same class of paints, it is interesting to note that the post-cleaned percent decrease in torque to acheive a given speed is comparable (Fig. 7). BREWTON

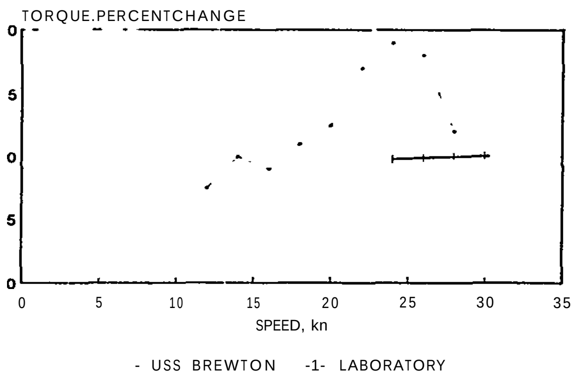

Fig. 7. USS Brewton vs. laboratory: power change after cleaning.

required about 18% less shaft horsepower to acheive a speed of 25 knots after an underwater hull cleaning to remove microbial biofilm. In comparison, the laboratory test shows approximately a 10% decrease in torque required to acheive a speed on the FDM equivalent to about 25 knots after the disk was cleaned. More trials are required before a strong correlation between laboratory and field data can be established.

Based on standard fuel consumption curves for the KNOX class, the economics of the cleaning operation were calculated. The $5600 cleaning cost, for example, would be paid back in fuel savings within a mere 14 to 24 steaming hours over the range of speeds tested (28-12 knots). This represents about 350-600 gallons per hour fuel saved, depending on steaming speed.

CONCLUSIONS

The exact relationship between microbial biofilm properties and drag has not been defined. However, in order to develop a better quantitative understanding of the range of properties and effects of marine biofilms, the hydrodynamic effect of microbial biofilms on the drag of antifouling coatings has been evaluated.
The results of the laboratory studies indicate that microfouling does indeed have the potential to significantly increase drag at length scales characteristic of Naval ships. The majority of the coatings tested perform as well as standard Navy coatings, but as evidenced by the top performers there is room for improvement.

In addition, the ship trial demonstrated that removal of a mature marine slime layer on USS BREWTON caused a significant change in the ship powering condition. However, it is not now common practice to conduct underwater hull cleanings on U.S. Navy ships solely for the removal of microbial biofilms. Improvements in cleaning techniques, biofouling detection, and paint technology will play a major role in determining the call for removing microbial biofilms. It seems possible to greatly decrease the drag penalty to ship operators if proper antifouling and hull maintenance measures are adopted.

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The First of a Class: Production of Large Military FRP Displacement Hulls

No. 3A-2

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ABSTRACT

The production of large FRP vessels for military missions is underway in shipyards throughout the United States. These vessels. in many cases, can be built to commercial standards using guidelines already in place. These guidelines are developed through interfaces with private industry and experienced production personnel. By binding the builder to a set of military specifications which detail the entire production process the vessel cost of construction is increased.

Commercial production process are practiced, which may not meet current standard Navy specification requirements, but produce a superior laminate quality. The Navy and industry can work in concert to produce a military procurement process which will allow builders to remain flexible enough in their production processes to continue to improve quality and efficiency. This can be accomplished through eliminating details of processes and parameterizing specifications to focus on laminate result:;.

INTRODUCTION

Swiftships, Inc., a builder of primarily aluminum and steel vessels was awarded a foreign military sales contract for the construction of two 29 meter (90 ft) fiberglass reinforced plastic Route Survey Vessels. This contract initiated construction of the first large FRP hulled vessel to be constructed by Swiftships. The major structural attributes of this twin screw trawler type vessel are single skin FRP hull of vinyl ester resin with E-glass reinforcement fitted with aluminum decks and superstructure.

This series of vessels is to be constructed for the Republic of Egypt for use as a Route Survey Vessel (RSV) for recording the underwater configuration of the coastal routes of Egypt. The contract was awarded with a Navy specification executed by the Supervisor of Shipbuilding, Conversion and Repair of New Orleans, LA.

Historical Development

The basic design of the RSV was established during a design contract prior to the issuance of the construction contract. The hull design and outfitting for ship services were based on the premise that standard commercial practices were to be used in the construction of these vessels to reduce the vessel cost in comparison to a standard Navy, military specification, driven combatant.

In following this idea, a commercial trawler mold was selected for the hull shape. The scantlings were designed to American Bureau of Shipping (ABS) Standards, but mission critical electronics and systems were tightly held to standard military specifications.

Vinyl ester resin was chosen as the FRP matrix with E-glass reinforcement due to its superior resistance to seawater absorption and blistering compared to more widely used polyester resin systems. The upgrade to vinyl ester resin is viewed as a long term quality and longevity investment for the RSV hull and structure which should offset the initial construction cost increase.

Although vinyl ester resins exhibit superior material properties in the laminates than do typical polyester resin systems, these properties were not taken advantage of in the scantling design calculations, as the hull was designed and reviewed based upon polyester resin system material properties as defined by ABS Rules lor Building and Classing Glass Reinforced Plastic Vessels (ref. 1). The resulting over design is viewed by the builder as an increased factor of safety on the hull.

Agenda

The contract was embarked upon in the typical fashion with the exception of one variation. The first order of business was to procure a lamination facility and tools, and obtain personnel to perform the hull layup.

The aluminum portion of the vessel was constructed simultaneously with the hull and joined upon completion of the two parts. A maximum amount of pre-outfitting was performed to minimize the welding around and above the FRP hull and to reduce the production costs.

An experienced subcontractor's crew was retained to perform the actual hull and scantling lamination to minimize the effects of the variables associated with the experience curve typically imposed upon a first time endeavor[1].

MATERIALS TECHNOLOGY

Material Properties

Due to the nature of vinyl ester resin systems laminated in large panels, as is required to produce a 29 meter (90 ft.) hull, the allowable "quality deficiencies" defined by typical Navy specifications, developed for smaller FRP hulls was not practical. Both the builder and the Navy were taken to task in the start up of the hull lamination process acceptance panels. Although the panels typically exhibited far superior physical strength properties and very low void contents (see Table 1), the panels were rejected due to the following requirement in the specification.

TEST	SPECIFICATION REQUIREMENT	TEST PANEL	PROCESS CONTROL PANEL
FLEXURAL STRENGTH	24 ksi min.	58.8 ksi	59.6 ksi
Flexural Modulus	$1x10^6$ psi min.	$2.4x10^6$	$2.5x10^6$
Tcnsile Strength	22 ksi min.	33 ksi	37 ksi
Interlam. Shear	1.0 ksi min.	6.95 ksi	7.28 ksi
Resin Content	50-60 %	57.1 %	58.7 %
Void Content	Less than 4 %	>0.5 %	>0.5%

TABLE 1

"There shall be no voids extending through more than one ply of laminate.

There shall be no voids larger than 1/2 inch in their greatest dimension.

There shall be no more than one void larger than 1/8 inch in its greatest dimension for each ply Of laminate in any 6 inch by 6 inch area; with a maximum of six in any 6 inch by 6 inch area. There shall be no more than three voids larger than 1/8 inch in their greatest dimension for each ply of laminate in any 12 inch by 12 inch area; with a maximum of 20 in any 12 inch by 12 inch area.

Laminate void content shall not exceed four percent."

After testing by the builder and evidence supporting the superiority of a laminate with occasional 1.27 cm (1/2 inch) voids to the requirements of ABS and the Navy, a deviation was accepted to change the allowable void distribution to the following:

"There shall be no voids extending through more than one ply of laminate.
There shall be no voids larger than 1/2 inch in their greatest dimension.
Laminate void content shall not exceed four percent."

These revised requirements are more in keeping with standard commercial practices per the intent of the contract.

The second hurdle which confronted the builder was the definition of secondary vs. primary bond. The Navy specification states that the entire hull, excluding doublers and structure, which averages some 16 layers, must be laid up as a primary bond. A primary bond was defined such that the lamination of the subsequent layer must be performed prior to 24 hours elapsed time from the catalization of the previous laminate. This stipulates all exposed layers of the hull, some 464.5 sq. meters (5000 sq. ft.) each, must be laminated upon every 24 hours. Considering the void restrictions from above, all 1.27 cm (1/2 inch) voids and greater on the previously laminated layer must be repaired in the same 24 hour time frame. Continuous hull lamination was virtually impossible, and certainly impractical.

The driving force behind the primary/secondary bond issue was the supposition that after a laminate cure of 24 hours, a subsequent laminate polymer bond would not be initiated with the previous laminate. This caused a lower interlaminar shear strength value in the final matrix. This phenomena is due primarily to the lack of continuation in the polymer chain reaction exhibited most frequently in general purpose (GP) or polyester resin systems.

In vinyl ester systems, the polymer chains are typically less effected by the cure time from laminate to laminate and will in fact bond very well between laminates laid upon each other after the initial layer has cured and exhibits barcol hardnesses of over 50. Barcol hardness is generally considered an indication of the level of resin cure.

The builder conducted research and testing, with the guidance of Supervisor of Shipbuilding, New Orleans, which exhibited minimal loss in interlaminar shear strength in vinyl ester laminates made with up to seven days elapsed between laminations (See fig. 1). In view of the evidence, the Navy accepted a deviation allowing the definition of secondary bond to be extended from 24 hours to a five day interval.

Interlaminar Shear Bond Test Results

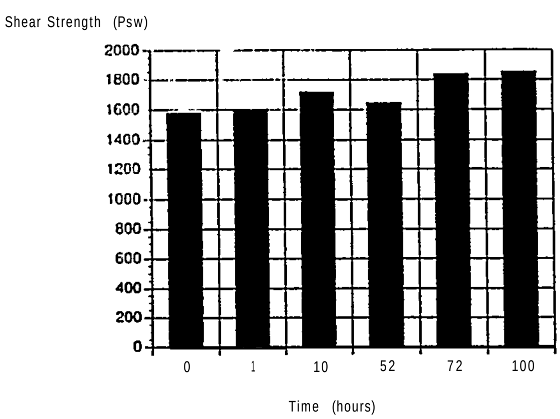


Figure 1

PRODUCTION TECHNOLOGY

Some restrictions present when laminating FRP structures include environmental control (temperature, humidity, and cleanliness) and materials handling and preparation. The environmental issues are taken to a grand scale when a shipyard is required to control temperature, humidity, and dust in a production facility around and inside a 30 meter (100 ft.) mold.

A single facility was chosen to produce the hull as well as fabricate and assemble all other FRP parts including bulkheads, foundations, battery boxes, etc. The environmental issue was easily solved in the areas of temperature and humidity by the addition of a Heating, Ventilation and Air Conditioning (HVAC) system and insulation in the building. All electrical boxes and tools were made spark proof to eliminate the hazard of explosion during the spraying of polyvinyl alcohol in the mold, to aid in hull release from the mold, or ignition of the styrene vapors omitted during lamination.

The most labor intensive portion of environmental control during production was the elimination of the dust caused during the nightly grinding of the laminate laid during the day. The laminate would be ground nightly to expose voids needing repairs and to assure a smooth, uniform surface for the next laminate. This was necessary to eliminate the possibility of bridging which could be caused by lamination over rough areas. Any evidence of ground fiberglass or resin dust on the surface to be laminated was quickly acted upon by the Quality Assurance (QA) inspectors and resulted in a hold on production until the area could be vacuumed clean of the "foreign matter." The excessive grinding and cleaning was beyond the normal requirements present in a commercial fiberglass facility.

To reduce the surface area which had to be ground nightly, a solution to grinding every layer was required. Laminate production was re-scheduled to lay the boat in sections with a two to three pair "shingle" lay up employed to reduce the cured surface area (See fig. 2). Since all laminate overlaps were to be no less than 5 cm (2 inches), and

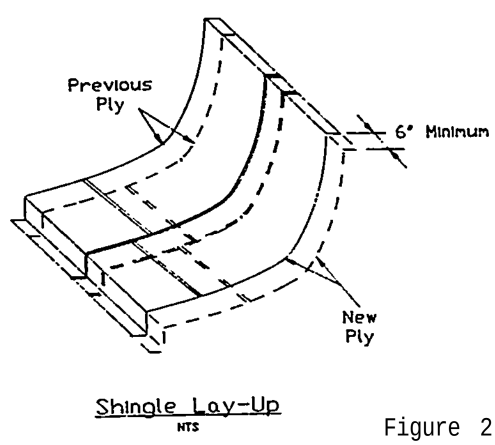


Figure 2

five pairs wet on wet is the maximum wet thickness recommended by the resin manufacturer to avoid excessive exotherm at the promoted level, three pairs wet on wet shingle was the thickest local laminate used.

Tied to the exotherm and number of wet on wet pairs variable was the promotional and catalization levels used to get the gel results from catalyst and promoter. The gel time of the resin used in the impregnator ideally should be long to avoid resin from gelling in the impregnator. Both the gel results and promotional system should be long and cold for the introduction of multiple layers of laminate on the work surface to avoid excessive exotherm. The gel *time* for lamination on vertical surfaces, which was the majority of a boat hull, should be short to prevent the resin from running out of the material as it stands on the hull sides.

Alternatively, a thixotrope agent can be added to the resin to retard run out, but it has adverse effects on the workability of the resin, again causing *voids.*

A compromise to the catalyst/promoter/ thixotrope ratio dilemma was reached which allowed the impregnator to keep from gelling up, the resin to adhere to the material until gelling and the laminate build up to be sufficient to reduce the necessary grinding and cleaning.

Education

Education of the builder, Supships and the Navy, in material properties was a great obstacle in the final acceptance of the lamination process prior to production of the first hull. Although the LPD was deemed acceptable by ADS for commercial standards. The Navy was educated in allowable quality characteristics to judge the acceptability of laminates and the material properties of laminates made using the builders production system.

The builder was educated in the fine tuning of resin systems, their catalyst ratios required for the impregnator versus the flow coater, the impregnator settings and speeds to achieve the required glass/resin ratios. Testing was also performed prior to hull layup to determine the material configuration acceptable in receiving rolls of *woven* roving/mat material so it would properly operate in an impregnator, and finding the proper promotional levels for the resin system in conjunction with various materials.

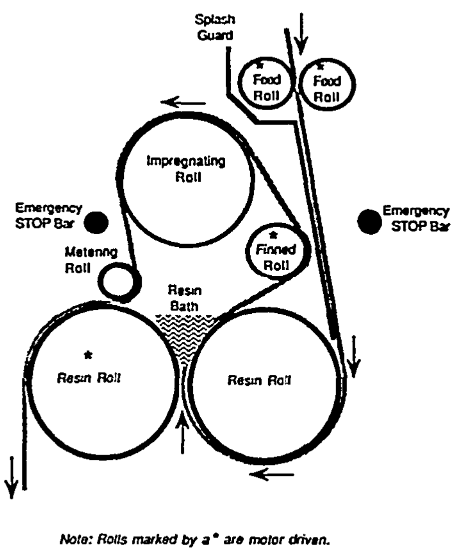
The impregnator was an indispensable tool to lay up a large vessel and was especially valuable in *the* lamination of large panels such as decks and bulkheads. The impregnator system has been used very successfully by builders such as Westport Shipyards for hard chine planing craft with few non-developable surfaces and also proved to be quite successful in the

TOOLS AND HARDWARE

The Use of Impregnating Systems

For the hull layup, an impregnator was used to lay a large volume of laminate to meet the primary bond parameters and to create a highly uniform laminate quality. A *seven* roll impregnator (ref. 2) was used to impregnate the material before it was laid to the mold and rolled and squeegeed into place.

The seven roll impregnator wets the material in the bath then presses the material through a series of rollers to insure proper bundle impregnation. The final set of rollers, with a micrometer clearance adjustment, squeezes the excess resin from the laminate to achieve the proper glass/resin ratio (See fig. 3).



VENUS-GUSMER'S NEW SEVEN-ROLL IMPREIGNATOR

Figure 3

HULL & SUPERSTRUCTURE PRODUCTION

Mold verification

Since the vessel was constructed using modular ship production techniques, the accuracy of the plans, lines and offsets were paramount. Unfortunately the mold used in the hull production was in existence prior to the RSV conception and the set of lines delivered with the mold were inaccurate. Although the complete contract design package was based upon an inaccurate set of lines, the hydrostatics and arrangements were virtually unaffected. The only portion of the design package that was truly impacted by minor variations in the mold geometry was the interface between modules, such as the hull and deck.

As the unmolded inside surface of the hull was uneven, due to the laps between adjacent layers of laminate, the inside dimension of the hull at deck edge could only be approximated, even after painstaking verification of the mold half breadths. This necessitated a hull/deck joint which would allow the required margins and excess in the deck (ref. 4). The deck joint as defined during the contract design stage was well suited for allowing excess. This joint will be discussed more extensively later.

Mold verification is a very important step in the design spiral and should be performed as early as possible in the production process. Slight variations in lines fairing have much smaller effects on naval architectural and systems engineering endeavors than on production engineering.

Mold & Laminate Materials Preparation

Before beginning the actual hull lamination, the mold had to be leveled both athwartships and longitudinally based upon the design weight and trim estimate. This task was accomplished by shooting the 1 meter (3 feet), 2 meter (6 feet) and 3 meter (9 feet) buttocks with a transit at each of the ten stations. Since the hull consists of only curved surfaces with no hard chines, and the lines were known to be inaccurate, the buttock lines were plotted against the existing lines to determine the actual declivity of the mold as it set on the supports and then leveled symmetrically athwartships.

Several benchmarks were then etched into the mold top and their relative heights, breadths and diagonals were recorded for resetting the mold after removal of the first hull prior to the lamination of subsequent hulls.

After the mold configuration was verified, the 2.44 meter (8 ft.) waterline was marked with 7.62 cm (3 inch) wax fillets on 3.66 meter (10 ft) centers, and at the port and starboard forward and aft perpendiculars. These fillets would define the hull trim and list when removed from the mold.

Prior to gelcoat the mold surface was prepared in the usual way by applying several coats of wax and a thin coat of Poly vinyl alcohol (PVA).

The laminate materials were kept in a dehumidified storage facility for ten days prior to use to eliminate the risk of moisture contamination affecting the sizing of the laminate. This assured proper resin wetting and bonding. The temperature of the material was kept a minimum of l°C (2° F) above the ambient temperature at a humidity of less than sixty percent to avoid condensation on the material after removal from dehumidified storage.

During the hull production process preparation of laminate laid prior to subsequent layup included complete sanding of the surface to remove any roughness which could cause bridging and voids. After sounding, repairs were made by grinding out the laminate containing the 1.27 cm (1/2 inch) or greater void using a minimum of twelve to one scarf. The laminate was then replaced with patches sized larger than the scarfed area as required by the Navy Specification.

The problem with this repair technique was that it produced a raised portion of laminate surrounding the perimeter of the ground area and tended to produce voids in the subsequent laminate because of bridging.

There was much speculation concerning the detrimental effects of a void. The Navy specification required repair of voids with their greatest dimensions of 1.27 cm (1/2 inch). These voids were generally only a few thousandths of an inch in depth occurring in a laminate of 6 cm (2 1/2 inch) overall thickness. Many fiberglass experts and consultants believe that the removal of the voids and surrounding Laminate, then replacing the removed portion by small patches, causes more disturbance in the matrix and a reduction of strength of the hull than the voids themselves. This belief was based upon the presumption that continuity in the glass fibers was more desirable than the reliance on the interlaminar shear strength of the resin between layers of E-glass.

The impregnator was an indispensable tool to lay up a large vessel and was especially valuable in the lamination of large panels such as decks and bulkheads. The impregnator system has been used very Sucessfully by builders such as West port Shipyards for hard chine planing craft with few non-developable surfaces and alS0 proved to be quite successful in the lamination of round bilged trawler type hulls as Well. Another notable asset of the impregnator is the lack of airborne styrene emissions because the resin is always contained, making for a more comfortable work environment.

Limitations of the impregnator include the lamination of hard to reach and work areas such as the stem and keel. Areas which historically involve high labor intensity to eliminate bridging and resin pools were not good candidates for the impregnator because the time involved to work the areas increased the likelihood of the resin "kicking off" in the bath. This caused a loss of the resin volume in the bath 19 liters (approx. 5 gallons) and the necessity to unload the cloth, dump the bath and clean the impregnator. With only one impregnator in operation, this exercise would completely stop production or necessitate switching to a hand layup technique. Additionally, the length of cloth already wet out during the cleaning operation was lost. This was typically a loss of 4.5 sq.meters (45 sq. ft.) of material.

The impregnator proved to be a high maintenance item with spare parts generally unavailable on a short lead time which necessitated stocking of spares. Great care was exercised in the daily cleaning of the tool as well as preparation prior to use, including charging the resin and catalyst systems and setting the roller micrometers.

Hand Layup Techniques

The only mechanical system used during the construction of the RSV for hand layup situations was a "flow coater".

The flow coater was used to wet out material with resin catalyzed at the gun head, then flowed in a stream, like a shower head as opposed to an atomized mist. As with the impregnator, styrene emissions are low with the flow coater because the airborne resin is not atomized subject to high velocities.

The flow coater was used to laminate the stem and keel as mentioned earlier and to laminate the longitudinal girders and stringers. It is interesting to note that the girders and stringers accounted for roughly one half of the lamination required on the vessel, so the use of efficient hand layup techniques was critical. The layup of the stringers, although accounting for half of the laminate, was the most labor intensive and where the experienced layup crew was the greatest asset.

Laminator Training and Qualifications

A Laminating Process Description (LPD) was prepared prior to start up and revised during the production of laminate qualification panels. The LPD was used as a training tool for the laminators and operators before any lamination took place on the shop floor.

Hours of safety training, including a complete review of the material safety data sheets (MSDS) for all the chemicals used, was conducted for all personnel. A major concern in any fiberglass facility is the cognizance of the fire hazards involved in lamination. Safety was stressed as a high priority throughout the construction process through numerous fire drills and an elaborate styrene evacuation system installed in the mold.

All personnel were required to produce laminate test panels which were then tested to verify the adaptability of the laminators and operators at achieving optimum glass/resin ratios and acceptable void contents.

Throughout the construction process all resin was tested in house prior to promotion for viscosity and after promotion for controlled gel time and temperature to insure proper promotion. Gel cup samples were taken from the mixing gun heads prior to daily production and on the event of 5-10 degree temperature changes in the production facility.

Test panels were laid up daily concurrently with hull lay up and tested in-house for glass/resin ratio, void content, flexural strength and modulus, tensile strength and modulus and shear strength to insure proper laminate quality. Complete testing was done in-house on test coupons from the hull as well as less frequent but regular testing performed by a certified outside laboratory to verify the in-house testing results.

Laminate Quality Requirements

Early in the production process it was established that virtually void free laminate could be achieved even during the lamination of large areas. The trade off for near perfect laminate, of course, was the time required to produce this quality of laminate versus the time required to make repairs.

Figure 4 illustrates that there is not necessarily a well defined relationship between area of laminate produced and number of repairs for a given area. Many variables exist which are not defined in this analysis, including lamination environment or area of the hull.

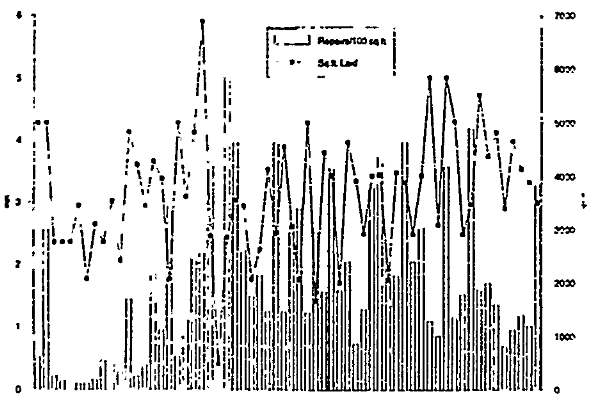


Figure 4

In order to progress the production process, an upper control limit of four repairs per 9.29 Sq. meters (100 sq. ft.) was established, based upon a requirement in the specification limiting the allowable percentage of hull repairs versus the hull surface area. A mean of two repairs per 9.29 sq. meters (100 Sq. ft.) was also established as a target goal. These numbers were conceived mathematically, but not based upon true statistical analysis of the process, because no data was available prior to start-up.

No lower control limit was initially set. The upper control limit was to be adjusted to two standard deviations, plus the mean after data was compiled during production.

After the start of production, however, it was realized that the goal of near perfect laminate, based upon the 1.27 cm (1/2 inch) void specification requirement, was counter-productive. Since the previous laminate was required to be ground anyway, the time required to grind out one or two pairs in a 5.08-7.62 cms (2 or 3 inch) diameter circle to remove a void became negligible. The final method of repair was made by placing the wet out patch on the scarfed area immediately prior to laying the impregnated material of the subsequent laminate. Although the repair process was an added responsibility to the laminators, the real impact was an adverse psychological affect on all of the crew. The attitude of the crew was adjusted to expect some repairs to be made; a lower control limit was determined realizing that some number of voids were acceptable.

Finding voids in laminate which the crew was expecting to be acceptable tended to cast a negative shadow upon the previous days work and built animosity between the production team and the quality assurance personnel. When the attitudes were adjusted to realize the goal was for only two repairs (average) per 9.29 Sq. meters (100 sq. ft.) and to maximize the production output, the tension between the workers and the people checking the work was eased. This resulted in a cohesion among the whole team, including the builder, the lamination subcontractor and Supships, that everyone was working towards an achievable goal; to build a high quality boat in an expedient manner.

As an effort to include Total Quality Management (TQM) techniques, high power spotlights were made available on the lamination platforms for the laminators to perform the quality control function on their own work. The laminate quality increased greatly for initial production of acceptance panels to actual hull lamination due to inclusion of quality control at the laminators level.

In the final analysis, based upon two hulls, it is shown in Figure 5 that the common goals of all players had been achieved, and a sense of pride in quality workmanship on everyone's part was established.

Installation of Internal Structure

All of the stringers and longitudinal girders were laid up as continuous while the transverse members were intercostal. The sequence of producing the stringers and girders, with the exception of the solid laminate girders in way of the integral fuel tanks, was to fit non-effective structural foam shapes into the hull and laminate some number of layers upon them, secondary bonding the laminate to the hull as bonding angles.

The fitted foam shapes were bonded to the hull with syntactic foam produced by working microspheres, milled fibers and resin into a putty. Although, the syntactic foam had much better physical properties than the non-effective structural foam used 130 g/cc (eight pound per square foot) polyurethane, the Quality Control Inspectors insisted on a "close and accurate fit" between the foam shapes and the hull, minimizing the use of syntactic foam bedding compound. This interpretation of the Navy specifications caused much work and rework in the fitting of the unlaminated foam shapes in the hull, even though all of the structural integrity and strength was derived purely from the laminate which was to be laid upon the shapes. A more reasonable commercial specification from which the QA inspectors could work from would reduce the labor involved on fitting the foam.

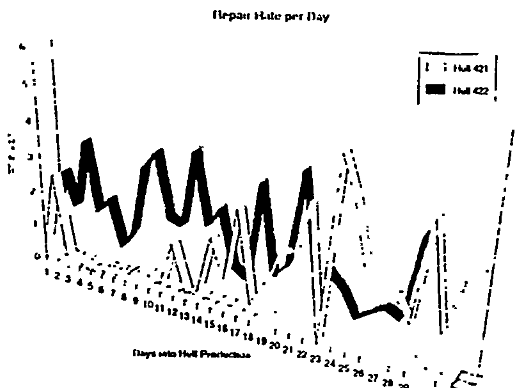


Figure 5

After the lamination of the longitudinal structure. the prefabricated transverse structure was installed and attached using bonding angles.

All prefabricated components were constructed with excess and all joints were designed to allow for some adjustment to be made when the parts were assembled.

An example of joints designed for the assembly of prefabricated parts is the aluminum to FRP main deck to hull joint, detailed in Figure **6**.

The 1.27 cm (1/2 inch) thick aluminum shelf was fabricated concurrently with the deck, removed from the deck and attached to the hull. Keeping the frame spacing close and accurate during the shelf installation was painstakingly controlled, but the variances in transverse alignment were not critical because the deck plate could be trimmed to land upon the shelf with the desired overlap.

Experiments were conducted to the satisfaction of the inspectors and engineers to verify the ability to weld on the aluminum in the proximity of the fiberglass hull without creating thermal damage to the FRP. A source of research (ref. 5) conducted from steel to FRP joints was used for guidance prior to performance of the tests. The pre-outfitted main deck and superstructure was landed on the hull after the below deck level pre-outfitting was accomplished.

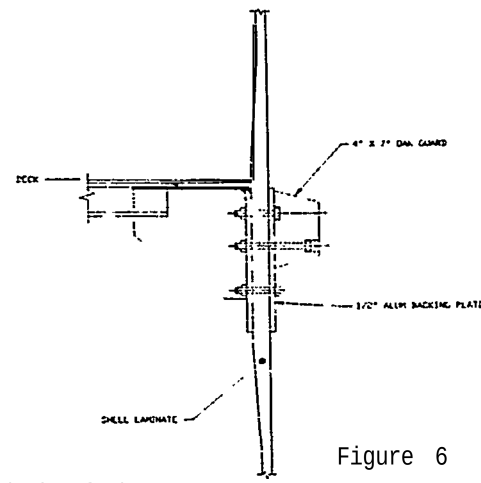


Figure 6

CONCLUSION

Process of Continuous Improvement

Total quality management was practiced throughout both hull lamination processes, and improvements were made on the process, but the inflexible specifications limited the efforts of the builder to produce a quality product at a lower price. Although the specifications can be changed through the use of deviations and waivers, the effort required to bring about the acceptance of the changes is enormous. All specification changes must be reviewed and accepted by at least three governing bodies, Naval Sea System Command (NAVSEA), (Seabat) and Supships.

In lieu of writing a binding set of specifications to define the intricacies of the FRP production process, perhaps an alternative would be to let the builder produce a product which meets minimum parameters in the laminate, such as void content, strength characteristics and glass to resin ratios, with the builders own processes and at the builders own risk as is required by ABS. This scenario would heighten the advantages of using the process of continuous improvement by allowing slight changes in the process based upon real time innovations and techniques. The customer would still receive a product which meets the objective - a hull of sufficient strength and quality to perform the assigned mission.

This would be analogous to the production of an aluminum hull. Instead of the Navy or Supships monitoring and inspecting every phase of the aluminum plate and shape production at the mill, they accept the mill certification as proof that the aluminum has been produced acceptably. Instead of the inspectors overseeing every facet of the hull and deck welding, inspecting every pass being laid down and all areas of the weld prior to local backgouging and weld preparation, the final welds are inspected and sample welds are tested.

Summary

The contract to build the RSV was awarded to the builder for two reasons. The first reason being that the Egyptian Navy required the vessels to perform the assigned mission. The second is the United States of America funding was earmarked for a U. S. yard to help stimulate the U.S. economy.

In essence, the RSV requirements are simply to provide a platform to transport the electronic gear necessary to perform its mission. This platform should be able to move at a specified rate, have all of the necessary safety equipment for any emergency and have the sea keeping ability to provide an environment acceptable to the electronic equipment and survivability in a given sea state. All of the above requirements, with the exception of the speed, are covered through other regulatory body requirements, such as ABS or U.S. Coast Guard.

The Navy specification should include, as a minimum, the parameters required by the mission, speed, sea keeping, approximate vessel size, range and consumption. Commercial regulatory requirements, such as ABS and Coast Guard, should be referenced to assure proper construction of the craft. In lieu of the production processes being defined by committees, production personnel with hands on experience should be responsible and accountable. Commercial standards should be enforced, based upon industry wide acceptance.

This would integrate more fully with the second reason the contract was let, the stimulation of the the U. S. economy by promoting shipbuilding in the U.S..

The premise that U.S. shipbuilders are incapable of producing vessels which are capable of fulfilling military missions without strict guidance of the Navy is limiting the capability of U.S. yards to compete in the world market. These limitations are due partly to the inflexibility of binding Navy specifications which severly retard the use of the process of continuous improvement and the integration of real time, state of the art technology. The lack of flexibility of Navy specifications carried from contract to contract over the years are the result of the effects. of bureaucracy and its inherent momentum which makes change difficult. The Navy has many sharp minds with helpful ideas to aid builders in becoming leaders in the world shipbuilding market, but the current fixed structure inhibits change.

In the age of shrinking military budgets and increasing social programs to promote business development, the requirements placed upon U.S. shipbuilders to increase yard overhead to support logistics requirements and perform non-essential tasks to comply with sometimes unapplicable specifications are counter productive.

The free enterprise system should be allowed to work in the realm of military spending where tasks are performed to add value to a product rather than exercised to meet specifications.

Both of the objectives of the RSV contract were fulfilled: the Egyptian Navy has the tools required to support their mission and the U.S. economy was stimulated through jobs. The process, however, could be more efficient to allow the production of commercial craft to commercial standards which fit the military mission required throughout the navy procurement process. This would not only ease the burden on taxpayers for the final product, but also streamline production processes for U.S. shipbuilders which would allow them to once again compete in the world market and allow the U. S. to reclaim its position among the premier shipbuilding nations in the world.

LIST OF ABBREVIATIONS

ABS - The American Bureau of Shipping
FRP - Fiberglass reinforced plastics
GP - General Purpose
HVAC - Heating, Ventilation and Air
MSDS - Material Safety Data Sheets
NAVSEA - Naval Sea Systems Command
PVA - Poly Vinyl Alchohol
QA - Quality Assurance
Rsv - Route Survey Vessel
Supships - The Supervisor of Shipbuilding and Repair
SEABAT - Naval Ship Combat Sciences & Engineering Services Conditioning
TQM - Total Quality Management

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Can U.S. Shipbuilders Become Competitive in the International Merchant Market? No. 3B-1

Jorgen Andersen, Visitor, Burmeister & Wain Skibsaerft A/S, and **Cato F. Sverdrup,** Visitor, Burmeister & Wain Holding A/S

God must have been a shipowner. He placed the raw materials far from where they were needed and covered two thirds of the earth with water.

[Erling Naess]

ABSTRACT

This paper begins with an assessment of the future shipbuilding market in order to evaluate if there is a basis for conducting attractive business.

Having concluded that the market forecast looks interesting, at least for the efficient shipbuilders, the paper goes on to evaluate if U.S. shipbuilders have the potential to become competitive.

Finally, specific suggestions are offered as to how U.S. shipbuilders can become competitive.

INTRODUCTION

It lies implicit in the title of this paper that U.S. shipbuilders are not competitive. This is evidenced by examining the meagre orderbooks of U.S. shipyards. The situation is serious and aggravated by the announced cuts in naval construction.

The first question that comes to mind is: Why are U.S. shipyards not competitive?

- is it due to subsidies?
- Is it low productivity?
- Is it the bureaucracy of the U.S. regulatory authorities?
- Is it too high prices for materials?

The list of questions can go on.

Answers to these questions have been and are presently being offered by many individuals and organizations, and have been and will be widely published.

This paper will also address the questions, but in the context of proposing answers to a set of more fundamental questions concerning the future:

"Will the shipbuilding market be attractive?"

if the answer is affirmative:

"Have U.S. shipbuilders got the potential to become competitive?"

and if the potential is there:

"How do U.S. shipbuilders become competitive?"

THE MARKET FORECAST

If a man will begin with certainties, he shall end in doubts; but if he will be content to begin with doubts, he shall end in certainties.

[Francis Bacon (1561-1626)]

As the purpose of building ships is to make money, let us look at the expected market for this Business Sector.

As in other industries, the balance of supply and demand determines price levels which in turn have a major influence on the potential profitability of shipbuilders.

The major factors influencing the demand/supply balance are shown in the following simplified model, figure 1.

economic growth	yard facilities
transport work	contraction/ expansion
existing fleet	productivity
age structure/ scrapping	subsidies
ships on order	perception of the long term future
fleet efficiency	financing availability
rules and regulations	political behaviour
shipowner behaviour	
political behaviour	
DEMAND	**SUPPLY**

Fig. 1. Factors affecting the Demand and Supply for Yard Capacity

On ***the demand*** side, the following questions should be answered:

- how ***big*** is the demand?,
- how does the demand ***vary over time?,***
- what types of ships will be in demand?, and
- in which ***size ranges?***

The forecast future growth in industrial production in the Organization for Economic Cooperation and Development (OECD countries), is shown in figure 2.

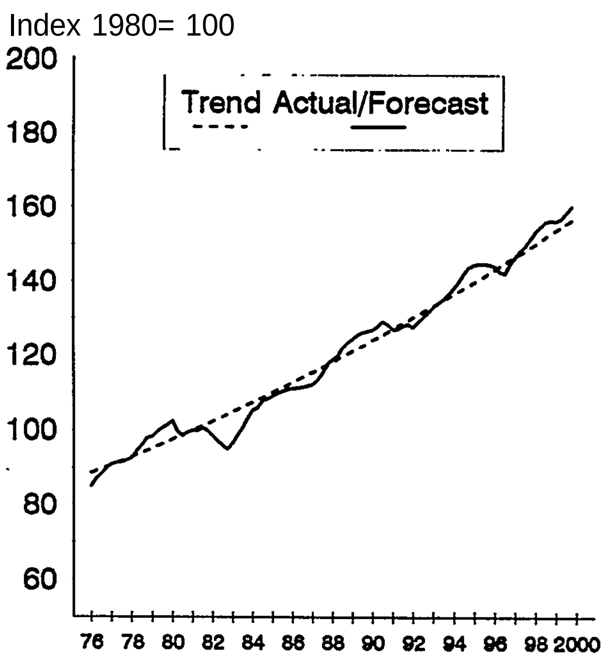


Fig. 2. Industrial Production, OECD (1)

The expected growth rate trend is 2,5 percent per annum.

The anticipated global seaborne transportation generated by the economic activity is shown in figure 3.

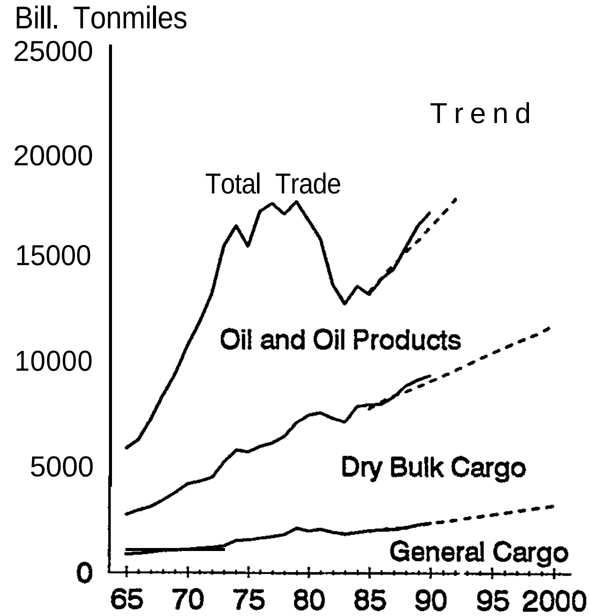


Fig. 3. Global Seaborne Transportation (1)

This transportation requirement, together with scrapping and trend towards larger ships, is expected to result in the following pattern of contracting and deliveries of newbuildings - figure 4.

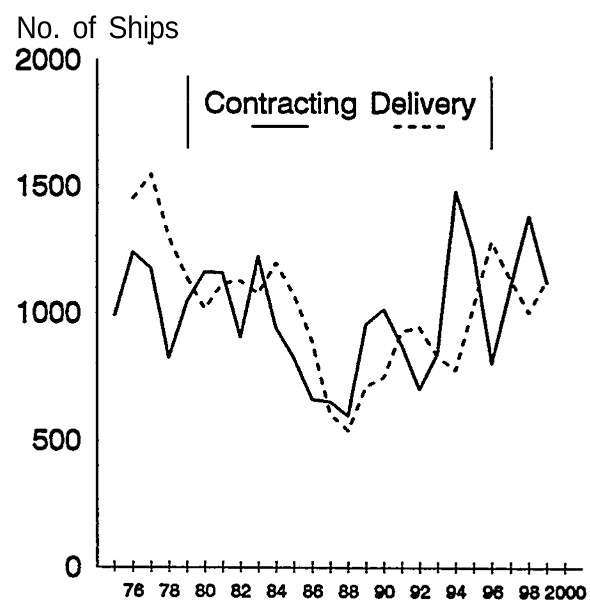


Fig. 4. Contracting and Deliveries of Ships above 2.000 DWT. (1)

It is estimated that the requirement for various types and sixes will be as shown in fig. 5.

	Aver. No. of ships per year
Tankers:	
Product	85
Crude < 150.000 dwt	
" > 150.000 dwt	90
Total	240
Dry bulk:	
104.000 dwt	125
40-80.000 dwt	80
>80.000 "	
Total	2
General cargo/container:	
<8.000 dwt	250
>8.000 "	200
Other types:	120
Total	1050

Fig. 5. Required No. of ships above 2.000 DWT during 1992-2OtKl (1)

The ***supply*** side of the shipbuilding industry has changed dramatically from 1977 to 1991, as shown in figure 6.

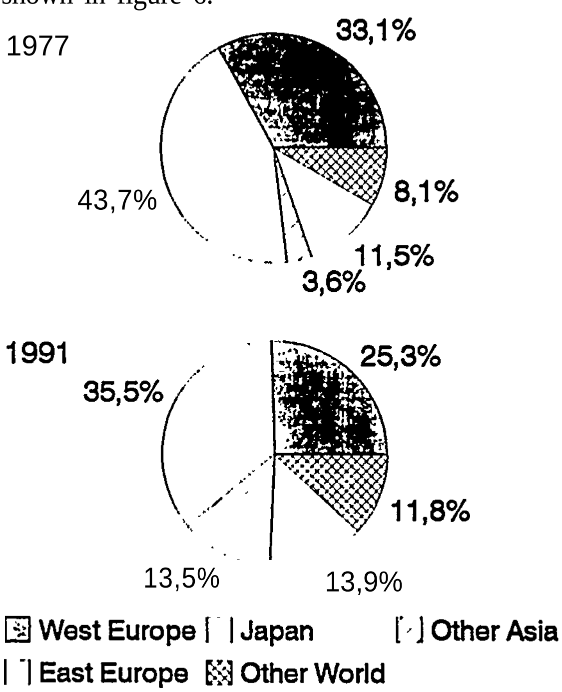


Fig. 6. Maximum Yard Capacity 1977 and 1991 (1)

The expected future capacity can only be a very rough estimate indeed, considering the following:

Japan has decided to eliminate the self-imposed "capacity ceiling".

Japan, S. Korea, Denmark and others arc implementing massive investment programs to boost productivity.

Japan has big problems in attracting younger qualified people to the shipyards and may have to import labor.

The Japanese and S. Korean workers are demanding shorter working hours and better conditions, which may diminish improved productivity opportunities.

The impact of emerging shipbuilding nations like China, Russia, 'East" Germany and Brazil is difficult to gauge.

The requirement for double hull tankers will increase the workload on the yards, and reduce output.

If prices increase to an attractive level then some yards will be tempted to increase capacity.

All together we expect the ***supply/demand*** balance for yard capacity is as shown in figure 7.

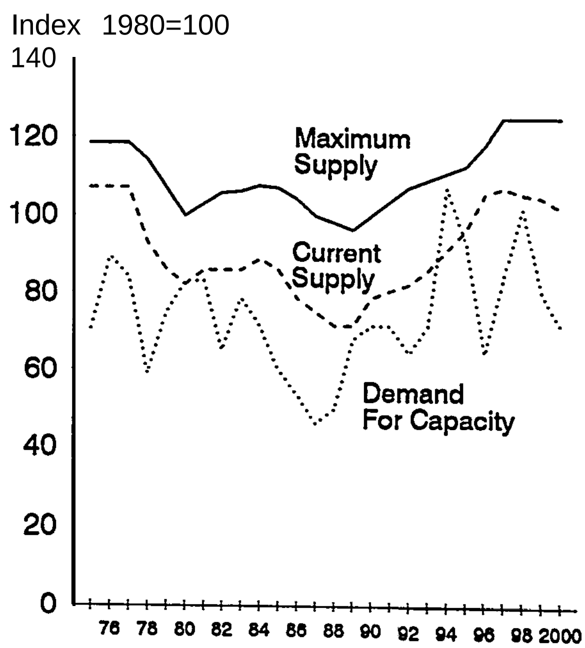


Fig. 7. Supply/Demand for Yard Capacity (1)

"Current supply" is the short term capacity which can fluctuate within a few years whereas the "maximum supply" is the potential capacity, which can only be changed over a longer time span.

The question of subsidies will also have an influence as to whom actually wins the orders.

No attempt will be made to answer this controversial and complicated issue here.

Not only is it impossible to accurately define and quantify the subsidies provided today in individual countries, but how should one evaluate the impact of:

The possible result of the current negotiations within the OECD working party No. ***5;***

- The "Gibbons Bill" (H.R.2056), if it is finally passed by the Senate and signed by the President;

- The approved subsidy to former East German yards of up to 36 percent until end '93; and

The future level of subsidy level within the EEC;

and other factors which will influence the level of subsidies?

One should not forget, however, that the subsidy level within the EEC has been reduced in recent years from almost 30 percent to the present level of 9 percent, and the elimination by the U.S. of its subsidies. We believe that this trend towards virtual elimination of subsidies will continue.

Based on all the above parameters, the estimated market price index for cargo ships, measured in current U.S. dollars, is as shown in figure 8.

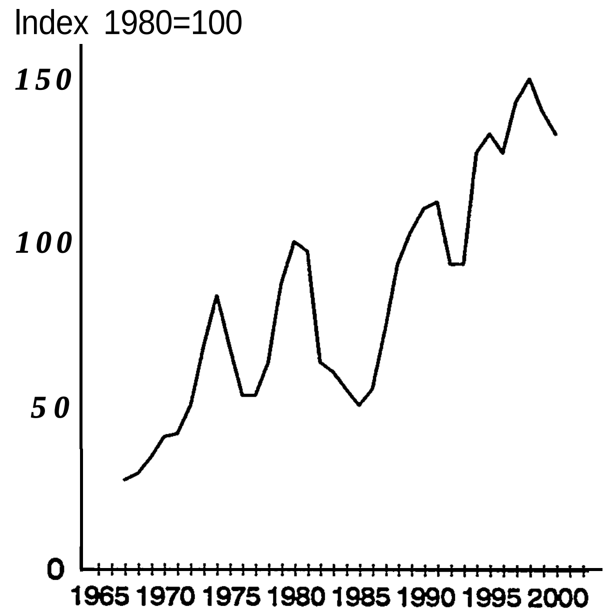


Fig. 8. Newbuilding Price Level - Past and Future (1)

In conclusion we believe that, at least for the next decade, the demand/supply situation will result in a price level which will be attractive to eflcient shipbuilders.

THE POTENTIAL

Seen from the outside looking in, we can identify three reasons why U.S. shipbuilders have the potential to take advantage of these positive global market forecasts:

1. Low labor rates,
2. Neutrality to currency exchange rates, and
3. Ability to develop and adopt new technology.

U.S. shipbuilders have low gross hourly labor rates as c-an be seen in figure 9

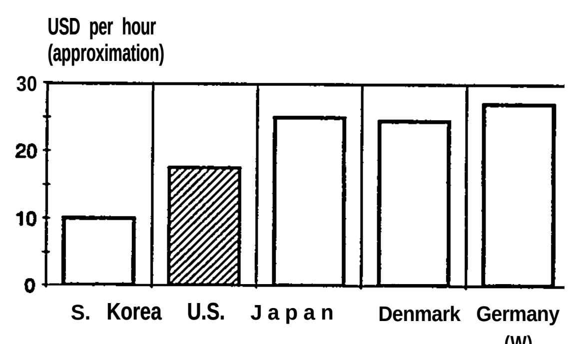


Fig. 9. Hourly Labor Rates

Japan, Germany (W) and Denmark, accounting for about 70% of the global output (in DWT), all have substantially higher (up to about 40% higher!) labor rates than the U.S.

As labor costs constitute about 15-20% of the total costs of building, this means that the U.S. shipbuilder will have a cost advantage of 6-8% if the comparison is made at the same productivity level.

Shipowners evaluate prices for ships in U.S. dollars, as most of their income and expenses are in U.S. dollars. This gives U.S. shipbuilders a great advantage since they are, by and large, neutral to the exchange rates of the U.S. dollar to other currencies. The only exceptions are the few instances where foreign equipment cannot be paid for in U.S. dollars.

The fluctuation of the U.S. dollar exchange rate in recent years can be seen from figure 10.

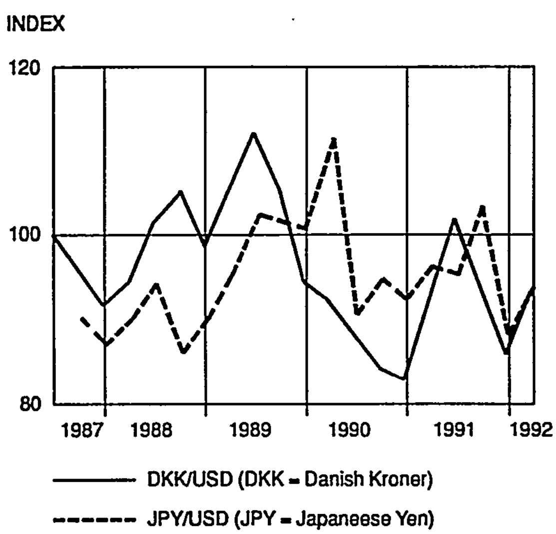


Fig. 10. Currency Exchange Rates

The exchange rate DKK/USD fell by 50 ***percent*** from January 1985 to January 1988.

These fluctuations mean that the prices quoted by yards not having a U.S. dollar based economy will fluctuate correspondingly. The following case from our own yard illustrates by how much at the present time:

Sales price of ship 60 million U.S. dollars.
No money spent in U.S. dollars.
Payment terms (month/year):

5%	6192	(contract)
15%	12192	
20%	2193	(start production)
20%	7193	(keel laying)
20%	10/93	(launch)
20%	12193	(delivery)

If we decided not to secure the U.S. dollar against Danish Kroner, we would, based on actual fluctuations within the last year, be running the risk of encurring a loss of up to about 12 m US Dollars equivalent to about 20 percent of the sales price.

As we are shipbuilders, not gamblers, it is our policy to secure the U.S. dollar, which can be done, but, depending on interest rate differentials, sometimes at a cost which comes off our bottom line.

Some non U.S. shipbuilders have solved the problem by only quoting in their own currency. Their success or otherwise depends on the price they are quoting and whether it is a buyer's or seller's market.

U.S. shipbuilders will not have these fluctuations and can enjoy a stable basis for their pricing.

Thirdly U.S. industry has a high ability to develop as well as to adopt new technology, concepts and ideas. The adoption of the Toyota "Lean Production" concept by some American automobile producers is a good example of this.

We conclude that U.S. shipbuilders have potential to become competitive.

HOW TO BECOME COMPETITIVE?

Annual income twenty pounds, annual expenditure nineteen ninety-six, result happiness.
Annual income twenty pounds, annual expenditure twenty pounds and six pence, result misery.

[Mr. Micawber in
David Copperfield]

Having concluded that the market will be attractive and that U.S. shipbuilders have the potential to become competitive, how can U.S. shipbuilders ***actually become*** competitive?

The approach taken is to ask:

"What would we do if we were to run a shipbuilding company in the US. building ships for the international merchant market?"

First we would make some qualified statements in relation to each major area.

Business Approach

Shipbuilding must be viewed in the long term. It is crucial to ensure high productivity and thereby minimal costs as ships are sold primarily on price. To ensure high productivity, shipbuilding must be regarded as an *industria1 operation,* and not as the conclusion of one or more one-off projects.

Marketing/Products Approach

Basically there are two types of shipbuilders.

One is the Seller of Capacity where an owner requires a ship defined specifically by that owner. The yard designs and builds that ship.

The other is ***the*** Seller of Products where the yard designs standard ships in accordance with expected requirements in the market and offers the standard designs to potential owners. Optional (but limited) extras are incorporated into the standard design for the individual owner, and the ship is built.

By being a Seller of Products, Series Production can be established, i.e.:

- A continuous production of a number of ships of the same type and size.

The minimum number of ships in a series should correspond to about the yearly number of launches from one building berth or dock.

Series production will ensure

Lower costs due to the repetition effect, rational industrial manufacturing and scale of production. Cost reductions, compared to one-off production, will result for material suppliers, subcontractors and the yard itself.

Figures 1 la and 1 lb show the reduction in manhours (production and design) experienced at Burmeister & Wain Skibsvarft A/S.

To ensure that the figures are comparable, adjustments for variations in specifications for different owners have been made.

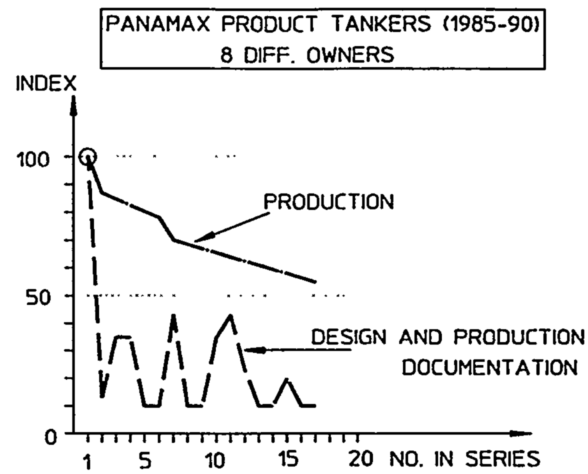


Fig. 1la. Manhour Curve-Series Production

These 17 product tankers were all double hull design.

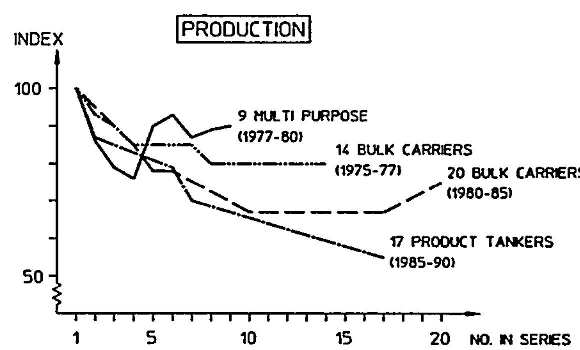


Fig. 1 lb. Manhour Curve-Series Production

The curve for the 9 multi purpose ships was heavily effected by special circumstances after ship No. 4 (the period 1979-80), as was the increase on the last ships in the series of 20 bulk carriers.

In a series of 10 ships, we would budget for the manhours on ship number 10 to be 30 percent less than the first ship.

Higher volume will be achieved through the same facilities using series production compared to one-off production.

Shorter throughput time and thereby less capital employed and consequently also reduced costs of financing.

Our U.S. company would be a ***Seller of Products*** and the Product Policy could read something like:

- to design standard ships required in the market in sufficient numbers for series production.

Marketing strategy would rest on a detailed knowledge of the world market's demand for ships. It is essential that this knowledge is constantly updated in order to anticipate and profit from future changes in the market. Market research and close cooperation between the Marketing/Sales functions and design will ensure that we have an advantage over the competition.

Present and future markets are characterized by a shortage of funds for buying ships. Few owners have the financial strength of the past, when often they were capable of paying cash for their vessels. It is therefore of vital importance to supply not only a good technical product, but also a financial package which ensures a competitive commercial product.

Our U.S. company would not undertake work for the Navy or repair/conversion work as this would have a negative influence on productivity.

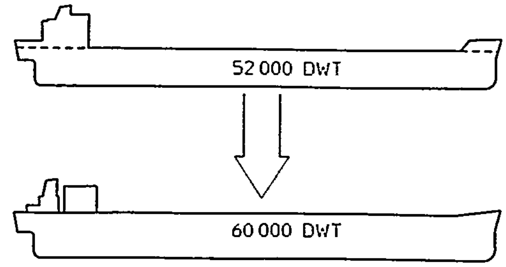
Design

The design function has the single biggest influence on productivity.

The design work will be carried out with great attention to ease of production and the utilisation of up-to-date Computer Aided Design (CAD) systems.

Simplification, standardization and ***production friendly design*** will be key words for the designers.

Examples of this are shown in figures 12a-12d.



	52.000 DWT	60.000 DWT
Forecastle	YES	NO
Poop	YES	NO
Box superstructures	NO	YES
Cargo hold length	SEVERAL	SAME
Cargo hatch sizes	SEVERAL	SAME
Double bottom height	SEVERAL	SAME
Modulized E.R.	NO	YES
No. of hull pieces	51.000	35.000
Weld length	248.000M	200.000M
Pipe length	38.000 M	26.000 M

Fig. 12a. Simplification of Bulk Carrier

Fig. 12b. Simplification (bow)

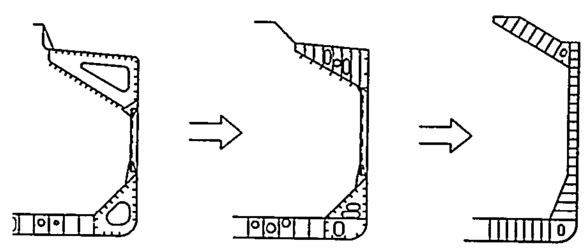


Fig. 12c. Standardization/Simplification

Fig. 12d. Production Friendly Curviture

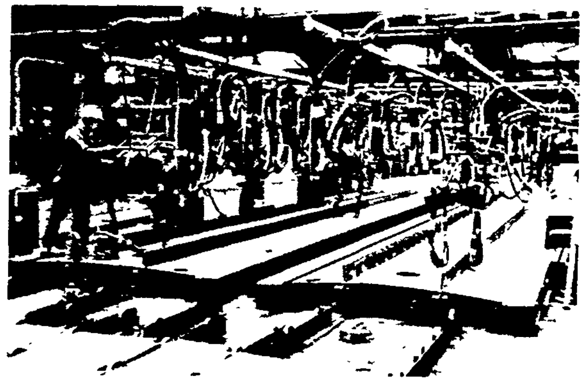


Fig. 13a. Flow-line for Sub-assemblies

Our U.S. company will employ its own designers, assisted from time to time by engineering companies in order to level out the work load.

Standards and Procedures

Our company will work for acceptance by the U.S. Coast Guard, and other U.S. authorities, of international standards and procedures in order to be able to procure equipment at international price levels and also to ensure speedy approval.

Some analyses have indicated that the additional costs of U.S. Flag Vessels, built outside the U.S., are on the level of 7-10 percent, and even higher figures have been suggested. Some Japanese yards have added 10 percent on the price to account for U.S. flag requirements.

Industrial Engineering

Industrial engineering disciplines will be applied in order to ensure:

1. efficient flow of materials,
2. selection of the most suited production equipment and processes, and
3. efficient design of flow-lines, jigs and fixtures etc.

Examples are seen in figures 13a-13d.

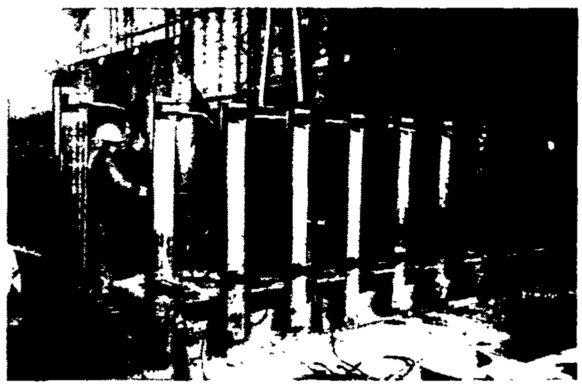


Fig. 13b. Jig for Double Bottom Blocks

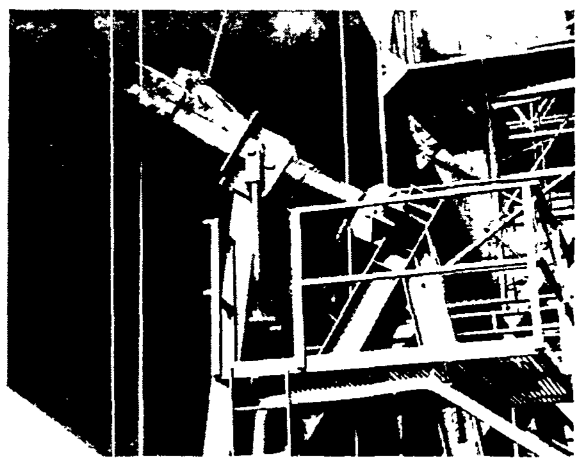


Fig. 13c. Hydraulic Jig for Joining of Sub-blocks

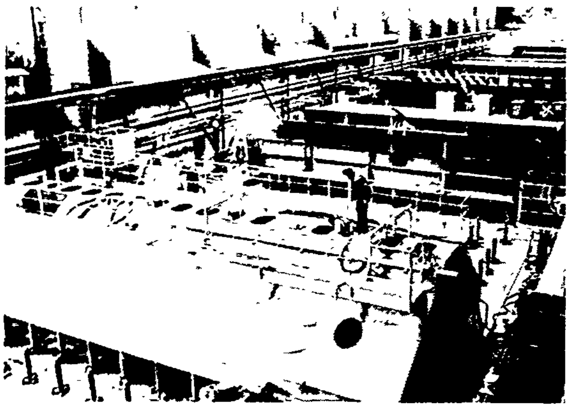


Fig. 13d. Flow-line for Block Fabrication

Our U.S. company will use the methods of shop fabrication of pipe and machinery packages as well as extensive early outfitting and surface treatment of hull blocks.

Incentives and Management/Employee Relations

Our U.S. company will apply Incentive Compensation Systems under the principle:

The higher the eficiency the higher the pay

and the management of our company will be conducted on the basis of "two way participation," informative and frank.

The above qualitative statements will be supplemented with the *quantified* productivity targets listed below.

What is required?

The required productivity is dictated by the competition in the market. The productivity target will consequently be to reach the level of the most productive competitors.

We will use two measures synonymous with productivity:

1. Manhour consumption (measured as manhours per compensated gross tons, MH/CGT), and
2. throughput time.

The most productive yards can today achieve 10 MHICGT and *it will be our U.S. Company's **target to achieve that figure within five yearsfrom start of operation.***

It should be recalled that U.S. yards today have a cost advantage of 6-8 percent at the same productivity level due to lower labor rates (ref. figure 9).

The target for throughput time is best illustrated by using a Panamax (dry) bulk carrier as a reference point.

For such a vessel, with LxBxD = 225m x 32m x 19m, and based on a volume of 5 vessels per year, the throughput time in production should be as shown in table 1.

Production phase	Duration (weeks)
Start steelcutting - keel laying	*23*
Keel laying - launch	10
Launch - seatrials	
Seatrials - handover	
Total	40

corresponding to abt. 9 months.

Table 1. Throughput time

A product tanker (double hull) with the same main dimensions should have a throughput time of about 10 months.

Due to the virtual non-existence of U.S. commercial shipbuilding since the early 198Os, it is not possible to make a reasonably accurate assessment of the present productivity level in U.S. shipyards. Therefore, it is not possible for us to evaluate exactly by how much U.S. yards have to improve in order to reach the levels of their most productive international competitors. Having said that, it is our belief that the gap is substantial.

There may be some U.S. shipbuilders reading this paper who can provide some statistics which we could use as a basis for comparison. We would welcome such a contribution to the debate. A debate which would be of great value to the U.S. shipbuilding industry.

Finally we believe U.S. *shipbuilders can **become competitive - if they are determined!***

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Cost of U.S. Coast Guard Regulations to the US. Maritime Industry and Coast Guard Initiatives to Reduce These Costs

No. 3B-2

Radm. A.E. Henn, USCG, Member, Lcdr. W.R. Marhoffer, USCG , Member

ABSTRACT

For a number of years it has been alleged that compliance with U.S. government regulations -- specifically those of the U.S. Coast Guard -- adds so much to the cost of a new U.S.-flag vessel that U.S. shipyards are rendered noncompetitive. An often touted figure is an average 15% cost increase due to ship design and constructions regulations. Case studies and owners' reports have also identified incremental costs associated with both reflaggings to U.S.-flag and the construction of U.S.-flag ships in foreign shipyards. It is the purpose of this paper to summarize past studies addressing the cost of regulatory compliance, discuss possible explanations for the variations between the conclusions of these studies, identify factors other than regulatory compliance which impact the competitiveness of the U.S. shipbuilding industry, and describe several recent Coast Guard initiatives to further reduce the already low cost of compliance with Coast Guard regulations.

INTRODUCTION

On January 28, 1992, President Bush issued a memorandum, "Reducing the Burden of Government Regulation," and in that connection called for a thorough review of both existing and proposed federal regulations. Accordingly, the Secretary of Transportation, through a notice in the February 7, 1992, Federal Register, requested public comments "on which Departmental regulations substantially impede economic growth, may no longer be necessary, or impose needless costs or red tape."

In response to the comments received, the Coast Guard undertook an in-depth assessment of issues related to costs imposed upon the United States maritime industries by domestic ship design and construction regulations for U.S.-flag oceangoing vessels. This assessment included consideration of whether the safety benefits associated with particular regulations warranted associated additional costs. This regulatory review focused attention on the old question of the extent to which the U.S. maritime industries are required to operate in a safety regulatory environment that adversely affects their international competitiveness.

With nearly all non-Jones Act U.S. commercial ships being built in foreign shipyards since the enactment of the Section 615 amendment (allowing U.S. flag operators receiving Operating . Differential Subsidies to purchase new vessels from foreign shipyards), there has been a collapse in both commercial shipbuilding activity and the marine machinery and equipment industry in this country. U.S. shipbuilders have little choice, in many cases, but to purchase marine machinery and equipment from foreign vendors. The Shipbuilders Council of America (SCA) has recently claimed that foreign manufacturers of marine machinery charge premium prices, adding an average 15% to the material costs of a U.S.-flag ship built in a U.S. shipyard, to cover the costs -- real or perceived -- of compliance with U.S. Coast Guard design and inspection requirements for U.S.-flag ships.

The United States government is seriously concerned about the continuing erosion of both the U.S.-flag Merchant Marine fleet in foreign trade and the U.S. Active Shipbuilding Base. With the number of U.S. Navy shipbuilding contracts expected to decrease over the foreseeable future, the U.S. shipbuilding industry will likely decline further unless it can compete successfully for commercial orders in the international market. Given this economic reality and government concern, it is appropriate to reexamine the effects of Coast Guard shio desiun and

The views expressed in this paper are those of the authors and do not necessarily reflect those of the Department of Transportation or the U.S. Coast Guard.

construction regulations on the - competitiveness of the U.S. maritime industries.

BACRGROURD

A number of studies and estimates addressing the incremental cost of construction to U.S. versus foreign shipbuilding requirements have been prepared over the past two decades. The following list contains summaries of some relevant cost comparisons.

+ The American Commission on Shipbuilding, created by Congress through the Merchant Marine Act of 1970, surveyed the U.S. shipbuilding industry in search of means to increase productivity and reduce construction costs. Its "Report of the Commission on American Shipbuilding" cites an addition of 3-5% of the cost of a U.S. flag vessel for compliance with the technical requirements of the Coast Guard, American Bureau of Shipping (ARS), and U.S. Public Health Service [1].

• In 1978 the Shipbuilders Council of America used the example of a 56,000 DWT product carrier with a cost of $45 million as a basis for obtaining estimates from member shipyards of the cost of compliance with selected government regulations. In its "Study of Cost of Federal Government Regulations on Shipbuilding Prices", the SCA reports that U.S. government regulations "necessitate an average 14 percent (11 percent to 16 percent range), add-on to shipyard costs on a value added (labor plus overhead) basis." [Z]

  Of the total $3,388,000 (approximately 7.5% of the estimated delivery cost) increase attributed to government regulations, $2,134,000 -- or 4.5% of the completed cost of the vessel -- is attributed to the technical requirements of the Coast Guard, ABS, and U.S. Public Health Service. The remainder of the cost increase was due to ordinary industrial regulations applicable to nearly all American manufacturing and construction industries, including employee fringe benefits mandated by the Longshoreman's and Harbor Workers' Compensation Act, the Employee Retirement Income Security Act, Federal Unemployment Insurance, and requirements of the Occupational Safety and Health Administration c31.

4 The SCA published a report in March of 1979 entitled "A New Direction for U.S. Maritime Policy." In addition to presenting a series of recommendations for a revised national maritime policy, the report cites the 14 percent add-on cost determined in the SCA's "Study of Cost of Federal Government Regulations on Shipbuilding Prices" discussed above and includes that study as an appendix. The SCA report adds that ". ..the conclusions herein stated need to be equated, in a comparative sense, with the cost of government regulations which may prevail in other shipbuilding nations of the world. No attempt has been made in this study to quantify any such differentials..." [43.

• Prior to the end of the Construction Differential Subsidy program in 1981, the U.S. Maritime Administration (MARAD) conducted cost analyses of foreign versus domestic shipbuilding to establish . appropriate subsidy levels. In a 1978 analysis prepared under a contract from MARAD, a major Japanese shipbuilder estimated the additional cost of building the first of three 1530 TBU RO/RO container ships to U.S. requirements to be $1,893,000. This amounts to 7.5% of the material cost and 4.9% of the total ($38.5 million) cost of the vessel.

  Of the $1.893 million additional cost for application of Coast Guard requirements, approximately 28% was attributed to lifesaving equipment and accommodations materials, 23% for mechanical equipment, 41% for electrical equipment, and 8% for additional design and labor.

• A MARAD-sponsored study of the total impact of government regulation, including reporting and administrative costs in addition to higher construction costs due to more stringent engineering standards, resulted in a December 1979 report entitled "Cost Impact of U.S. Government Regulations on U.S.-Flag Ocean Carriers." The report concluded that the additional cost directly attributable to discretionary requirements imposed by the Coast Guard -1 that is, not mandated by law or treaty -- amounted to less than one-half of one percent of vessel cost for both the 845 million tanker and the $54 million containership considered.

- In the bidding process for its U.S.-flag C-10 ContainershiDs. American-President Lines (APL) requested all bidding shipyards to quote on the bases of both a ship for U.S.-flag registry and a ship for Panamanian-flag registry. The cost differential between the U.S.-flag ships and "equivalent" foreign flag ships meeting classification society and international requirements, based upon initial Asian and European shipyard bids, rangqd from approximately $1.6 million to $4.5 million per ship, the average being $2.5 million per ship [5]. This initial bid premium of $2.5 million was significantly reduced, however, by cooperation between the Coast Guard, APL, and the German shipyards to facilitate use of the regulatory provisions for equivalence. APL concluded that there exists a 3-5% premium associated with construction of a U.S.-flag ship in a foreign shipyard.

- In 1981, Lykes Bros. Steamship Co. purchased and reflagged two German-flag RO/RO sister ships, one built in Japan and the other built in Germany. The reflagging costs directly attributable to Coast Guard regulatory requirements amounted to $2.8 million for the former ship and $4.5 million for the latter [6].

- Also in 1981, the wrecked vessel SEATIGER, a tanker built in Japan in 1974 for Liberian registry, was rebuilt and simultaneously converted to meet U.S. standards for reflagging as the OVERSEAS BOSTON. A MARAB/General Dynamics shipyard study of this reflagging, based upon estimates rather than documented shipyard costs, concluded that design and construction requirements for U.S.-flag registry would increase the cost of a comparable new vessel by approximately $1.8 million. Eliminating the $47,000 worth of habitability upgrades attributable to union requirements yields a cost increase directly attributable to Coast Guard regulations of roughly $1.76 million [7].

  American Automar Inc. reflagged the AMERICAN EAGLE. a RO/RO built in Sweden in 1981;in the summer of 1983. The owner estimated the cost of compliance with Coast Guard regulations to be $1.4 million 181. This figure corresponds to about 4.2% of the total purchase and conversion cost for this vessel.

  In the spring of 1989, a survey team of MARAB officials visited several Japanese shipyards. The yards has been requested, in advance, to identify the additional costs, if any, associated with compliance with Coast Guard regulations. One yard reported a 2% increase in delivery (total) cost, due to delays in the construction schedule to obtain necessarv approvals, delays to make needed modifications to U.S.-SUDDlied materials and equipment,.. restricted sources of supply for components, and "personality" (presumably cultural) difficulties in dealing with the Coast Guard.

  Another shipbuilder reported.an increase in material cost of 12 or 13 percent. With the material cost of Japanese-built container ships accounting for about 70% of the delivery cost, this cost of compliance equates to roughly 9% of the total vessel cost.

  A third Japanese shipyard reported a resultant 10 to 12% increase in material cost, corresponding to 7 to 8.4% of the total vessel cost.

DISCUSSION OF THESE COST ANALYSES

Government regulation is but one factor which should be considered when comparing construction costs in foreign shipyards with those in U.S. shipyards. Employee wages and indirect compensation, foreign government subsidies to shipbuilders, and construction time required to complete a ship are among many other factors which may affect the delivery cost of a vessel. It is difficult to either confirm or refute the validity of any of the incremental cost figures presented above.

The two SCA studies discussed above compared U.S. flag vessels to "standard" foreign flag vessels of the same size and service before the entry into force of the International Convention for the Safety of Life at Sea, 1974 (SOLAS 74) and its 1981 and 1983 Amendments. Similarly, all of the reflagged vessels discussed above were built prior to the implementation of the 1981 and 1983

SOLAS Amendments. Foreign and domestic technical requirements were not comparable at the time of these particular studies: SOLAS 74, as amended, has minimized the difference between the engineering design requirements in force worldwide and those in Coast Guard regulations. The structural fire protection requirements in the 1981 amendments are essentially equivalent to the Coast Guard requirements for cargo ships. The 1983 amendments eliminated most of the significant differences between foreign-flag and U.S. requirements for lifesaving systems. The fact that the SOLAS Amendments moved international requirements closer to those of the Coast Guard only confirms the validity of the Coast Guard regulations in these areas. This narrowing of the differences between various national ship safety standards would effectively eliminate or substantially reduce many of the incremental regulatory costs for newly built ships.

With more nearly equal technical requirements in effect as a result of amendments to SOLAS, the cost differential between construction to U.S. versus foreign regulations will naturally be diminished. As an example, had the 1981 reflagging for Lykes Bros. of the two sister RO/ROs discussed above been performed on ships complying with the 1981 and 1983 amendments to SOLAS, the Coast Guard estimates the reflagging costs would have been reduced from 84.5 to $2.1 million for one ship and from $2.8 million to $1.8 million for the other, or about half of what they actually were. More recent amendments to SOLAS would have eliminated the need for replacement of the low-pressure CO_2 extinguishing systems, reducing these reflagging costs nearly by half again.

Considering again the Lykes Bros. reflaggings discussed above, it is interesting to note that the ship built in Germany cost approximately 60% more to reflag to U.S. standards than its "sister ship" built in Japan. This considerable difference in the reflagging costs for two supposedly similar ships, built to the same specifications in the same year and classed by the same society, suggests that there exist significant differences in both the application of requirements among various shipbuilding nations, and the national industrial standards affecting the quality of materials and components locally available for shipyard use. Shipyard compliance with, and flag administration enforcement of requirements is also problematical: combustible insulation material installed on the German-built ship did not conform to the construction specifications.

The SCA studies treated the cost of compliance with ABS rules as an "add-on" cost, in addition to the costs of compliance with Coast Guard and Public Health Service regulations. In practice, all commercial ships in l foreign trade must be "classed" by a reputable classification society in order to obtain insurance, and few significant differences exist between the technical requirements of the leading classification societies. Eliminating this common cost of compliance with classification society rules reduces the magnitude of the co& differential cited in the SCA studies.

In enacting major maritime safety legislation exceeding (or preceding) the implementation of comparable international standards, the U.S. Congress has demonstrated its belief that certain safety benefits outweigh the associated costs. Examples include the upgraded tanker steering requirements of the Port and Tanker Safety Act of 1978 and the double hull tankship requirements of the Oil Pollution Act of 1990.

The cost differential may be presented in dollar amounts, percentages of ship cost, or both. Because the percentage figures may be based on the price the purchaser pays the shipyard for the ship -- not the total ship cost, which may include sizable foreign government subsidies -- the dollar amounts may often be analyzed with greater confidence.

U.S. shipbuilding has operated as an essentially unsubsidized industry for the past decade. While U.S. Navy shipbuilding contracts and such incentives for U.S. construction as the Jones Act and Operating Differential Subsidies may be viewed as indirect subsidization, the payment of direct commercial shipbuilding subsidies ended in 1981 with the cancellation of the Construction Differential Subsidy program. The governments of other shipbuilding nations -- in particular Japan, South Korea and Germany -- continue to heavily subsidize their shipbuilding industries. According to MARAD, direct subsidies from the German federal and state governments to the HDW shipyard for the construction of the C-10 containerships for American President Lines exceeded 25% of the construction costs.

U.S. SHIPBUILDING COMPKTITIVKNKSS

A number of studies have concluded that the productivity of U.S. shipyards, measured in terms of labor hours required to construct comparable commercial ships, was (at the time of the studies) significantly lower than that of many Japanese and European shipyards. A study by A. P. Appledore ztd. concluded that, for the period 1976 to 1979. "productivity in the best Japanese and Scandinavian yards is of the order of 100 percent better than in good U.S. shipyards" [9]. A cost accounting system study by Levingston Shipbuilding Company revealed that the actual labor hours required by Ishikawajima-Harima Heavy Industries (IHI) to construct the first ship in a series of bulk carriers was less than 30 percent of the labor hours required by Levingston to build the first ship -- a modified IHI design -- in its series Cl01 - Similarly, -a cost estimate prepared by a major U.S. tanker owner stated that the actual labor hours required to build comparable ships were 46 percent of U.S. requirements in Japar and 57 percent in Europe [ll].

While it is generally acknowledged that many U.S. shipbuilders have improved their productivity since the studies discussed above were conducted, construction times in U.S. yards continue to exceed those of the better foreign yards. MARAB officials estimate an average time from the start of fabrication to delivery of 18-24 months for U.S. shipyards and 9-12 months for leading Japanese and European yards. With 1990 U.S. shipbuilding hourly employee compensation costs (including fringes) less than those of most Northern European shipbuilding nations and about equal to those of Japan [12, 133, crucial cost factors such as construction time must be improved to increase the competitiveness of the U.S. shipbuilding industry.

In its recent report on the economic effects of enactment of H-R. 2056, The Shipbuilding Trade Reform Act of 1992 (or "Gibbons Bill"), the U.S. International Trade Commission estimated the average cost difference between U.S. and foreign- built ships based upon bids foe construction contracts for similar shies from 1989 to 1991. The Commission found that bid prices for commercial ships made by U.S. shipyards were, on average, 97 percent higher than comparable bids by foreign yards [14]. The Commission attributed this price differential to the lack of recent U.S. experience in commercial shipbuilding and overspecialization of U.S. labor, as well as foreign government subsidies.

The government regulations specifically applicable to the ship itself -- such as Coast Guard regulations and the standards incorporated by reference therein -- are as applicable to foreign shipbuilders constructing ships for U.S. owners as they are to U.S. shipbuilders. "Premium" costs added by foreign shipyards building U.S.-flag vessels to comply with Coast Guard regulations have often been based upon a misunderstanding of the regulations -- particularly the "equivalence" provisions which allow the use of foreign materials, equipment and arrangements demonstrated to be equivalent to those contained in Coast Guard regulations. Through a cooperative effort between the German shipbuilders, American President Lines, APL's marine consultant and the Coast Guard, the "premium" costs for APL's C-10 containerships were identified and essentially eliminated 1151. Similarly, a comparison of the costs associated. with the reflagging of several foreign vessels (i.e., Lykes Bras.' M/V CYGNUS and M/V LYRA, and American Automar's M/V AMERICAN EAGLE) reveals that the seeking of equivalencies results in lower conversion costs [163.

Coast Guard regulations are not applicable to foreign flag ships even if built in U.S. yards. Were U.S. shipyards truly competitive in the global marketplace with the exception of the "burden" of compliance with Coast Guard regulations, one would expect U.S. shipyards to be active in building vessels for foreign owners. With the exception of a few fishing boats being built for foreign owners by small U.S. yards, there is-no foreignflag commercial shipbuilding in the United States, nor has there been for nearly 30 years. The absence of foreign flag shipbuilding in the U.S. must be attributed to factors such as the long delivery schedules and corresponding high delivery costs at U.S. yards, not any "added" cost of compliance with Coast Guard regulations.

The U.S. shipbuilding industry has bemoaned the lack of opportunities for series construction. The July 1991 SCA "Ship Construction Report, 1989-1990 in Review" states, "The primary reasons for remaining cost disparities between the U.S. and foreign yards are (1) foreign shipbuilding subsidies, and (2) the fact that U.S. builders quote prices for first-of-class and short-run programs rather than series builds." While the 1973 Report of the Commission on American Shipbuilding viewed the construction of standard ships in series as the most important factor in productivity, more recent studies have concluded that increased productivity is the key to improved competitiveness and that series production is not crucial to implementing substantial productivity improvements 1173.

Faced with competition from subsidized foreign competitors in the commercial shipbuilding marketplace and the naval construction opportunities resulting from the Reagan administration's planned 600-ship Navy, the larger U.S. shipyards have relied almost exclusively on naval shipbuilding contracts for the past decade.[002909'Howc the government's Shipbuilding and Conversion, Navy (SCN) budget is in decline, and the Navy's shipbuilding plan for fiscal years 1992-1997 projects a sustained low level of new construction. Several U.S. yards have recognized the impending shortage of naval orders and are attempting to reenter the commercial shipbuilding market. These yards have arguably lost their expertise in commercial Ship design and construction (including a _ familiarity with Coast Guard. classification society and S&AS requirements) and are hampered by large accounting, inspection and combat systems staffs which, while required for Navy contracts, constitute wasteful administrative overhead for shipyards competing for commercial contracts.

At the same time, certain experience gained and productivity improvements made through naval construction projects may be transferred to commercial shipbuilding. For example, military specification welding procedures and performance qualifications might be accepted as equivalent to those, based upon the American Society of Mechanical Engineers (ASME) Code, now required by Coast Guard regulations. This acceptance would eliminate the need for U.S. shipyards attempting the transition from naval to commercial shipbuilding to requalify and possibly retrain competent welders simply to comply with Coast Guard regulations.

CURRENT INITIATIVES

There is no doubt that the availability and cost of quality marine materials and equipment has significant potential for affecting the competitiveness of U.S. shipbuilders. Unfortunately, the decline in U.S. commercial shipbuilding has led to an erosion of the domestic supply base for marine machinery and materials. Shipbuilders must turn to foreign sources of supply for many critical components. The U.S. shipbuilding industry maintains that foreign suppliers of marine machinery and equipment charge "premium" prices to cover the cost -- real or perceived -- of compliance with Coast Guard ship design and construction requirements. In a May 21, 1991 letter to the then Chief of the Coast Guard's Office of Marine Safety, Security and Environmental Protection, the president of the SCA stated, "Shipyards can always find extreme cases where the price for equipment, which is well-proven technically and used for years in foreign-flag ships, is increased as much as 65% when U.S. Coast Guard rules are applied. The more normal price premium situation adds an average of 15% to the material costs of a U.S.-built U.S.-flag ship."

The U.S. government has long been 1 sensitive to industry claims of excessive regulation. An interdepartmental Maritime Regulatory Review Study Group examining this issue in 1982 found that significant progress had already been made in offering regulatory relief without compromising safety C181. Since that time, the Coast Guard has repeatedly reexamined its regulations to determine where classification society rules, SOLAS requirements and industry consensus standards could be used in place of Coast Guard regulations for maximum efficiency to the industry. Notable, ongoing Coast Guard efforts to relieve the regulatory burden on the maritime industries are described below.

Relief Within.3wusgu~ati.ons

Through pro-active participation in the International Maritime Organization (IMO), the Coast Guard systematically broadens the scope and increases the specificity of requirements in the SOLAS Convention and other IMO instruments. Among the notable accomplishments are mandatory damage stability requirements for dry cargo vessels, development of recommended intact stability standard for all ships, requirements for automatic sprinkler systems on all passenger ships, and development of guidelines for emergency training and crew drills. Once the desired results are achieved internationally, the Coast Guard has typically accepts or adopts the international requirements and eliminates corresponding domestic regulations.

The Coast Guard incorporates numerous industry consensus standards and performance-based requirements in lieu of detailed design requirements into new regulations and revisions of existing regulations. Since 1968, the Coast Guard's Marine Safety Program has adopted over 250 industry consensus standards into its regulations. This practice has substantially lessened the regulatory burden on the U.S. maritime industries and eliminated many pages of federal regulations while maintaining the desired level of safety. The advantages of doing this are threefold: first, it makes use of recognized standards which are familiar to the industry so that redesign and special retooling are unnecessary: second, ft reduces the time necessary to obtain approvals and reduces the cost premium associated with "Coast Guard approved" equipment: and third, it ensures that the regulations are current with the latest technology. The adoption of international industry standards (e.g., those of the International Organization for Standardization (ISO) and International Electrotechnical Commission (IEC)) also allows American industries to be more competitive in the world market. The National Shipbuilding Research Program (NSRP). with the full concurrence of senior shipbuilding,'ship operating, and government officials, has recognized that a body of national shipbuilding standards is essential for the U.S. maritime industries to be competitive. The Coast Guard continues to work with national standards writing organizations such as the Society of Naval Architects and Marine Engineers standards development panel and the American Society for Testing and Materials shipbuilding committee to develop consensus standards in order to replace detailed federal regulations.

The Coast Guard incorporates by reference into the Code of Federal Regulations many of the American Bureau of Shipping Rules for ship design and construction. In 1982, the Coast Guard entered into a Memorandum of Understanding with ABS through which ABS is authorized to conduct certain aspects of design review and inspection of new vessels on the Coast Guard's behalf. This MOU and its implementing Navigation and Vessel Inspection Circular No. 10-82 have been favorably received by the maritime industries and have worked well to reduce the duplication of effort and ease the administrative burdens such duplication imposes on industry.

"Levelina The Plavino Field" Via Compliance and Enforcement

The Coast Guard has taken other steps to "level the playing field" on which U.S.-flag ships compete with foreign shipping. The actions described below are intended to improve both safety and the competitive posture of the U.S. maritime industries by preventing the operation of unsafe ships in U.S. waters.

Exercising its authority under U.S. law and the SOLAS Convention, the Coast Guard conducts control examinations of foreign flag ships calling at U.S. ports to verify compliance with the terms of their international safety certificates. The program currently places the greatest emphasis on passenger ships and tankers and focuses on fire safety, crew training, and emergency drills. This program continues to reveal numerous cases of noncompliance with international and domestic reouirements. When safety discrepancies are-found, the Coast Guard freauentlv withholds sailino clearance and, on occasion, intervenes to withdraw a vessel's Safety Certificate until all safety aspects of a vessel are found satisfactory.

In 1991, the Coast Guard hosted two International Marine Safety Workshops to develop strategies for the improvement of marine safety worldwide. The participants, top executives representing flag Administrations, classification societies, ship owners, and hull insurers, developed numerous recommendations for policies and actions that will reduce substandard flag State and classification society performance, promote a high level of compliance with international safety standards, and improve the uniformity of enforcement by flag Administrations, individual classification societies, and the International Association of Classification Societies. These workshops enabled the Coast Guard to build the broad support needed to effect sweeping new safety initiatives through IMO, for example, the passenger ship fire safety upgrade requirements approved at the sixtieth session of IMO's Maritime Safety Committee (MSC 60).

Earlier this year, the United States and several other nations jointly submitted to MSC 60 three papers presenting recommendations, stemming from the Marine Safety Workshops mentioned earlier, for curbing the . operation of substandard ships and establishing criteria for responsible flag States and classification societies. One paper proposed the creation of a worldwide data system to record and share information on serious safety deficiencies and to help to identify substandard vessels. Another proposed the development of standards for flag States and identified elements such as the number, experience and technical qualifications of personnel, faCilitieS and infrastructure, and oversight programs as essential for an effective flag State control program. The third paper, noting that a number of the more than 40 classification societies now in existence do not appear to have the technical expertise or infrastructure to perform traditional classification society work, proposed amending SOLAS to require ships to meet structural standards established by'a classification society recognized by IMO.

Acceptance of Alternative Standards

One ongoing project which the Coast Guard believes holds great promise for increasing the availability and decreasing the cost of acceptable marine materials and equipment is a joint industry-government project with the SCA and the NSRP to evaluate for acceptance, and publish in the public domain, alternative standards for marine materials and equipment. The SCA has concluded that much of the "premium" price charged by suppliers is added to cover perceived rather than actual additional costs required to comply with Coast Guard regulations. The Coast Guard agrees. It is the Coast Guard's view that, with a small number of l exceptions, there should be little or no premium cost associated with compliance with Coast Guard regulations. The regulations have long contained equivalency provisions which clearly permit the use of foreign materials, equipment and arrangements demonstrated to be equivalent to the materials, equipment and arrangements cited in regulation. The primary method for determining this equivalence is a comparison of the foreign or international standards to which the equipment is made to comparable standards in Coast Guard regulations. Many shipbuilders and shipowners have used these equivalency provisions to take advantage of the greater availability and cost savings associated with the purchase of foreign equipment.

The problem with this approach is that each submittal to demonstrate equivalence has been regarded as proprietary: the Coast Guard cannot share the determination of equivalence with other parties, and shipyards and consultants have guarded the results of their efforts jealously. This has lead to the wheel being reinvented -- and time and money expended by both the shipbuilding industry and Coast Guard -- to duplicate previous reviews for equivalence. An additional problem, in the Coast Guard's view, is the fact that U.S. shipbuilders, out of lack of understanding of Coast Guard regulations and an innate conservatism, impose upon equipment vendors a requirement that does not exist -- that all materials and equipment be "Coast Guard approved."

To remedy this situation, the SCA proposed and the Coast Guard agreed to a cost-shared joint project to identify and remove unnecessary restrictions in the shipbuilding regulations, especially as they affect acceptance of ships' machinery and materials. The long-term goal of this effort is to reduce the time and money expended by both the Coast Guard and the U.S. shipbuilding industry to obtain approvals for alternative materials and equipment for U.S.-flag ships. A two-phase program was envisioned.

Phase I of this project, completed in December 1991, examined the process for obtaining Coast Guard acceptance of alternative design, material and component standards via the equivalency process, and documented the Coast Guard and SODAS requirements pertaining to acceptance of materials and equipment. To provide a means of working cooperatively with the Coast Guard without violating conflict of interest guidelines, the SCA reestablished its support of the marine industry training program by providing training positions at shipyards. The Coast Guard dedicated an experienced marine inspector to this project during a six-month industry training assignment.

During Phase II, recommendations for streamlining the acceptance process as well as specific standards for ship systems and their associated materials and equipment will be evaluated for acceptability. This will InVOlVe an industry-led effort to perform detailed engineering comparisons of selected foreign and international standards to U.S. standards to determine acceptability. The principle product of this project will be the public dissemination of these determinations of acceptability. As a result, the necessary engineering analysis, testing, documentation, and evaluation need be done only once, not each time a shipbuilder desires acceptance of a particular standard.

Earlier this year, the SCA pro;osed this project to the NSRP for sponsorship. The NSRP Executive Control Board accepted the project and authorized $215,000 in fiscal year 1993 funding to proceed with Phase II. The Coast Guard recognizes the NSRP's established mechanism for publication of material related to ship production, and fully supports the use of the NSBP for project sponsorship. Both MARAD and the Coast Guard are represented in the NSRP and both will work with industry through this project.

CONCLUSION

While the percentage and dollar amount figures vary widely, it appears that some small incremental cost of compliance with Coast Guard regulations exists. It should be apparent, however, that regulation is clearly not responsible for the current high cost differential between U.S. and foreign shipyard construction costs. It may be unrealistic to expect the incremental cost to be completely eliminated, due to legislatively-mandated requirements, differing interpretations of good marine practice, and the lack of unanimity among other maritime nations in the application of requirements -- even those implementing agreed-upon international conventions. The Coast Guard is sensitive to this incremental cost and its effects on the economic health and international competitiveness of the U.S. shipbuilding industry and the U.S. Merchant Marine fleet.

Coast Guard policies, both past and present, have been effective in reducing the regulatory burden and improving the competitive posture of the U.S. maritime industries. These policies will be continued and supplemented with new initiatives to accelerate the achievement of Coast Guard goals to reduce the regulatory burden and effect even greater cost savings for the U.S. maritime industries. The Coast Guard is committed to reducing even further the incremental cost of construction of

U.S.-flag ships. As always, the Coast #Guard stands ready to work with U.S. shipbuilders and ship operators to overcome the inefficiencies of the past and aim toward global competitiveness.

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Self Assessment of Advanced Shipbuilding Technology Implementation

No. 3B-3

Walter L. Christensen, Member, presentation also by Louis D. Chirillo, Fellow, Bellevue, Washington, Stephen Maguire, Member, Avondale Shipyards, Inc., and Anthony Gambello, Visitor

ABSTRACT

This report lists and describes ten factors and associated evaluation criteria which can be used to assess the degree of implementation of advanced shipbuilding technology in a shipyard.

If the U.S. shipbuilding industry is to improve its competitive position in the global shipbuilding market it must move more quickly and agressively to implement productivity initiatives. To this end, two recommendations are presented at the conclusion of this report.

ACRONYMS

- PWBS: Product Work Breakdown Structure
- SWBS: System Work Breakdown Structure

INTRODUCTION

The NAVSEA Shipbuilding Support Office (NAVSHIPSO) was tasked during fiscal year 199 1 to develop candidate factors and supporting elements which can be used to quantify the degree of implementation of advanced shipbuilding methods by a shipyard.

BACKGROUND

Most of the Navy's existing cost estimating methods for shipbuilding are oriented to the Ship Work Breakdown Structure (SWBS) which is system and weight dependent. Ship construction Cost Estimating Relationships (CERs) are derived from historical data reflecting past accounting methods and performance (i.e., return costs) of particular shipyards. However, shipbuilding practices and methods are undergoing very substantial changes. Cost reductions resulting from newly adopted and developing shipbuilding technologies and production methods are not reflected in the existing historically based cost estimating techniques. Advanced shipbuilding technologies typically involve a modular, product oriented approach which cuts across elements of the existing SWBS. Thus, even the basic structure of the current approach to ship cost estimating is of questionable relevance for modeling the ship construction processes and cost estimates of the future.

Further, if the Navy is to have available a shipbuilding infrastructure/ mobilization base for affordable ships in the future and for surge requirements, the Navy might benefit from understanding and encouraging ongoing and future transformation projects at the shipyards. Currently, such encouragement is largely limited to cost-sharing of the National Shipbuilding Research Program (NSRP), under the Navy Manufacturing Technology Program. The Navy's ability to encourage might be greatly enhanced by a plan for shipyard transformation that represented a consensus view of shipyard managers. A consolidated plan might provide guidance to the Navy in its efforts to break down barriers to more efficient shipbuilding (some of which the Government has created, and only the Government can dismantle).

The immediate goal of this self-assessment survey is to :

- Provide a draft transformation outline for discussion and further development by the shipbuilding community.

Longer range goals of this self-assessment survey are to :

- Provide Navy cost analysis tools which quantify the most significant cost drivers of current and proposed (advanced) ship construction techniques. This should result in more accurate cost estimates for budgetary purposes.

- Enable the Navy's naval architects and marine engineers to modify ship design processes to best support advanced shipbuilding technologies and production methods.

- Provide a basis for development of Navy projects to encourage shipyard developments and to remove barriers thereto.

TRADITIONAL PRACTICES ARE DIFFICULT TO CHANGE

"Just give us the plans and material on time and we can build ships as productively as anyone." So say traditional production bosses. Nothing could be further from the truth, because a critical element is missing. Managers of the world's most productive shipyards have succeeded in getting their production people highly involved in design matters starting with development of detailed, working plans. Thus the entire design effort reflects and supports a premeditated building strategy for integrated hull construction, outfitting and painting; design is truly an integral part of planning. Additionally, compared to traditional shipyards, the organization of people, information and work processes in the most productive shipyards are interdependent and comprise constantly self-improving shipbuilding systems (1).

TRADITIONAL PREOUTFITTED MODULAR CONSTRUCTION VERSUS ADVANCED SHIPBUILDING TECHNOLOGY

Some shipbuilders think preoutfitted modular construction constitutes implementation of advanced shipbuilding technology. This is only partially true. The world's most productive shipyards use a planning methodology which organizes work, people, facilities and other resources so as to drive the process towards highly efficient, prod: uct oriented ship construction methods (including preoutfitted modules) and away from system oriented ship construction methods which are less effrcient and less manageable.

Traditional preoutfitting of hull blocks (modules) divides installation work into two basic stages; on-block and onboard. However, many shipbuilders continue to employ system-by-system installation drawings followed by relatively large work orders that specify preoutfitting work by systems or pok tions of systems. These large, unsequenced work packages complicate attempts to achieve uniform and coordinated work flows. They often result in work teams competing with each other for access to work sites and in poorly sequenced installations which must be reworked.

No less illogical, people who perform detail design, material definition and material procurement system-by-system are often unnecessarily preoccupied with portions of systems that will not be required for some time. Detail design and material definition, both vital aspects of planning and material procurement, are system oriented, whereas preoutfitting is geographically oriented. Under such circumstances, the efficiency of even comprehensive preoutfitting is limited because of the inherent conflicts between the planning, design, and build strategies.

Efforts to avoid these conflicts and improve productivity compelled the Japanese shipbuilding industry to focus on a single, integrated product-oriented strategy which, in turn, led to the development of modem scientific shipbuilding methods.

EVALUATION CRITERIA TO ASSESS DEGREE OF IMPLEMENTATION

This section explains criteria used to develop the self-assessment form, Table I.

Group A - Business & Management

The business and management group consists of basic requisites for any business activity to be viable. It must be readdressed in light of the significant changes necessary to improve productivity. The group consists of factors 1 and 2 below, which must be implemented in the sequence shown in order to assure the success of the manufacturing process improvements outlined in Groups B and C which follow. Group A factors are mandatory prerequisites to a successful transition to product oriented ship construction and, although measurable, do not quantitatively contribute to improved productivity.

Factor 1 - Business Plan. The criteria in the business plan factor are leading indicators of a shipyard's ability to be globally competitive. Unless a corporation is committed to be a world class shipbuilder and structures its financial and marketing strategic plans accordingly, it will probably not succeed in the international shipbuilding market. Failure internationally will lead to closure in many cases, because Navy and domestic commercial orders will not sustain current levels. Conversely, success intemationally could improve the domestic situation due to improved affordability. Additionally, if the corporation's top management does not recognize that a significant portion of its procedures consist of non-process and non-value added waste, and does not include appropriate items in its business plan to reduce that waste, (i.e. productivity improvement initiatives) it will not become competitive in the global market.

Factor 2 - Leadership And Management. Once management decides what market it wants to participate in, it must develop a strategy that drives the corporation towards the productivity improvements of product oriented ship construction methods. To do this, top management must show lower level managers that they will not deviate from implementing these best proven methods. Top management's commitment to implementing product oriented ship construction methods must constantly be visible to the entire corporation.

Management must address the fact that approximately SO%-90% of process problems are caused by their system rather than their workforce and take responsibility for solving their system-caused problems. Human dynamics requires that human roadblocks and passive observers be converted into supporters of changes that are being implemented.

Group B - Product Oriented Process Technology

This group addresses improvements in organization of work, resources and processes which measurably affect productivity. The generic steps required to establish and maintain an environment for long term improvement are:

1. organize work according to group technology,
2. organize and schedule resources into work flows that embody group technology,
3. categorize functions, (e.g., design, material definition, material procurement, and types of work) that affect the work flows,
4. reorganize so that lines of authority and accountability reflect the requirements of group technology, and
5. implement statistical process analysis. This is the reason for implementing group technology in the first place! If a shipyard is not committed to continuous improvement process via statistical analy-

sis, there is no reason to group work more scientifically than it is already done (i.e., most yards already group work by craft, by common tooling requirements, other simple measures).

Croup B consists of factors #3, #4, and **#5,** below, which must be fairly well implemented in sequence, leading to statistical analytical methods.

Factor 3 - Product Work Breakdown Structure (PWBS). PWBS is a common language used to organize work. Early identification, procurement, and scheduling of long lead time material (LLTM), resources (manning, site and equipment availability) and interim products, allows efficient organization of work emphasizing group technology and manufacturing resource categorization. LLTM can be identified and ordered from building specifications and contract plans. Combined, early efforts by production, planning and design personnel using PWBS, allows definition and development of interim products which are designed for production, thus facilitating the integration of product oriented outfitting with structural assemblies (blocks). The result is realistic schedules and manpower estimates. Completely pre-outfitted modules do not necessarily represent a well planned construction project.

This paper uses a broad interpretation of group technology when it refers to PWBS. Interim products have a volumetric flavor during fabrication. A Process Work Breakdown Structure might better describe the interim products during installation. And finally, a System Work Breakdown Structure might be most appropriate to control interim products during system testing.

Factor 4 - Process Lanes. Process Lanes is the embodiment of a Product Work Breakdown Structure, in that it organizes people, facilities, tooling and other resources to suit PWBS. It categorizes and assigns "like" kinds of work to specifically designed "work centers" in order to benefit from "learning curve" and "assembly line" type efficiencies which result from having the same people do the same type of work every day, at the same location, with a constant organized flow of material.

The goal is a process that operates predictably, can be analyzed via statistics, can have small group improvements (because the statistics let the workers freely discuss problems), and continuously improves. None of this can be accomplished if a "work center" is processing a haphazard variety of dissimilar interim products!

When Process Lanes are established, detailed Process Lane schedules are developed based on volume and capacity of each work center. Management can then closely monitor work center cost and efficiency, and identify and correct "like" problems (i.e., reduce rework costs) at a specific location. But, if total throughput is not increased, or operating cost (manning) reduced, or this work center is not the bottleneck, there will not be a significant improvement!

Factor 5 - Statistical Process Analysis. Once work and resources are organized in a logical way to produce products by problem area by stage, immediate feedback of statistical information from the worker and his/her supervisor within their sphere of influence is made possible. This allows the use of statistical and analytical methods to produce immediate feedback to the worker and his or her supervisor on progress and quality.

Group C - Iterate Process Refinements

Once statistically based analytical processes and methods that have been successful in creating constant and somewhat self-managing systems which foster a continuous learning and self-improvement process, iterative im-. provements can be implemented at strategic locations throughout the process train. The preceeding steps (Group A and Group B) must have been implemented and be reasonably underway for this technology area to be useful.

The following factors provide a sample of significant initiatives that can be undertaken after successful implementation of Groups A and B. These factors in Group C can be worked in any order. Other factors can be added, as appropriate.

Factor 6 - Quality Of Support Spiral. This area provides information which allows accurate cost and schedule estimates and controls. It is a continuous loop that inputs feedback from the people who do the work (production, mated rial definition, material procurement, etc.) into the planning and control efforts. A rigid, tightly, structured feedback system makes inaccuracies in schedule aud manpower estimates more visible. As work processes become more accurate and work packages become better defined, standardized work packages evolve that are used to improve work estimates. Later, as statistical and analytical processes are used, labor (man-hours) can be equated to a measurable entity of material (called parametric-component weight). This ability allows more accurate scheduling, progress reporting, bid estimating, and assessment of change order impacts.

Factor 7 - Small Group Activities. This area creates a system of constant, gradual (incremental) and continuous improvement by everyone. Some writers refer to this as “team culture.” It is not “quality circles” as misapplied by many U.S. manufacturing industries several years ago. First, work must be rationalized. Then, appropriate and meaningful data must be made immediately available to the worker within his or her sphere of influence. Next, management-caused problems must be separated from worker-caused problems. Following this, management must respond and correct the management-caused problems. When it is obvious to workers that these problems are being corrected, they will continuously respond with spontaneous, incremental improvements among themselves. This constant, never-ending process will result in daily improvements. At the end of a year the total improvement can be impressive.

Factor 8 - Design Refinements via Process and Customer Feedback and Factor 9 - Manufacturing Accounting System. Like factors 6 and 7, these two factors can be started concurrently. At this point an organization is operating in a much more productive manner.

Group D - Hard Technology

This group recognizes the need to include modem manufacturing technology in any studies and programs relating to the implementation of advanced shipbuilding technology in any shipyard. The value of larger cranes, faster automated equipment, robotic machinery, computer aided design (CAD), computer aided manufacturing (CAM), computer integrated manufacturing (CIM), etc. has been, and continues to be, studied by the National Shipbuilding Research Program.

Factor 10 - Facilities, Equipment and Automation. The benefits resulting from facilities and equipment improvements, and automation are significant, however they cannot be extracted and evaluated since they are integral to the process itself. This factor is included in this report to assure its continued consideration in future productivity improvement studies.

If implemented prior to Groups A, B, and C above, a shipyard is paying lots of dollars for a robot that can do the wrong thing faster and better, or to replace non-value-added work that should not be there anyway and is a symptom of bad management and a system that is out of control!

CONCLUSIONS

The degree of implementation of Advanced Shipbuilding Technology in U.S. shipyards varies considerably and is not very high. Also, it was observed that continued implementation of initiatives at most shipyards has either ceased or is progressing at a very slow rate. This is unfortunate because it has been estimated , in testimony given to the Commission on Merchant Marine and Defense, that replacing traditional shipbuilding methods with advanced shipbuilding techniques at U.S. shipyards would result in cost savings up to 40%. In addition, the world's leading shipyards are quoting significant schedule savings.

It comes as no surprise, therefore, that the U.S. shipbuilding industry is not competitive in the world market, and, as a result, market share of world ship construction and repair contracts is woefully small. Obviously, something is wrong (Maybe many things are wrong.) This is not intended to be an indictment of the shipyards alone. It should be recognized that many of the shipyard management systems that have been developed in response to Navy requirements may be creating barriers to the shipyard's transformation process.

It is imperative that the Industry move quickly to implement measures to reduce our shipbuilding/ship repair costs, shorten our building schedules and improve our quality. Similarly, the Navy needs to continue in its ongoing efforts to identify and eliminate barriers to long-term success of its shipbuilding supplier base. The Japanese have reached these goals by the introduction of advanced shipbuilding methods (product oriented ship construction) to their industry. The U.S. shipbuilding industry must mimic (and hopefully improve) their processes if we are to survive.

RECOMMENDATIONS

Concerned organizations such as the National Shipbuilding Research Program (NSRP), Society of Naval Architects and Marine Engineers (SNAME), American Society of Naval Engineers (ASNE), Shipbuilders Council of America (SCA), et al, should develop and pursue initiatives to expedite implementation of advanced shipbuilding methods in American shipyards. Among the early initiatives it is recommended that:

a) a structured educational program be developed to assure all shipyards understand the principals of product oriented ship construction and the potential benefits resulting from its implementation, and

b) a strategy be developed to assist shipyards in making the transition from current shipbuilding practices to improved shipbuilding practices (i.e., from system to product oriented design and construction). The strategy should address the problems inherent with the existence of two management systems simultaneously, (one for each shipbuilding practice), and means by which this unwieldy and inefficient (but temporary) situation and its problems can be handled until eventually only one management system exists. However, there may continue to be elements. Financial aid (perhaps in the form of temporary government subsidies) should be addressed, as a possible source of funds to absorb “one time” transition costs.

ACKNOWLEDGEMENTS

This report is dedicated to improving shipbuilding as U.S. shipyards struggle to implement advanced technologies to improve shipbuilding costs, schedules, quality, customer satisfaction and international market share. Much of the material comes from countless writings and personal conversations with Lou Chirillo of L.D. Chirillo Associates and Steve Maguire of Avondale. Other contributors are RADM Robert Traister, USN (NAVSEA 91); Ed Kinney (SEA 05B, ret.); Professor Richard Starch (U.

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3(l) Lou Chirillo, private communication, 1991.

The views expressed herein are the opinions of the author and not necessarily those of the Department of Defense, the Department of the Navy, the Naval Sea Systems Command, the NAVSEA Shipbuilding Support Office or any other person.

Table I. - Self-assessment of Advanced Shipbuilding Technology Implementation

GROUP / FACTOR	Degree of Implementation: Individual Element	Total Factor	Weight Factor
Group A : Business and Management			
Factor 1: Business plan			
1a Long term commitment (to producing quality, affordable products; to customer needs; to development of human resources; to sound business practices; to long term decision making, etc.).			
1b Strategy for marketing (diversified and responsive system, but limited to a few 'niche' products at any one time).			
1c Extraordinary marketing effort.			
1d Draft future structure to guide transformation (PWBS in accordance with group technology, manufacturing accounting system, continuous improvement process).			
1e Strategy for productivity improvement (including a schedule for implementation).			
Factor 2: Leadership and Management			
2a Top Management understands the business plan and directs its implementation.			
2b Human dynamics addressed by the top manager.			
2c Organization structured to be responsive to business plan, customer needs, & production technology transformation.			
2d The top manager continuously demonstrates commitment.			
2e The top manager participates in selection of productivity improvement projects, etc.			
2f The top manager monitors the progress of productivity improvement projects etc.			
Group B: Implementation of Group Technology			
Factor 3: Product Work Breakdown Structure (PWBS)			
3a Categorize work by PWBS (by sameness of problem areas inherent in their manufacture.			
3b Produce product schedule based on PWBS.			
3c Integrate schedules with production (have production verify manning and space availability).			

Factor 4: Process Lanes

4a Plan & schedule work by PWBS.
4b Group production resources to match PWBS assignment by problem category.
4c Group design, planning, and other support resources, where appropriate, to match production groups.
4b Establish decentralized, hierarchial planning, scheduling, & control.

Factor 5: Statistical Process Analysis

5a Implement top management policy & follow through.
5b Establish process requirements for cost, schedule, & quality.
5c Start measuring process variables.
5d Train workers in problem solving techniques: x bar & R charts, cause & effect diagrams,Pareto analysis, etc.
5e Identify unique vice systemic problems, special vice common problems.
5f Establish a database for long-term analysis & establish goals for continuous improvement.

Group C: Iterate Process Refinements

Factor 6: Quality of support spiral

6a Implement a structured system which provides regular feedback of quality, schedule adherence, & manpower expenditures.
6b Enlist users to be an integral part of the planning, scheduling, measuring, and reporting efforts.
6c As quality, cost and schedule performance improve, use feedback to develop standardized interim product work packages.

Factor 7: Small Group Activities

7a Rationalize work. First, ensure product work breakdown structure and process lanes are implemented for applicable groups.
7b Analyze problems statistically. Make information of work performance immediately available to workers & identify problems. This distinguishes the 85% of management-caused problems from the worker-caused problems.
7c Workers recommend improvements. Management responds.
7d Workers implement improvements. Management supports improvements & perpetuates cycle.

Factor 8: Design Refinements via Process & Customer Feedback

8a Analyze PWBS/process lanes data & determine optimal interim product standardization.
8b For non-standard products, develop opportunities for optimal process lanes utilization.
8c Utilize structured process to solicit customer feedback.
8d Translate above feedback into design refinement via continuous improvement process.

Factor 9: Manufacturing Accounting System

9a Implement system that complements flexible production system & promotes reductions in process time/in-process material, that facilitates management decision making in new manufacturing philosophy, & that promotes long-term customer-oriented planning.

Group D: Hard Technology

Factor 10: Facilities, equipment & automation

The benefits resulting from facilities, equipment & automation can be significant; however, they need to be analyzed in context of production transformation.

Their return on investment will be maximized only after process flows are stable & well understood.

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Producibility in the Naval Ship Design Process: A Progress Report

No. 4A-1

Robert G. Keane, Jr., Life Member, and Howard Fireman, Associate Member, Naval Sea Systems Command

ABSTRACT[1]

In October 1989, A Ship Design for Producibility Workshop was held by the Naval Sea Systems Command (NAVSEA) at the David Taylor Research Center (DTRC). The purpose of the workshop was 'To develop the framework of a plan to integrate producibility concepts and processes into the NAVSEA Ship Design Process.' The major recommendations of the workshop included initiatives related to increased training of NAVSEA design engineers in modem ship production concepts, development of producibility design tools and practices for use by NAVSEA design engineers, improved cost models, implementation of produability strategies for ship design process improvements, modification to existing acquisition practices, and improved three-dimensional (3-D) digital data transfer. The workshop was one of NAVSEA's first Total Quality Leadership (TQL) initiatives and was subsequently expanded into the Ship Design, Acquisition and Construction @AC) Process Improvement Project. This paper reports on the major findings and recommendations of the workshop, the near term accomplishments since the workshop, and the long range strategic plan for continuously improving producibility in the Naval Ship Design Process.

l The views expressed herein are the opinions of the authors and not necessarily those of the Department of Defense or the Department of the Navy.

ACRONYMS

ASMS - Advanced Surface Machinery System
ATC - Affordability Through Commonality
CAD - Computer Aided Design
CDRLs - Contract Data Requirements Lists
CEFs - Critical Evaluation Factors
CONREP - Military Sealift Command Construction Representatives
C41- Command/Control/Communication/ Computers/Intelligence

DAC - Design, Acquisition and Construction
DOD - Department of Defense
DTRC - David Taylor Research Center
ECB - Executive Control Board
ESG - Executive Steering Group
FY - Fiscal Year
I-&I&E - Hull, Mechanical, and Electrical
MlT -Massachusetts Institute of Technology
MOU - Memorandum of Understanding
NAVSEA - Naval Sea Systems Command
NIDDESC - Navy-Industry Digital Data Exchange Standards Committee
NRC - National Research Council
NSRP - National Shipbuilding Research Program
PARMs - Participating Managers
PATs - Process Action Teams
PDES - Product Data Exchange Standard

PODAC - Product Oriented Design and Construction
QMBs - Quality Management Boards
RESUPSHIP - Resident Supervisor of shipbuilding
SBIR - Small Business Innovative Research
SDM - Ship Design Manager
SWATH - Small Waterplane Area Twin Hull
TQL - Total Quality Leadership
U.S. - United States
3-D - Three-Dimensional

STATEMENT OF THE PROBLEM

The U.S. Navy is not fully realizing the significant benefits which could accrue from modem shipbuilding methods. These benefits include reduced construction cost, improved quality and reduced construction time.

During the last decade, many U.S. shipbuilding yards have made major improvements in the way ships are produced, adopting zone-oriented and related modem construction techniques. Effectively implementing these shipbuilding advances has frequently required changes to the specifications, drawings and other contractual documents typical of a Navy ship contract design package. Despite the keen interest that the Navy has in producibility, the NAVSEA ship design process has not kept pace with developments in the shipbuilding industry. To more fully realize the significant benefits of modem ship construction, actions must be taken to consistently include producibility in future Navy ship designs.

INTRODUCI'ION

TheU.S. shipbuilding industry continues to be generally uncompetitive in commercial shipbuilding on a world scale. The predominant market of the leading U.S. shipbuilders today is the U.S. Navy. The reasons for and implications of this situation are of significant concern to the Navy, whose dependence on the industry is so great.

The Navy asked the National Research Council (NRC) of the National Academy of Sciences to identify promising technology developments that have the potential to improve the productivity of the U.S. shipbuilding industry. The NRC report, references (1) and (2), which was developed by the Marine Board, noted that the U.S. shipbuilding industry is in the midst of a fundamental transition. U.S. shipbuilders are introducing advanced ship production technologies such as zone-oriented methods, with resultant productivity improvements in terms of reductions in construction man-hours and schedules, and an improvement in quality.

The U.S. shipbuilding industry has drastically changed its construction process in recent years. The use of ‘modular,’ ‘zone-oriented,’ ’group technology, ’ and other construction techniques have replaced the traditional ‘system-oriented’ approach. These changes have come about as a result of projects which analyzed the shipbuilding practices used by the highly productive Japanese shipyards. Many of these projects were funded by the National Shipbuilding Research Program (NSRP) and some were conducted by U.S. shipbuilders at their own expense. These analyses demonstrated that it was not advanced facilities or a superior work force that allowed Japan to be highly productive, but rather their rigorous planning and organization of work using good, basic industrial engineering concepts.

The NRC Marine Board emphasized that the Navy needs to take better advantage of the productivity improvements which these developments offer. One of the major recommendations in the report (1) states:

> To foster the use of zone-oriented ship construction, the Navy should:

1. develop means to apply the technology in prehminary and contract design,

2. educate its personnel on the advances being embraced by shipbuilders so that Navy practices and procedures can be adapted in support of them, and

3. work together with its shipbuilders to provide a receptive environment for the use of productivity improving technology.

In the early stages of the Navy ship design process , NAVSEA has not generally placed strong emphasis on producibility. Mission performance, integrated logistic suppa manning and other operational requirements are considered higher priorities. Over the past five years, however, much interest and some improvements in specific programs have occurred. References (3) through (10) highlight just some of the activities in this area.

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In recognition of the problem, a NAVSEA Steering Committee was established in the Spring of 1989 under the chairmanship of the Deputy Director of the Ship Design Group. The Committee established a long range objective as:

> To integrate ship produciiility concepts and processes into the NAVSEA ship design process.

The Need for a Workshop

An early decision of the Steering Committee was to use a workshop to define the actions needed to achieve this long range objective. They held a two-day planning session in June 1989 to develop the framework for a larger group to generate a more complete set of recommendations. This process improvement is one of the first TQL initiatives of the Naval Sea Systems Command. That planning session used the diverge/converge consensus building process as described in reference (11) to reach cotiensus on the eleven top priority actions to be addressed by the workshop. Those actions were grouped into six categories which became the basis of six working groups which were established for the workshop in October 1989. The major findings and recommendations of the six working groups are described below.

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In comparison with the long range objective, the Steering Committee defined the objective of the workshop more narrowly as:

> To develop the framework of a plan to integrate produability concepts and processes into the NAVSEA ship design process.

In order to fully address all these aspects of ship design for producibility, representatives from the Navy, shipbuilders, academia and design agents were requested to participate. The Producibility Workshop was held on 24 through 26 October 1989 at the David Taylor Research Center, Carderock, Maryland. The primary product of the workshop was an overall strategy for including producibility in the NAVSEA ship design process with an enumeration of specific actions which needed to be taken.

Workshov Definition of Produabitv

Ship producibiity takes on different meanings depending on perspective and point in time during the designlacquisitionlconstruction cycle. For the purposes of the workshop, the focus was on reducing

[2] The phrase 'early stage design' in this paper refers to feasibility studies and preliminary/contract design.

Navy ship acquisition costs through the greater use of design features and acquisition practices which facilitate shipyard production. The following definition was adopted:

> Ship producibility refers to any concept or action that reduces the ship acquisition cost without any degradation of performance.

Ideally, a successful producibility concept will provide better integration of design and production activities, resulting in savings in production labor, material and/or construction time. Given that trade-offs among these three areas can result in a combination of pluses and minuses, the net result must still be lower acquisition cost. Performance degradation includes any facet of the ship's performance after delivery, including: mission capability; maintenance/ logistics requirements; expected service life of materials; fuel consumption; or any life cycle cost increases.

The adopted definition was not ideally suited to the purposes of all of the workshop attendees. Some believed that it did not encompass their particular concerns. However, the focus was not on definition, because the purpose of the definition was to facilitate communication, not to hinder analysis.

WORKSHOP MAJOR FINDINGS

The following summaries provide an overall thrust of both the planning session and the workshop.

The overall finding of the workshop was:

- the current early stage ship design process does not adequately address producibility, and the Navy is not fully realizing the significant cost and schedule benefits of the latest advances in ship construction technology.

There are numerous reasons for this, the most important being grouped into the following six categories.

Training

- NAVSEA ship designers are not sufficiently knowledgeable of the latest advances in ship construction technology to incorporate producibility features in the design.
- Existing training at NAVSEA in ship construction technology is extremely limited.

Engineering Tools

- There are no community-wide recognized or institutionalized producibility requirements.
- NAVSEA design policies, procedures, and standards do not routinely address design trade-offs relative to ship production efficiency and lack quantitative measures of producibility.

Cost Models

- The NAVSEA ship acquisition cost estimating process used in assessing the cost impacts of different design options is not adequately sensitive to producibility considerations in a ship design.
- The process infrastructure and methods required to support the integration of acquisition, design, construction and cost engineering are not clearly identified.

StrateQ

- There is a lack of concurrent product and process design and an inconsistent approach to addressing producibility among ship designs.

Acquisition Practices

- Acquisition strategy has a large impact on design and the design approach.

- Ship acquisition practices frequently inhibit incorporation of design changes by shipbuilders which could enhance producibility.

- There are a large number of acquisition program factors which influence the ship detail design and construction process.

3-D Digital Data Transfer

- Making 3-D digital data available to shipbuilders can result in significant reductions in costs by eliminating expenses, time and errors due to regeneration of design data. NAVSEA has only limited ability to generate, utilize and transfer this type of data.

WORKSHOP MAJOR RECOMMENDATIONS

The workshop generated a number of recommendations to improve the inclusion of producibility in Naval ship designs.

Training

- Establish extensive training programs to educate NAVSEA engineers in modem shipbuilding methods and in the application of producibility practices.

Training programs are needed to educate ship design engineers in modem ship production techniques and design features which accommodate them. These need to be thoroughly and continually updated programs, coupled with "hands-on' experience that will make producibility a familiar subject to the designers. The long term goal is to enable engineers to routinely include producibiity in their design trade-offs.

Engineering Tools

- Determine the most important measures of produabihty to use in ship design.

- Update computer based ship design synthesis models to include producibiity features.

- Provide a Produabity Design Practices Manual with 'do's and don't's' to the NAVSEA ship design community.

Engineering tools constitute the technology base which will enable NAVSEA design engineers to identify, evaluate and select ship producibility concepts in early stage ship design. A produabihty design practices manual should be a catalog of lessons learned and feedback data from ship construction processes. Measures of producibility would enable quantification of pro ducibility concept trade-offs. Inclusion of producibility features in ship design synthesis models will facilitate the evaluation of ship impacts aeated by producibiity concepts. The substance of producibility engineering tools should be included in the producibility training discussed above.

cost Models

- Determine cost drivers and focus on high cost drivers.

- Modify the NAVSEA ship acquisition cost estimating process to reflect producibility aspects.

To accomplish these 'cost' recommendations, the process infrastructure and tools required to support the integration of acquisition, design, construction, and cost engineering must be identified. Next, cost analysis must be introduced during the earliest stages of this process. The cost and design communities should function as a team with both participants having been aoss-trained in the areas of cost estimating, construction, and design technologies. The cost models developed for this effort need to be sensitive to producibility constraints. They need to be structured to reflect the relationship of labor costs to changes in design and manufacturing technologies and facilities improvements. This should include material alternatives which have impacts on labor costs. These cost models can be developed by evaluating existing cost data, by examining shipbuilder proposals, and by requiring shipbuilders to structure return cost data to reflect construction procedures used. These models can be tailored to produability questions in specific designs. After the development of the costing models, a method should be establishedwherebyproduabilityconstraining actions can be identified and priced as trade-off analyses in specific designs.

Stratenv

- Navy and industry management must commit sufficient resources to ship design for improved producibility in order to realize significant resource savings during ship construction.

Improved producibility will require the establishment of produability goals and the conduct of producibiity trade-offs in early stage design. The additional "up front" producibility work will require added design funds in order to achieve a net reduction of the total resources required to design and construct a ship. With this goal in mind, the required **resources should be** quantified.

- Modify the ship design process to maximize shipbuilders' early participation in NAVSEA ship design and to foster concurrent product and process design.

The current ship design and construction process needs to be modified so that producibility is considered throughout the process. Product design is the engineering activities required which define the ship to be constructed. Process design is the definition of the process by which the ship is to be constructed. The design of the construction process is currently delayed until atIer contract design, very late in the overall design cycle. By including process design in earlier stages, all design phases will consider how design decisions will be implemented by the shipyard. The Navy can accommodate shipbuilder production processes where they are acceptable relative to ship operational requirements. This can be accomplished by evaluating the implications of designing to fit the process before basic ship configuration features become locked-in.

- Establish a framework or methodology for making producibility decisions within the ship design process.

While different ship types and programs may require focusing on different details of producibility, a generic framework should have elements common to all ship acquisition programs. A consistent systematic procedure for considering producibility during early stage design is needed in order to institutionalize producibility as an inherent part of every Navy ship design.

Acauisition PracticQ

- Revise/apply contract terms and conditions to eliminate producibility constraints and make better use of contract incentives.

- Make better use of cost plus contracts for lead ship design and construction.

Some of the most significant actions which NAVSEA can take in early stage ship design to enhance produability are aimed at removing impediments to shipbuilder producibility improvements. Many of the impediments are created by the Navy being overly sensitive to certain acquisition or contractual matters. Within the legal alternatives, NAVSEA can structure ship acquisition strategies and contract structures to facilitate shipbuilder application of more producible design solutions.

The Navy can encourage shipbuilders to use efficient construction processes by including contract incentives for increased producibility.

3-D DiPital Data Transfer

- Establish a phased program to develop NAVSEA capability to generate, utilize and transfer 3-D digital data models.

- Develop appropriate data transfer contractual mechanisms and electronic protocol.

The NAVSEA ship contract design process produces a set of specifications and two dimensional hard copy drawings which together define the ship that the Navy wishes to acquire. Many of the drawings are based on three dimensional databases which contain additional information not contained on the two dimensional drawings. Generating and transferring this 3-D digital data electronically to shipbuilders will avoid human error in the translation, will help eliminate expenses and time due to regeneration of databases, will reduce production rework man-hours due to interferences, and will result in other improvements in the transition from design to production.

Designers and builders use information in different manners and inherently categorize information differently. Additionally, there are problems inherent in the transfer of information electronically, as communications protocols must be established. The digital data protocols need to be established which are necessarily unique to the marine industry and support their use. Furthermore, NAVSEA must inaease its investment in acquiring the necessary engineering software and hardware, and in training its engineers to effectively use this powerful capability.

Summary

The recommendations generated in the Ship Design for Producibility Workshop are action items which need to be pursued for implementation. The workshop proceedings and recommendations address the basic elements of the Navy ship design process, including people, methods, processes and products. They are illustrated in Figure 1. Changes are needed in all of these elements in order to achieve the goal of improved ship design for producibility. Fundamental changes in the ship design and construction process will be required. A long term commitment to improving this very complex process is required of all involved Navy and industry participants.

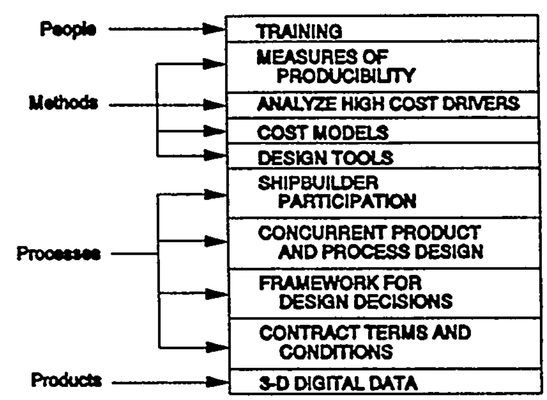


Figure 1 Design for Producibility Elements

INTEGRATING PRODUCIBILITY INTO THE SHIP DESIGN PROCESS

Like any other design process, the evolution of a ship design is a series of iterations beginning with a very broad concept and becoming more specifically defined with each iteration or stage of design. The fundamental reason for conducting the Producibility Workshop was to identify the actions which need to be taken in early stage (pre-detail) design to accommodate efficient ship construction. In order to address that purpose, it is necessary to understand:

- what is meant by the phrase 'early stage ship design,
- which elements of a ship design are "locked in" in early stage design, and
- which producibility considerations must be evaluated during early stage ship design.

This section of the paper provides an overview of the ship design process, indicates the parts of it which are referred to as 'early stage,' and describes a process for evaluating and deciding on producibility considerations during early stage design.

The description of the design process given here is brief and only sufficient to place the rest of the paper in context. The process has been described in more detail in several published works. References (12), (13), and (14) provide more detailed descriptions of the Navy ship design process.

Qvemew 0f the Naw Shiv Desim Process

Figures 2 and 3 illustrate the nominal phases of the Navy Ship Design Process and how they fit into the Department of Defense (DOD) Acquisition Process. Initial requirements are derived from threat assessments coupled with operational analysis. The desired ship characteristics are estimated during exploratory design performed within the Navy. The resulting operational requirements for a new ship acquisition form the starting point for the design process.

Ship design now proceeds through phases: feasibility studies, in which key characteristics of the ship are firmed up (i.e. major dimension, weights, configuration); preliminary design during which all technical areas are initially engineered; and contract design, where the final technical package (i.e. drawings and ship spetication) is developed for a contract award. These phases typically take over two years to complete and constitute what is referred to throughout this report as early stage design. The Navy generally develops its own designs, but interested shipbuilders are often involved during contract design to provide guidance on construction preferences before the specifications are finalized. Concurrent with the engineering work are the programmatic and logistics preparations. Part of this effort is incorporated into the contract, which contains numerous requirements for detail design and construction.

A Conslstent Process for Produciiilitv Desizn Deasrons

What is needed is a consistent decision process for integrating producibility into the many different naval ship designs. A true integration requires a new 'way of thinking,' a new attitude or culture that makes producibility an integral part of Navy ship acquisition activities.

The general approach to producibility will be the same no matter what type of ship is involved. However, the details of the analysis and the related results in a particular ship acquisition program will depend on many aspects, including: number of ships to be built, submarine or surface ship, combatant or non-combatant and degree of complexity. The competitive structure of the industry is also important. For an airaaft carrier construction program, there is only one qualified bidder; for modem submarines, two bidders; for major surface combatants not more than half a dozen; and about a dozen for small non-

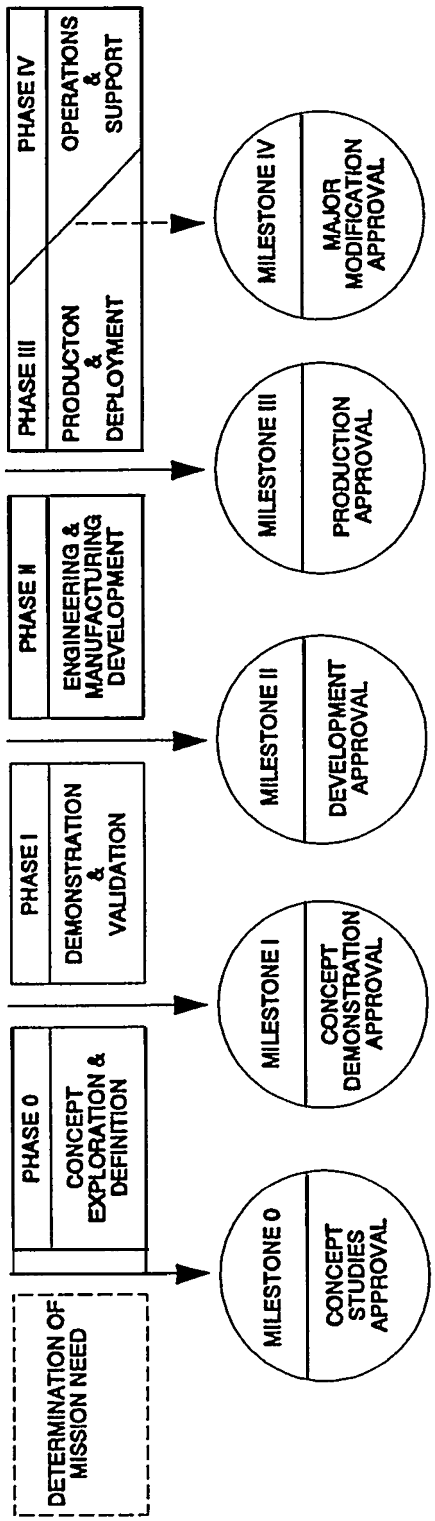


Figure 2 DOD Acquisition Process

combatants. Because of the wide range of factors involved, each acquisition program must be examined on its own merits in order to define the most appropriate producibility approach. These factors will form the basis of decision criteria to be applied in analyzing potential producibility concepts in specific ship designs. References (3), (9), and (15) describe examples of producibiity issues which have been considered during the design efforts of three specific ship acquisition programs.

A Framework for Produabilitv Desia Decisions

While different ship types and programs may require focusing on different details of producibility, a generic framework should have elements common to all ship acquisition programs. Although the Producibility Workshop definition for producibility did not allow for any degradation of performance, the process does provide a means to trade-off improved producibility against performance. A systematic plan for considering producibility in the design and construction process should cover four steps, which follow:

1. Identify potential producibility concepts.

2. Evaluate producibility concept ship impacts and estimate cost.

3. Select desirable producibility concepts.

4. Provide a lessons learned mechanism and feedback loop.

These steps are shown as an iterative evaluation model in Figure 4, which was provided by Professor Henry S. Marcus of Massachusetts Institute ofTechnology (MIT) (who was instrumental in initiating the workshop). The evaluation model presented here is generalized and simplified. The four key steps can relate to analysis of a

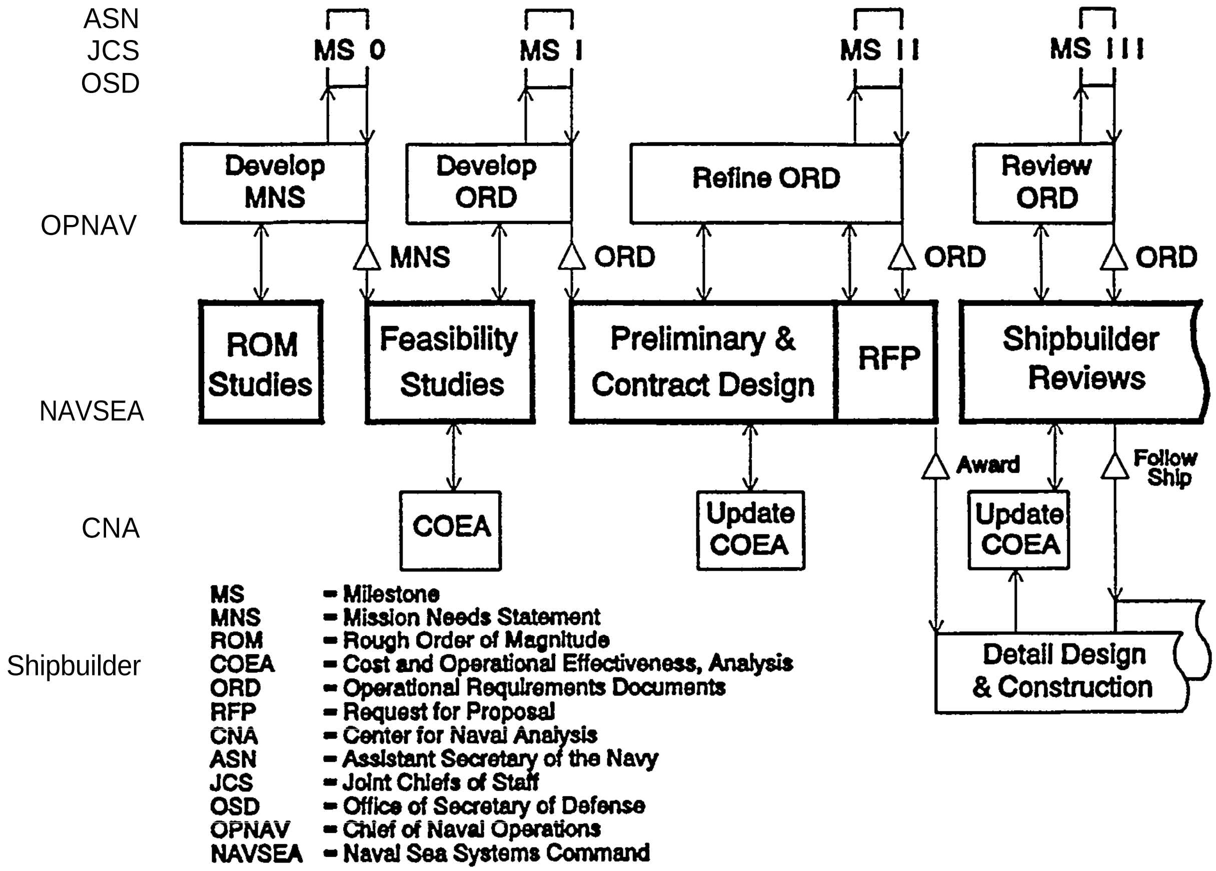


Figure 3 Overview of the Navy Ship Design Process

subsystem component or a dramatic new way of integrating design and production. The parallelograms indicate data bases, the content of which will vary with the topic under analysis. The rectangles refer to key activities (although in the interest of simplification, more than one activity may be involved in a single rectangle). The diamonds indicate key "Go/No Go" decision points.

The criteria used in this general model may also vary. The straightforward definition for produability used in the workshop demanded that a good producibility concept must reduce ship acquisition cost without any degradation of mission critical performance. A more complicated criterion might allow for trade-offs between produability and other ship design attributes. In addition, it may be desirable to use different criteria at different design phases.

The Navy has conducted producibility enhancement efforts for several ship designs. The main characteristics common to these efforts have been shipbuilder suggestion inputs and Navy review of the suggestions. Though these efforts have led to the acceptance of many beneficial ideas in Navy designs, they have not realized full potential. In most of the past Navy efforts, there was no systematic approach to review, no means of judging cost/effectiveness, and no decision criteria as a basis for selecting producibility concepts. The approach of treating producibility in an unstructured, subjective manner is inefficient, and less than fully effective.

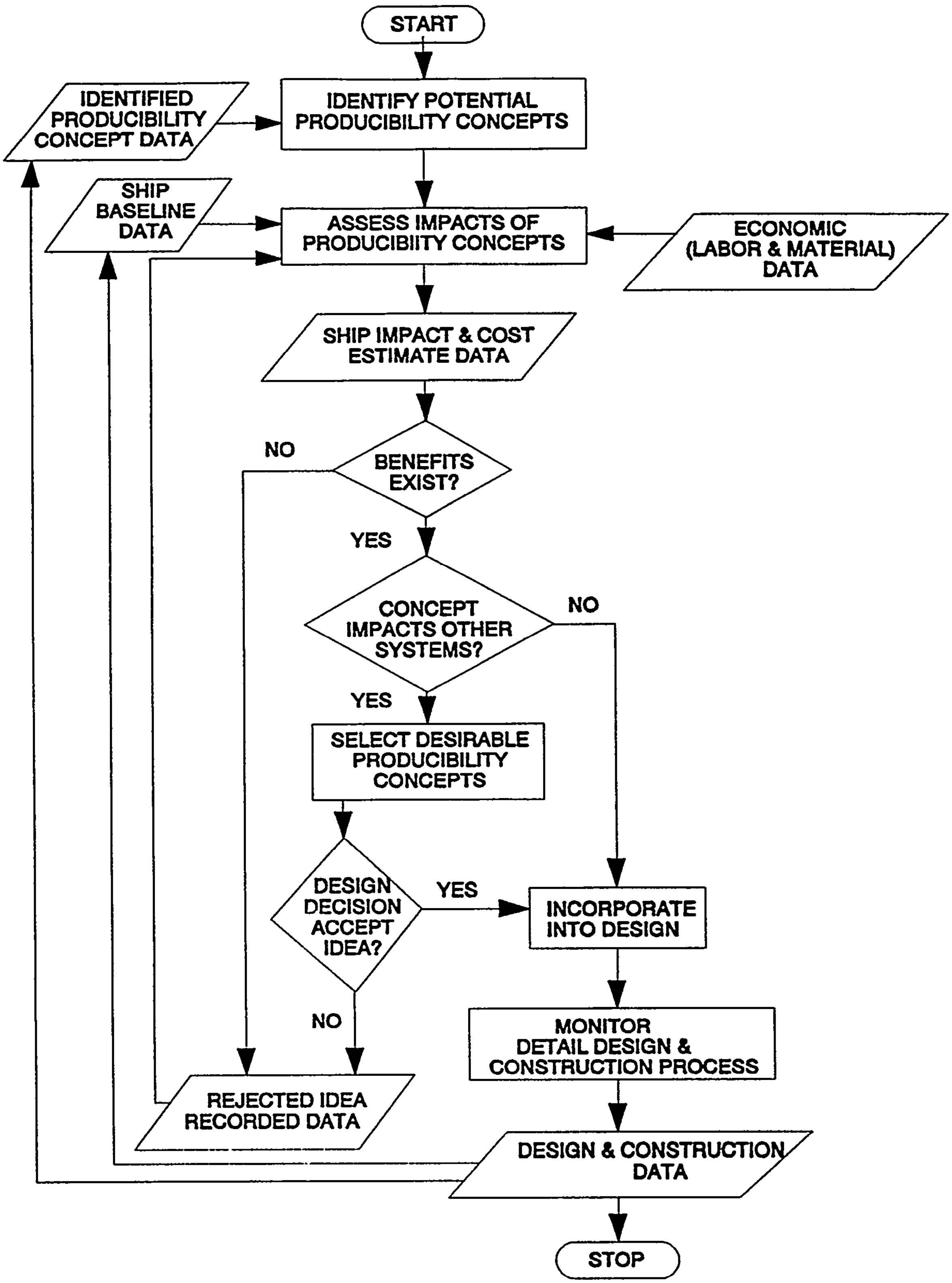


Figure 4 Framework for Producibility Design Decisions

The unstructured approach to designing for producibility lacks selection criteria, which results in inconsistencies in review and evaluation modes. In one ship design, for example, the Navy received over 4,000 shipbuilder ideas, and the review of these was unstructured. Receipt of shipbuilder comments at non-specified times complicated NAVSEA response mechanisms and the sheer numbers were an unmanageable quantity within the time allowed. The approach to collect suggestions was not exhaustive and there was no rationale for selection of suggestions for review and evaluation. The reviewers had neither the time nor a systematic means of quantifying producibility enhancement. The decision makers were provided with too little, too much or the wrong type of information necessary to make good decisions.

The shortcomings of past NAVSEA ship producibility efforts can be alleviated by developing tools to quantify costs and effectiveness of concepts and by integrating producibility efforts into the main stream of NAVSEA ship design development. There have been benefits from past NAVSEA producibility efforts. There is potential for significantly greater benefits through use of a rational, structured approach to identity, evaluate and select producibility enhancements.

NEAR TERM ACCOMPLISHMENTS

Since the October 1989 workshop progress has been made on many of the workshop major fmdings and recommendations. Significant accomplishments have occurred in training of NAVSEA ship design personnel, integrating producibility in ship design and acquisition strategies, and implementing 3-D digital data transfer. Little progress has been made in development of engineering design tools for evaluating the producibility of alternate designs, improvement in cost models that can quantitatively assess producibiity changes in design, and modiication of acquisition practices to maximize benefits of producibility. The following is a summary of progress in each of the six categories of workshop findings and recommendations.

TRAINING

Training NAVSEA ship designers in ship construction methods and producibility concepts was the top priority recommendation of the workshop and significant progress is being made in achieving this objective. Training, or more appropriately, education, has been a continuing and widening process including formal training courses offered at NAVSEA, on the job training and work assignments, and formal graduate level education under NAVSEA's long term training program. The following are a few examples of progress being made in this area:

NAVSEA Professor of Ship Production

For a number of years, NAVSEA has had a Memorandum of Understanding (MOU) with the University of Michigan. This MOU established the position of NAVSEA Professor of Ship Production, currently held by Professor Howard M. Bunch, who has developed educational and training courses for NAVSEA ship design engineers. The courses developed include:

- Advanced Ship Production,
- Design for Producibility, and
- Quality Function Deployment.

These courses have been taught by Professor Bunch under the auspices of the NAVSEA Institute and have been attended by approximately 300 NAVSEA personnel. These initial courses have emphasized basic or fundamental knowledge. As results are achieved in the development of new tools and techniques, these will be incorporated into the training. Finally, as shipbuilding technology continues to evolve, new lessons learned must feedback and be taught to the early stage ship designers.

NSRP Particination

NAVSEA commitment to NSRP has provided the opportunity for many NAVSEA engineers to participate on various NSRP panels. NAVSEA engineers are actively participating in panels SP4 (Design and Production Integration), SP-6 (Standards), SP-9 (Education). NAVSEA participation in the Executive Control Board (ECB) has been increased to include representation of NAVSEA Ship Program Managers. Inaeased participation in NSRP is offering immediate feedback and training to NAVSEA personnel. This feedback will keep NAVSEA engineers in touch with ongoing research in this area.

Shinvard On-Site AssiPnment of NAVSEA Shio Design Manager (SDM)

One of the many findings of the DAC Process Improvement Study was that NAVSEA should collocate the SDM at the Resident Supervisor of Shipbuilding (RESUPSHIP) Office during the Detail Design phase. The typical NAVSEA Contract Design package has a large number of contract drawings, contract guidance drawings, specification pages, project peculiar documents, study plans, etc. The transition phase from the NAVSEA Contract Design to the Shipbuilder Detail Design typically generates a significant number of questions, highlights mistakes in the contract package and general misunderstandings of the drawings and/or specifications. This transition phase is critical to the overall success of the shipbuilding program.

The T-AGOS 23 Construction program was selected as the NAVSEA prototype program for assignment of the SDM. The T-AGOS 23 has the challenge as the U.S. Navy’s largest Small Waterplane Area Twin Hull (SWATH) ship. The intent was to improve the transition from design to production by solving minor and some major design problems in real time, on-site at the RESUPSHIP in Tampa, Florida. This particular shipbuilding program is supported at RESUPSHP by Military Sealift Command Construction Representatives (MSC CONREP). The small integrated team of NAVSEA SDM, MSC CONREP, and RESUPSHIP personnel worked closely together towards achieving these objectives, that is to solve problems in a timely manner and get it right the first time. The SDM’s participation locally at RESUPSHIP offered the opportunity to have an instant NAVSEA response as anunofficial member of the RESUPSHIP staff.

The T-AGOS 23 was awarded to Tampa Shipyard on 28 March 1991. The six-month experiment at RESUPSHIP Tampa started in July 1991. The results of this prototype assignment were very encouraging. The SDM was warmly received by both RESUPSHIP and MSC CONREP. Numerous design questions were promptly answered. Several critical engineering change proposals were prepared by the SDM in the field and were quickly sent to the shipbuilder. The assignment of the SDM to the field offered the unique opportunity for all participants to better understand each other’s perspectives and provide a synergism not available dealing through the mail system or through periodic design reviews. The SDM gained “profound knowledge’ of detail design issues, errors in the contract design package, and ship producibility and vendor issues. The field office had the opportunity to better understand the rationale and logic of the contract design package and to more expeditiously get up on the learning curve of unique SWATH technology.

This assignment of the SDM to the RESUPSHIP Office is highly recommended for future shipbuilding programs. The SDM’s tour of duty should be extended for the duration of the detail design. In larger shipbuilding programs, this approach should be extended to the NAVSEA Hull Systems, Ship Machinery Systems, and Mission Systems engineers.

In summary, NAVSEA's commitment to educating and training its ship design and acquisition personnel has made good progress since the Produability Workshop. However, classroom instruction cannot take the place of on-site practical experience. Assignment of early stage ship design personnel to detail design projects at RESUPSHIP Offices is encouraged for all new ship acquisition programs.

ENGINEERING TOOLS

The Producibility Workshop recommendations pose a significant challenge to the Naval ship design and shipbuilding community. In order to produce quantifiable producibility engineering tools that can be of aid in early stage ship design, the naval shipbuilding community will have to develop databases of producibility lessons learned, producibility measures of effectiveness, decision making tools, etc. The long term goal is to integrate engineering tools that address producibility as a primary attribute into the earlier stages of the ship design process.

NAVSEA has a number of ongoing initiatives to achieve this longer term objective. Initiatives have been undertaken with the DOD Small Business Innovative Research (SBIR) program and the NSRP. Successful results from these initiatives will be the foundation of these future engineering tools.

SBlR Proiecb

NAVSEA is participating in the Fiscal Year (FY) 92 DOD SBIR Program. This program strives to encourage scientific and technical innovation in areas specifically identified by DOD. Phase I of SBIR projects is to determine the scientific or technical merit and feasibility of ideas (about a l/2 man-year effort). lf Phase I proves to be feasible, DOD will consider further work in Phase II (about 4 to 10 man-years of effort).

NAVSEA has submitted five proposals into the SBIR,program in this area. As of June 1992, contracts were yet to be awarded to pursue the Phase I proposals. The NAVSEA SBIR topics include:

1. Development of Naval Ship Producibility Lessons Learned Database,
2. Shipyard Productivity Measurement,
3. Life Cycle Cost Models for Naval Ship Design,
4. Analysis of Strategic Defense Industrial Technologies, and
5. Modeling Naval Ship Construction Delays.

NSRP - SP 4 Panel Tasks

NSRP SP 4 (Design/Production Integration) has a number of ongoing initiatives that are directly related to development of future engineering tools to aid the designer in addressing producibility during the early stages of ship design. The tasks funded are:

1. Development of Producibility Evaluation Criteria for U. S. Naval Ship Design. This task was funded in the FW 90 NSRP program. The final report is in the process of being submitted for NSRP publication. This study was initiated to:

   a. identity criteria by which the producibility of a design can be evaluated based on the actual work content involved in constructing the design at a shipyard, and

   b. develop standard procedures for using those criteria in evaluating producibility of specific design proposals.

   The results of this ongoing task are presented as part of the 1992 Ship Production Symposium.

2. Development of Generic Build Strategy. This task was approved for the 1992 NSRP program. As of June 1992, the contract for this task has yet to be awarded. This task will produce a generic build strategy as well as a master construction plan to serve as a guide for early stage design and future ship construction planning.

Dynamic Decision Model

During the DAC Process Improvement Study, many process improvements were identified. While consensus was reached that each idea would have a positive effect on the overall process, there was no means to evaluate just how effective the change might be prior to implementation. Toward the end of DAC Phase I, the study team became aware of the possibility to model the whole ship design and acquisition process on a computer. This tool would allow proposed changes to the process to be evaluated as to their impact on time, cost and quality.

A dynamic decision model was chosen for process change evaluation. Such a model, based on ideas of MIT Professor Jay Forrestor, uses control system theory to describe the interactions of a process, allowing for feedback, time, cost, and quality predictions. As of June 1992, the model is in the prototyping stage and operational to a modest level of detail for the design portion of the DAC process. Near term efforts will be to calibrate the model's performance against known past ship designs and test how changes affect the DAC process.

Development of turn-key engineering tools that are quantitatively sensitive to producibility is the goal for early stage naval ship designers. NSRP and NAVSEA have barely saatched the surface in this important area.

COST MODELS

As stated above, little progress has been made in improving cost models such that they can be used to quantitatively assess producibility changes during early stages of design. The first step in improving cost models is the collection of cost data that are consistent with shipbuilding processes.

It has been proposed that NAVSEA conduct a pilot study to resolve problems associated with maintaining cost data continuity. The pilot study would address two major concerns: (1) tracking cost information from the initial budget submittal through ship delivery; and (2) identifying information which will permit NAVSEA to manage and improve internal processes using actual data from the shipbuilders and the participating managers (PARMs) responsible for government furnished equip ment.

The development of accurate cost trends is an essential ingredient to making informed decisions. This requires the capability to resolve differences between similar classes of ships which can have a significant impact on cost forecasts if not properly addressed. By standardizing shipbuilding data collection at a level which permits flexible accounting of programmatic decisions, these difficulties can be resolved.

The concept of managing and improving processes using data is the cornerstone of the Deming philosophy. To gain control of internal processes costs must be captured in an appropriate manner. NAVSEA does not currently collect data from either the shipbuilders or PARMs in a manner useful for managing internal operations, although we are fully committed to continuous process improvement.

The people within NAVSEA who must determine which data, from the vast array of information available, is needed to improve operations are the senior managers who jointly own the internal processes requiring change. Many of these senior managers are currently working on teams as members of three Quality Management Boards (QMBs), sponsored by an Executive Steering Group (ESG), working on behalf of the DAC Process Improvement Program (16). Using the tools developed to support TQL, the QMBs will be asked to identify the Critical Evaluation Factors (CEFs) they would use to measure improvement and manage internal processes.

The cost of acquiring data can be very expensive; therefore, NAVSEA must foster an attitude of not collecting data unless they have specific plans for its use. The possibility that additional information will be required from the shipbuilders and PARMs is real; however, some of the information currently being requested may not be necessary. ln these cases, steps should be taken to eliminate these data submittal requirements.

Considerable planning has been accomplished in support of this pilot study. The need for process improvement in the area of standardizing shipbuilding cost data collection has been carefully documented. The notion that maintaining continuity of cost information throughout the acquisition, managing with data, only requesting needed information, using information wisely, and taking steps to work smarter will allow NAVSEA to be more efficient and better serve its customers. These cost data collection improvements are essential to improving the ship acquisition cost estimating process and ultimately developing cost models that are sensitive to produabity considerations in ship design.

STRATEGY

In June 1991, NAVSEA published a Strategic Plan for Improving the Ship DAC Process (17). The objective of the plan as defined by the NAVSEA Chief Engineer is:

> To identify the critical actions necessary to improve the quality of future ship designs (i.e., meeting customer's requirements) to reduce ship construction costs, life cycle costs and to reduce the time required from establishment of requirements to delivery of the lead Ship.

The DAC Phase II team is working on the implementation of the major recommendations from the Strategic Plan.

<u>Produabilitv Review Teams</u>

NAVSEA has established a framework for making producibility decisions within the ship design process. For new ship acquisitions, Producibility Review Teams are established and are an integral part of the design process for each new design. The Producibility Review Team has multidisciplined membership. Team membership is comprised of knowledgeable and experienced representatives from NAVSEA technical, program management, and contract codes; industry produability consultants; academia; and shipbuilders. Producibility Review Teams have been established and are making producibility decisions on the DDG 51 Flight IIA and CVN 76 ship designs.

<u>(37N 76 Ship Des&m</u>

The most significant proposed producibility improvements involve modifying the build strategy and addressing long lead time contractor furnished material. Improvements to the basic build strategy must be defined before construction starts. In order to execute a build strategy that inaeases the amount of preouthtting, the critical material must be available. For this reason, the Producibility Review Team recommended that the Navy enter into an advanced planning contract with the shipbuilder to provide sufficient time for the development of a revised build strategy and for the purchase planning of long lead time material.

During contract design a significant producibility improvement effort is planned. The build strategy will be maintained, and wilI be used to evaluate design changes which wiE also be evaluated for produabity. The development of a cost model based on the production process rather than weight is being investigated to support estimating the cost savings of produabiIity improvements.

S Inbuilder Particination

NAVSEA is currently maximizing shipbuilder participation in early stage ship designs that are limited to only one or two shipbuilders capable of building the ship. These designs include the DDG 51 and the CVN 76.

Not much progress has been made on ship designs that have a high number of potential shipbuilders. Fiscal constraints during the early stages of design and/or difficulty in determining how to down select to a smaller number of potential shipbuilders are the major causes.

ACQUISITION PRACTICES

While much of the Producibility Workshop dealt with changes needed in the NAVSEA ship design process, the workshop participants also recognized that some aspects of the broader ship acquisition process can inhibit or enable producibility improvement. Some contracting approaches, acquisition strategies and construction contract clauses can act to discourage or incentivize shipbuilders to design for produability. The summary findings and recommendations of the workshop with respect to Acquisition Practices are listed in Tables I and II. Little progress has been made to date to implement these recommendations. However, a few recent initiatives have been taken to begin to address these important but difficuk improvements to the ship acquisition process.

NAVSEA Professor of Shin Awisition

Since completion of the 1989 Producibility Workshop, NAVSEA has established a MOU with MIT. This MOU established the position of a NAVSEA Professor of Ship Acquisition, currently held by Professor Henry S. Marcus. As of June 1992, Professor Marcus has concentrated his research in the following areas:

- evaluating vendors/suppliers,
- international technical standards,
- contract Ianguage - case studies of three contracts,
- contract streamEning during emergencies (USS STARR and USS SAMUEL B. ROBERTS),
- comparison of TQL in three naval shipyards, and
- feasibility of having one shipyard subcontract to another (modeling production aspects).

Acquisition QMB

As part of the implementation phase (Phase II) of the Ship DAC Process Improvement Program, NAVSEA recently estab Iished an Acquisition QMB (16). The Acquisition QMB has oversight over two Process Action Teams (PATs) which have been chartered to implement specific recommendations from the DAC Strategic PIan (17), developed during Phase I. The DAC Phase II organization is shown in Figure 5. The Acquisition QMB PATs are determining how to implement the Phase I recommendations pertaining to the Acquisition Pro cess (PAT B-l) and the use of Product Oriented Design and Construction (PODAC - PAT D-l). The PAT B-1 objective is to modify the Preliminary and Contract Design process such that there wi.U be one continuous design process from Milestone I through contract award. PAT D-l is discussed below.

Table I Major Acquisition Process Influence Factors From Working Group 5

TYPES OF ACQUISITION APPROACHES

1. Contract terms and conditions.
2. Type of contract for ship detail design and construction.
3. Number of ships ordered.
4. Degree of participation by shipbuilder in pre-detail design.

TECHNICAL PRODUCT DEFINITION

1. Level of detail of Navy shipbuilding specifications.
2. Extent of guidance drawings.
3. Number of changes after contract award.
4. Systems based contract design.
5. Extent of use of CAD.

TECHNICAL PRODUCT REVIEW AND MONITORING

1. Government reactions to shipbuilder submittals.
2. Requirement for system oriented CDRLs.
3. Program reviews to enhance producibility.
4. Quantity of CDRL items.
5. Compatibility of Navy design and acquisition with shipbuilder zone approach.

OTHER ACQUISITION INFLUENCES

1. Extent of Navy incentives.

Table II Acquisition Process Recommendations From Working Group 5

TYPES OF ACQUISITION APPROACHES

1. Revise/apply contract terms and conditions to eIiminate producibility constraints and make better use of contract incentives.
2. Make better use of cost plus contracts for lead ship detail design and construction.
3. Maximize use of multiple ship orders.
4. Maximize early participation by shipbuilder in design; select shipyard(s) prior to contract design phase.

TECHNICAL PRODUCT DEFINITION

1. Carefully consider detail of Navy shipbuilding specifications.
2. Maximize use of guidance drawings.
3. Emphasize configuration management.
4. Use of zone design/specs vs. system design/specs.
5. Maximize use of CAD.

TECHNICAL PRODUCT REVIEW AND MONITORING

1. Improve Government responsiveness.
2. AIIow use of zone-oriented vs. system oriented CDRLs.
3. Evaluate use of program reviews to enhance produability.
4. Evaluate quantity of CDRL items.
5. Better align Navy design and acquisition with shipbuilder zone approach.

OTHER ACQUISITION INFLUENCES

1. Encourage use of modular procurement.

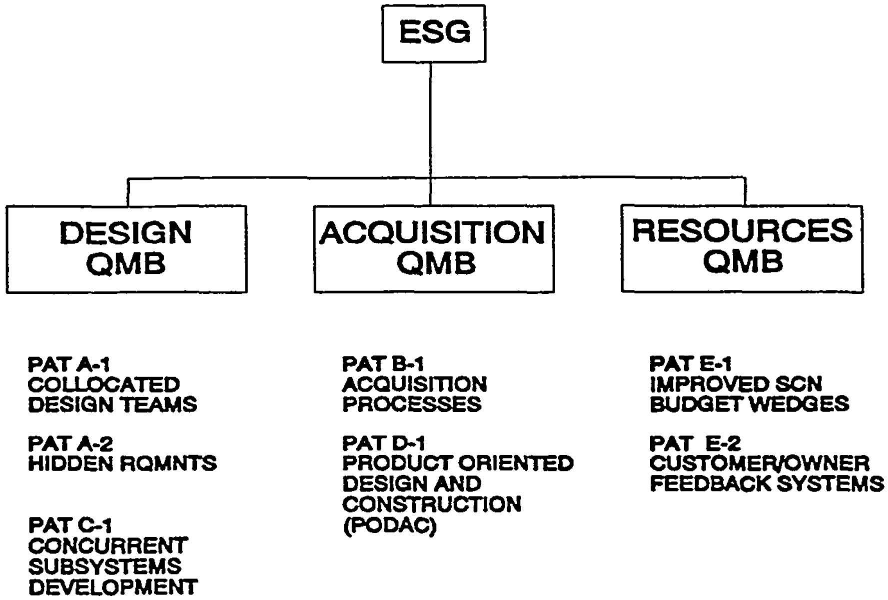


Figure 5 DAC Phase II Organization

Contract Strategies

Recent direction from the Secretary of Defense has changed acquisition practices from the 1980s. During the 1980s, the direction was to utilize firm fixed price shipbuilding contracts, even for the lead ship of a new class. The current acquisition strategy for the lead ship of a new class is to utilize cost contracts and contracts that have award fees. This decision will offer ship acquisition managers flexibility in contract development to incorporate potential producibility initiatives specific to the ship platform.

As a result of the Navy DDV study, affordability initiatives are aggressively being pursued during the DDG 51 Flight IIA Contract Design. This initiative is a cooperative effort between the Navy and the participating shipbuilders. The goal is to reduce hull, mechanical, and electrical engineering costs by $30M per ship.

3-D DIGITAL DATA TRANSFER

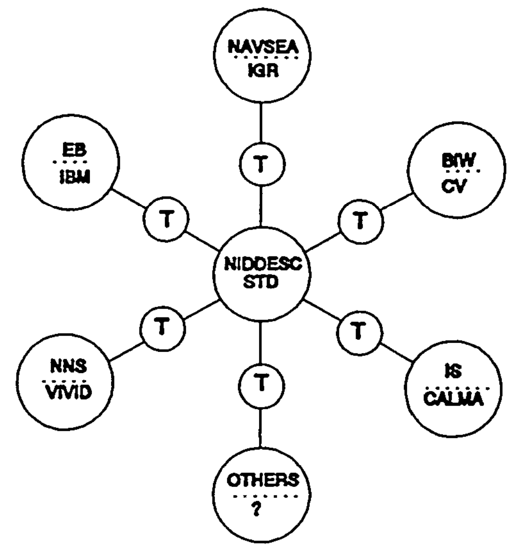
The naval ship design and shipbuilding community is making significant progress in the area of 3-D digital data transfer. During FY 91, NAVSEA awarded a Computer Aided Design (CAD) II contract to Intergraph Corporation. Billingsley (18) emphasized that availability of this contract to NAVSEA's early stage ship designers has the potential for 'revolutionary' improvements to the ship design process. By the end of FY 92, the principal technical codes within NAVSEA will be operating with the same CAD hardware (over 150 workstations) and software that is integrated. Training of in-house NAVSEA personnel has begun. Integration of CAD II systems to specialized ship design analysis tools has begun. This integrated approach will offer significant productivity gains in 3-D digital data transfer within NAVSEA.

Naw-Industrv Drmbl Data Exchange Standards Comnuttee fNIDDRSQ

A normal contract package from NAVSEA for new construction of a ship is an impressive quantity of documentation. The transition of the design is in the form of specifications, contract drawings, contract guidance drawings, project peculiar documents, design criteria manuals, etc. This wealth of documentation requires months of detail design effort to replicate into a zone-oriented design ready for production. In 1986, a cooperative Navy-Industry organization was established to tackle a data exchange agreement.

NAVSEA and the marine industry have been working together as members of NIDDESC (19). NIDDESC members have been working on development of a product model definition. NIDDESC has developed six application protocols. These protocols are based on Product Data Exchange Standard (PDES) entities. These entities provide a content and format standard for data. The data for exchange is both graphic and non-graphic. Product model information can be easily converted into traditional drawings.

Figure 6 displays an example of the connectivity between Product Model Systems developed under the NIDDESC organization. This shipbuilding standard will greatly aid in consistent data transfer between all concerned government and contractor organizations. The intent for product models is not to support only new construction but to maintain ship design information throughout a ship's life cycle (20).



IGR - Intergraph Corporation
- General Dynamics Electric Boat
E V - Bath Iron Works
- Ingalls Shlpbulldlng
FNNS - Newport News Shlpbulldlng and Dtydock
NIDDESC - Navy-Industry DIgItal Data Exohange Standards Commlttw
IBM - International Business Machines

Figure 6 Connectivity Between Product Model Systems

3-D Digital Data Transfer Between NAVSEA and Private Shipbuilders.

Most of the work sponsored to date by NIDDESC addresses the digital data transfer between shipyards, as is the case between the lead shipbuilder and the follow shipbuilder. However, the first critical transfer of 3-D digital data is between NAVSEA and the lead shipbuilder. NAVSEA and NSRP have recognized the critical nature of this transfer and have approved a SP-4 project entitled 3-D Digital Data Transfer to Shipyards.

The objective of this project is to identify those digital products which, if transferred to shipbuilders, would result in cost and time savings. These savings would result from the shipbuilder being able to avoid the costs and time associated with the regeneration of data and to more clearly identify to the NAVSEA ship designers the digital data required for advanced manufacturing. The identification of digital data transfer benefits to shipbuilders could result in modification of the NAVSEA contract design process to facilitate both the development and transfer of ship design information in an agreed upon digital format.

Currently, the NAVSEA contract design process produces hardcopy deliverables such as drawings for delivery to the shipbuilders. As Billingsley recently noted (18) NAVSEA is in the process of a revolutionary upgrade of its in-house CAD capability. This 'revolution' is being ignited by the purchase of over 150 CAD II engineering workstations and will eventually result in NAVSEA's contract design deliverable being a full 3-D digital data product model. The successful transfer of digital data between NAVSEA and shipbuilders requires:

- agreement on the information (data) to be transferred,
- agreed upon formats for the data, and
- contractual mechanisms to require both development and transfer.

The NSRP working in close cooperation with NIDDESC is the ideal forum for the development of such agreements. This project has significant potential benefits to the Navy and is consistent with the new goals of the NSRP; they are:

- improved manufacturing cycle efficiency,
- commitment to quality,
- expanded industry, government and academic participation in NSRP infrastructure, and
- capability of building to international standards.

Several papers on this subject will be presented during the 1992 Ship Production Symposium. NAVSEA has made significant progress on implementing the Workshop 3-D Digital Data Transfer recommendations. However, much work remains ahead to have the Navy and a majority of the marine industry standardized on the results of the NIDDESC work.

THE WAY AHEAD - LONG TERM STRATEGIC PLAN

The most significant progress since the workshop in 1989 is the increased awareness of and attention given to ship producibility by the senior military and civilian executives throughout the Naval ship design community. As described above, much progress has also been made in educating NAVSEA design engineers concerning ship producibility; establishing formal Producibility Review Teams for new ship designs as a framework for bringing NAVSEA ship designers and shipbuilders together to work as a team in evaluating and making producibility design decisions; and defining the geometry of the ship design in a full 3-D digital data model which can be readily transferred between different computer systems, and zonal versus systems definitions.

On the other hand, much work remains to be done to provide the early stage ship designers with the design methods, cost models and evaluation criteria to fully integrate produability into the NAVSEA ship design process (21). It is the authors' opinion that the fulI impact of concurrent engineering (that is, designing the construction process by which the ship will be built at the same time the ship is being designed) has not yet been realized. The potential impact on the ship DAC process is monumental, but the potential benefits in terms of reduced *time* and cost *are also monumental*. For this reason, the senior leadership of NAVSEA have personally endorsed a time-phased strategic plan for the 'Way Ahead.'

Design. Acquisition. and Construction (DAC) Process Improvement

The Way Ahead is built on a foundation of continuous process improvement of the DAC process and a number of pillars deriving from the DAC Strategic Principles. Two of these pillars are PODAC and Affordability Through Commonality (ATC), which are discussed below.

The DAC project has established strategic principles which provide a framework for continually improving the DAC process. These strategic principles are:

- customer focus/customer understanding,
- long range planning,
- concurrent ship and system development,
- availability of appropriate resources,
- Navy/shipbuilder/supplier partnership,
- total ship engineering,
- 'Best Known Method' build strategy,
- data continuity throughout ship life cycle,
- continuity of the ship development process,
- senior management commitment and involvement,
- fact-based management,
- process training, and
- process technology investment.

Ryan and Jons discuss each of these principles in reference (22).

PODAC

The results of the Produability Workshop and the DAC Study pointed out that more efficient ship construction processes could be used for the construction of Navy ships. As emphasized in reference (17), full implementation of PODAC is the best known method for reducing the time and cost of the ship construction process.

The major premise of product oriented ship construction is to integrate hull assembly, outfitting, and painting as early in the construction process as possiile.

PODAC is a concept for building a ship as a series of interim products, rather than system by system. Once interim products are defined, group technology principles can be applied for systematically classifying them into groups or families having design and manufacturing attributes sufficiently similar to make batch manufacturing practical. Process lanes can then be established for the efficient manufacture of similar interim products providing for efficiencies of batch manufacturing for small numbers of ships. Once process lanes are established, workers assigned to these lanes quickly become experienced in recognizing and avoiding manufacturing problems associated with those products and processes.

Additionally, the application of process control through statistical analysis of interim product accuracy can be implemented because similar interim products are being manufactured - providing a continuous feedback loop on the process.

Product-Oriented Design and Construction concentrates on optimizing the design and construction of interim products. Similar interim products coming off a dedicated process lane can be applied to naval combatants, commercial ships, drill rigs, floating or land based power generation plants, etc.

Most U.S. shipyards currently use some degree of product oriented construction. However, the level of implementation varies from shipyard to shipyard, and even between ship types in the same yard. U.S. shipyards have made significant improvements in hull fabrication and erection, and this remains the dominant activity in most shipyards. Other functions such as outfitting and painting are not being accomplished to the same degree.

Navy and shipyard management must fully agree that this is the most productive method for ship construction and commit to its implementation.

Industry and Navy must work together to develop generic or ship-specific build strategies describing how Navy ships will be built in accordance with Product Oriented logic and principles. The build strategies should be used to guide the Navy's Preliminary and Contract Design efforts. Working with industry the build strategy should be continually refined as the Navy design process continues, but when contract design is complete the build strategy should be known to all who plan to bid on construction.

PAT D-l has been chartered to develop a plan to implement the logic and principles of PODAC throughout NAVSEA and the shipbuilding industrial infrastructure. The PAT D-l plan of action is as follows:

1. In conjunction with the shipbuilding industrial infrastructure, develop a high level definition of the PODAC process.

2. Obtain a high level commitment to implement PODAC beginning in the early stages of design through delivery and life cycle support of Navy ships.

3. Develop a baseline description of the entire PODAC process including responsibilities, products and tools required at each stage of the process.

4. Identify constraints to the implementation of the PODAC process.

5. Develop incentives which would institutionalize the continuous evolution and improvement of the PODAC process.

6. Provide the expected time and cost benefits to be derived in the phased implementation of PODAC.

ATC

The ATC study team had its beginnings in discussions of the initial findings of the DAC effort and the ever-increasing affordability crisis within the country's defense industry. These discussions between senior managers within NAVSEA led to the suggestion of commonaliiv as the best hope for the future of Naval ship DAC. An interdisciplinary study team was formed in January 1992 to investigate the potential benefits of commonality, serve as a node for commonality information, and, if warranted, serve as a catalyst for highlighting the potential benefits to higher-level decision makers. Initial efforts centered on reviewing previous Navy and commercial applications of increased commonality and deciding on a level of commonality focus. A wide range from common components up to a single common ship was considered. The ATC team has chosen to focus upon the intermediate sub-system and system levels. Commonality was defined by the ATC team as:

> The use of common modules in fleet wide applications to reduce the design, construction, life cycle and infrastructure costs of Navy ships.

The ATC team's early focus has been on HhMrE systems, while acknowledging the future potential leverage and importance of Command/Control/Communication/Computers/Intelligence (c41) systems.

Three elements of commonality are advocated:

- standardize/ fewer components in modularize larger sub-assemblies,
- improve efficiency — more fabrication and testing accomplished in the more efficient shop environment, and

· reduce construction time:	rapid assembly of large subassemblies.

There are obvious tie-ins to several of the DAC PATs shown in Figure 5, in particular, PAT-C-l (Concurrent Subsystems Development) which is pursuing a design budgeting or 'turn-key' approach to installing communications equipment in new construction ships and PAT D-l with an objective of increasing PODAC of Navy ships. There is also a common thread with PAT A-l (Collocated Design Teams) as ATC is set up as a collocated design team. Many elements play in the ATC team achieving its objectives: technical, strategic planning, industry liaison, specifications and standards, and programmatics, to name just a few. Current pilot module concept design projects include an Advanced Surface Machinery System (ASMS) power module, auxiBary machinery modules and berthing modules. ATC is implementation oriented with a proactive strategy for the assemblage of resources required to accomplish a radical long-term change to the process of designing, acquiring, building and supporting Naval ships.

With the active support of senior military and civilian executives within NAVSEA, the ATC concept has been presented widely. Other senior leaders within the Navy have also committed their support. The Commander of NAVSEA recently presented a proposal to the Presidents' Club of the American Society of Naval Engineers and the Shipbuilders Council of America, and support has been very strong. The first ATC industry briefing was held in late April at DTRC. The challenge now is to convert a small study team into a larger and broader-based program implementation team with the resources to accomplish the daunting task of transitioning to an alternative process for ship DAC involving increased levels of commonality. The NSRP can play an important role in helping NAVSEA achieve the objectives of ATC. Together, NSRP and NAVSEA can form a partnership that will benefit the shipbuilding industry in becoming more competitive in the international market and thus benefit the Navy in maintaining an industrial base critical to its future.

SUMMARY

The changes facing the nation, the Navy, NAVSEA, and the U.S. shipbuilding industry in the years ahead are immense and (as recent events have shown) largely unpredictable and rapidly increasing. Most large organizations and industries adapt to change relatively slowly (and do so seemingly reluctantly).

This will no longer suffice!

In the decade of the 1990's and beyond, the ability to adjust to (and indeed to take advantage of) change will be crucial. The Navy and the shipbuilding industry together have faced such challenges before, and have done extremely well.

The initiatives described in this paper carry on this successful tradition of facing and overcoming challenges. By NAVSEA and the shipbuilding industry working together and re-examining and continuously improving our many processes from ship concept to commissioning, these initiatives will greatly assist the Navy and the shipbuilding industry in meeting and taking advantage of the rapid changes to be faced in the 1990's and in setting the direction for the 21" Century.

ACKNOWLEDGEMENTS

The authors wish to recognize several of the many people who have participated in Improving Produability in the Naval Ship Design Process. First, we would Eke to dedicate this paper to the memory of Bob Riggins, who was one of the editors of the Workshop Report and who made many contributions to naval ship design over his

35-year career. We also want to recognize Kit Ryan for his outstanding work in editing the Workshop Report. In addition, we want to further recognize the contriiutions of the Chairmen of the Working Groups from the 1989 Workshop:

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Working Group 2 - Dr. W&en Dietz (Engineering Tools)
Working Group 3 - Mr. Michael Hammes (Cost Models)
Working Group 4 - Mr. J. Christopher (Kit) Ryan (Strategy)
Working Group 5 - Mr. Michael Resner (Acquisition Practices)
Working Group 6 - Mr. Robert ComIy (3-D Digital Data Transfer)

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Corporate Repair Philosophy and Measuring for Continuous Improvement at Philadelphia Naval Shipyard

No. 4B-1

Lcdr. Lawrence R. Baun. USN, Visitor, and **Robert** G. **Gorgone,** Visitor, Philadelphia Naval Shipyard

ABSTRACT

Initial zone technology implementation at the Philadelphia Naval Shipyard (PNSY) in 1986 set the stage for one of the most significant shifts in culture and repair philosophy ever witnessed at a public naval shipyard. Attempting to fundamentally change the way that the shipyard conducted business forced senior and middle management to completely understand the dynamic and interrelatedprocessesthatwere utilized to perform depot level work. Through the Philadelphia Quality Process (PQP), this understanding was achieved and changes that were necessary to shift from a Ship Work Breakdown Structure (SWBS) to a Product Work Breakdown Structure (PWBS) began.

As all quality processes will point out, measurement is the key to obtaining the necessary data to make corporate decisions. As the zone technology model was refined from 1987 through 1991, the understanding of "how we do work" continuedto improve. Attacking processes that are sluggish, manual and not responsive enough to support the manufacturing process is the direct result of meaningful measurement focusing management attention. The purpose of this paper is to point out that the emphasis of the shipyard is now on the total "manufacturing process" rather than just "odds and ends" of planning and production. The utilization of zone technology provided the environment and attitude that supported improvements from within. Shipyard goals remain constant: improve producibility, reduce cost, and maintainguality. Continuousmeasurement, analysis and action to improve the shipyard's manufacturing process has been the mechanism used to achieve those goals.

ACRONYHS AND DEFINITIONS

AOE: Auxiliary, Oil and Explosives. The Navy letter designation for a combination oiler-ammunition ship.

AVT: Aircraft Carrier, Fixed Wing, Training. The Navy letter designation of a training aircraft carrier.

BB: The Navy letter designation for a battleship.

CAD: Computer Assisted Design. Design drawings and models produced utilizing computers.

CKO: Closed KEOP. A key operation which is completed.

COB: Complex Overhaul. The Navy term for an extended overhaul period where major repairs and alterations are conducted.

CPI: Cost Performance Index. The (CS)' 'term representing the ratio of expenditures vs. physical progress on completed work and work in progress.

(cEq²: Cost/Schedule Control System. Shipyard computerized system to track expenditures and physical progress vs. budget and time allocations for authorized work.

OV: Carrier, Fixed Wing. The Navy letter designation for an attack aircraft carrier.

DD: The Navy letter designation for a destroyer.

DSR: Design Service Request. The formal method where production shops request engineering assistance from the design division.

DSRA: Docking Selected Restricted Availability. The Navy designation for a planned, short-term, drydocking shipyard availability.

EDD: Estimated Delivery Date. Normally used when discussing material delivery requirements.

FF: The Navy letter designation for a frigate.

FON: Fiber Optic Network. A specific type of LAN utilizing fiber optics as the physical link between stations.

BP&A: Hull, Propulsion and Auxiliary. The acronym used to identify work as being part of the hull, propulsion or auxiliary systems on a ship.

IDP: Integrated Design Package. A three dimensional CAD drawing which overlays all systems in a given area to assure that no interferences exist.

JOPC: Job Order Process Card. The document used to specify work to be accomplished on an equipment or system and identify shops and budgets allowed.

KEOP: Key Operation. The lowest level non-trade unique, work instruction.

LAN: Local Area Network. The term used to describe the hardware and software link between computer systems and workstations.

NIIP: Navy Industrial Improvement Program. A program sponsored by the Secretary of the Navy which had the goal of improving processes and products of Wavy depot-level activities.

P&E: Planning and Estimating. The shipyard office responsible for job planning, estimating and scheduling.

PF: Performance Factor. The ratio of expenditures vs. allowances (normally on completed EEOPs).

PQP: Philadelphia Quality Process. The Philadelphia Naval Shipyard's version of Total Quality Leadership/Management.

PWBS: Product Work Breakdown Structure. The identification scheme used to identify ship work by products, normally by a geographic area.

RDD: Required Delivery Date. Normally used when discussing material delivery requirements.

SARP: Ship Authorized Repair Package. The contract between the shipyard and the customer concerning the repair and overhaul of a specific ship.

SLEP: Service Life Extension Program. An overhaul program designed to increase the service life of conventionally powered aircraft carriers by 15 years.

SLQ-32: An electronic warfare system installed on most U.S. Navy combatants.

SWBS: Ship Work Breakdown Structure. The identification scheme used to identify ship work by system.

TQL: Total Quality Leadership. The U.S. Navy's management program which strives to assure continuous improvement in all productive processes.

WMT: Waterfront Management Team. A group of production, planning, supply and other department personnel directly supporting the execution of a ship overhaul.

INTRODUCTION

As the management team of a non-nuclear public shipyard operating in an increasingly competitive- environment, Philadelphia Naval Shipyard senior managers-have understoodtli&a strategic plan, commitment to quality and a corporate repair philosophy were needed in order ensure the viability of the shipyard. In 1988 the shipyard entered a prog,;a;tz; quality education designed to a fundamental attitudes concerning quality at the shipyard". This process, known as the Philadelphia Quality Process (PQP) has been accepted as the method for assuring continuous improvement in shipyard processes. In 1989, shipyard senior managers, with the assistance of the Navy Industrial Improvement Program (NIIP) began a series of discussions which centered on the development of a shipyard five-year strategic plan. The strategic plan provided the focus, utilizing PQP as a vehicle to assure continuous improvement, and the necessary communication required to "make it work" form the foundation of Total Quality Leadership (TQL) (figure 1) -

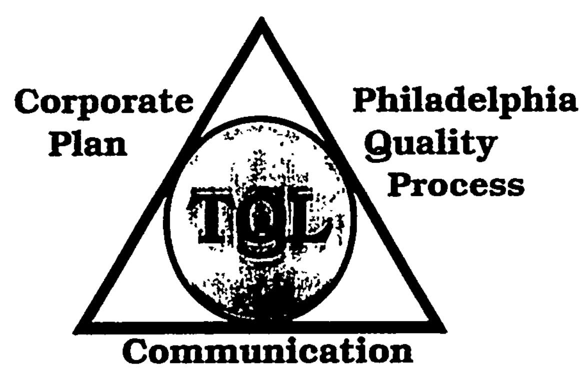


Fig. 1 TOTAL QUALITY LEADERSHIP

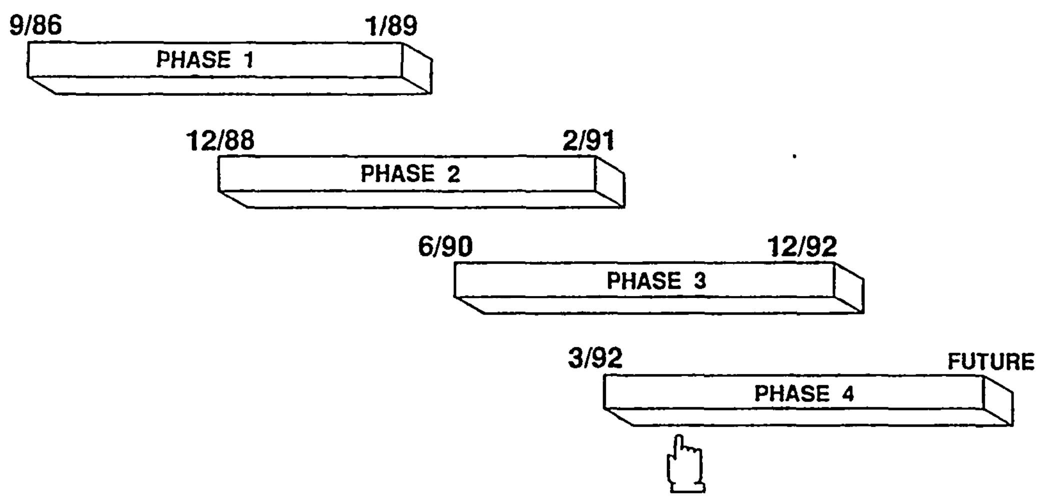
As a means of improving its competitive posture, the shipyard has made a fundamental shift from a svstems-oriented approach to ship rep&r and modernization to a product-oriented overhaul management philosophy. This product-oriented overhaul philosophy, also known as zone logic technology has become the accepted means of planning and executing work at the shipyard and is the foundation of the shipyard's corporate repair philosophy.

The introduction of zone logic technology at the shipyard actually began in 1986 with the Service Life Extension Program (SLEP) of the USS Kitty Hawk (CV-63). This initial phase of zone logic implementation was conducted on approximately 35% of a 1.7 million manday, 37 month duration project. The methods and organizational structure used for zone logic on the Kitty Hawk SLEP have been discussed in detail by Baba, et al (1). While evidence of many potential improvements in ship repair practices were apparent, the shipyard experienced considerable difficulty in having zone logic accepted by all shipyard management and workforce. Prior to entering the planning stages fortheUSS Constellation (CV-64) SLEPin 1988, shipyardmanagement evaluated the pros and cons of zone technology and made the decision to continue using zone technology as the method to planning and executing ship overhauls. Burrill, et al (2) summarize the methodology used on Kitty Hawk SLEP and the process of applying lessons learned to uss Spruance (DD-963) Drydocking Selected Restricted Availability (DSRA) and subsequently, USS Constellation SLEP. Petersen-Overton (3) discussed numerous changes made in the planning and production organizations prior to USS Constellation SLEP and reported on the initial results from this project as well as the results of zone technology implementation on smaller availabilities.

The SLEP of the USS Constellation is now at 80% completion. This presentation studies the current status of the Constellation SLEP and evaluates the results of changes made in the shipyard's corporate repair philosophy including zone technology implementtition, project management and the quality process used to measure and improve on this project. In addition, numerous other changes and improvements in the way of planning and executing a complex ship repair and alteration project have been made at the shipyard. These changes and their effect on productivity on the Constellation SLEP are discussed.

STATUS OF BONE TECXNOLOQY IXPLESfENTATION

As zone technology implementation extends into its seventh year, the shipyard is entering a new phase in the implementationplan. Petersen-Overton (3) described this as a four-phase plan. Figure 2 illustrates the zone technology implementation plan and its current status.



PHASE I:- INITIAL IMPLEMENTATION INCLUDING THE FIRST YEAR OF EXECLJTION ON KITTYHAWK

PHASE 2:- PLANNING PHASE FOR USS CONSTELLATION SLEP, COMPLETION OF USS KII-IY HAWK SLEP AND EXECUTION OF USS SPRUANCE AND USS HEWES

PHASE 3:- EXECUTION OF USS CONSTELLATION SLEP IN CONJUNCTION IN CONJUNCTION WITH OTHER COMPLEX OVERHAULS I AVAILABILITIES

PHASE 4:- PLANNING AND EXECUTION OF USS FORRESTAL AND USS JOHN F. KENNEDY COMPLEX OVERHAULS

Fig. 2 ZONE TECHNOLOGY IMPLEMENTATION PHASES

With the Constellation SLEP nearing completion, and advanced planning started on the USS Forrestal (AVT-59) and USS John F. Kennedy (CV-67) Complex Overhauls (COH), the shipyard is entering Phase IV of the plan. Numerous internal audits of the yard's zone technology planning and production processes and a review of measurements used have been conducted. Phase IV will consist of the application of lessons learned on the Constellation SLEP to the Forrestal and Kennedy COHs. In addition to aircraft carrier overhauls, zone technology continues to be used on other types of-ships repaired at the shipyard. Table I lists projects completed or planned using zone iogic technology.

- Intesrated Plannina for Production - an organized, thought out approachto planning and executing the project.
- Work Packaains usinu Zone Technoloav - specifically the packaging of work into "doable" work packages that are to be executed bv trade. bv chase. bv oeoaraohic area.
- Measurement for Continuous Improvement - detailed analysis is conducted on a continuing basis of all in-process work hold-ups and to identify systematic problem areas.

PROJECT	PRODUCTION MANDAYS	STATUS
US8 KITTY HAWK (CV-63)	550,000	COMPLETE
US8 HEWEB (FF-1078)	lS,000	COMPLETE
US8 SPRUANCE (DD-963)	15,000	COMPLETE
US8 CONBTELLATION ((X-64)	806,000	IN PROGRESS
US8 DETROIT (AOE-4)	35,100	COMPLETE
US8 WISCONSIN (BB-64)	30,000	COMPLETE
HS KIXON (D-218)	25,000	COMPLETE
US8 SEATTLE (AOE-3)	3b,OOO	MAY 1992
US8 FORRESTAL (AVT-59)	275,000	SEPT 1992
US8 JOFIN F. KENNEDY (CV-67)	700,000	BEPT 1993

Table I SONE TECHNOLOGY PROJECT STATUS

UBS CONSTELLATION STATUS

At the 80% point of completion in the USS Constellation SLEP, the shipyard is experiencing a sisnificant improvement in the cost performance of its production shops when compared with previous SLEPs. Figure 3 shows the completed work (closed KEOP) performance factor (actual cost of work performed divided by budgeted cost of work performed) on all five SLEPs to date. The performance factor is plotted against the percentage of time expired. The gains in efficiency indicated at this point in the overhaul shows an average 11% improvement as compared to the previous four SLEPs at the 80% point.

It is generally accepted that the improvements realized are a combined result of several changes made in the way of doing business. These changes represent the corporate repair philosophy and are described below.

- proiect Manaaement implementation - this enables experienced, shipyardproductionmanagersto be removed from the daily administrative burdens of running a group or shop and concentrate on project management.
- Waterfront Wanauement Team - this has enabled a team of planning and production project managers to work in the same location, physically near the worksites. Communication and efficiency in handling changes has been vastly improved as the Project Manager has on his team members of all offices required to support the project.

Increased use of Intesrated Desiun products -Areas of the ship which require extensive renovation or alterationhaveindividualsystems designs integrated in a three dimensional Computer Assisted Design (CAD) format. Interference control and resultant work stoppagesaredrasticallyreduced.

- In creased use of Desisn Aids for Producibility - use of initiatives suchasphotogrammetry for shipchecks and automated thru-ship cable routing instructions have vastly improved the accuracy and control of work packages provided to production shops.

CORPORATE REPAIR PHILOSOPHY

Integrated Planning for Production

It is no secret that emphasis placed on up-front planning will result in a smoother-flowing, better executed availability. But what should this planning consist of? It is not enough for a planning department to issue job orders, issue a schedule, issue drawings, order material and hope that production shops can carry it all out. The shipyard strategized the execution of the Constellation SLEP through an integrated planning and production schedule. This schedule was described Burrill, et al (2). When the advanced planning for USS Constellation SLBP began, managers decided that if zone technology were to. be successfully applied to Constellation, a total review of the shipyard planning and production process was required. Managers initially drew up a strategy chart which incorporated their individual experience of the ship overhaul planning and execution process. What resulted was somewhat disjointed and lacked direct responsibility for the many sub-processes. The managers, using training received in the quality process, then developed process model worksheets identifying products, requirements and customers in each step of the overhaul process. Through this customer-product relationship, the individual processes were better defined with deliberate relationships identified and clear lines of responsibility spelled out. A "master schedule" was developed which identified the requirements of the shipyard's customer, incorporated experience from four previous SLEPs and took into account long-lead time material delivery schedules. This "master schedule" was used to identify an intermediate product, a production schedule. Through the integrated planning and production schedule, all %uppliers" or support offices were given the requirement to provide their products to support this schedule. Theseproducts includematerial deliveries and receipt inspection, job order and drawing development, test

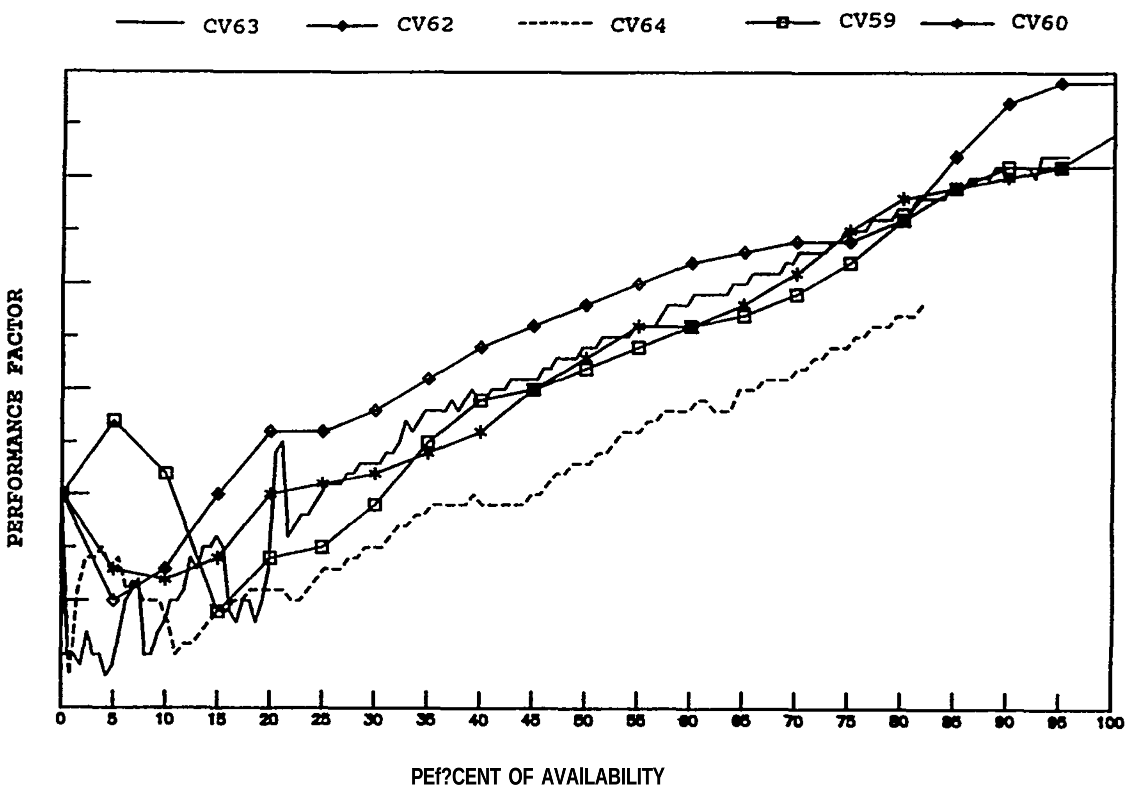


Fig. 3 CLOSED EBOP PERFORMANCE ON Cv-SLEP

SPeCifiCatiOn writing and work package issuance. The end result is the CV-64 "availability strategy" shown in Figures 4a and 4b. This "availability strategy" has been used as the tool to have all schedules driven by the production schedule. The sub-processes which SuPPort this availability strategy are then measured to assure conformance to the schedule and continuous imprOVement-

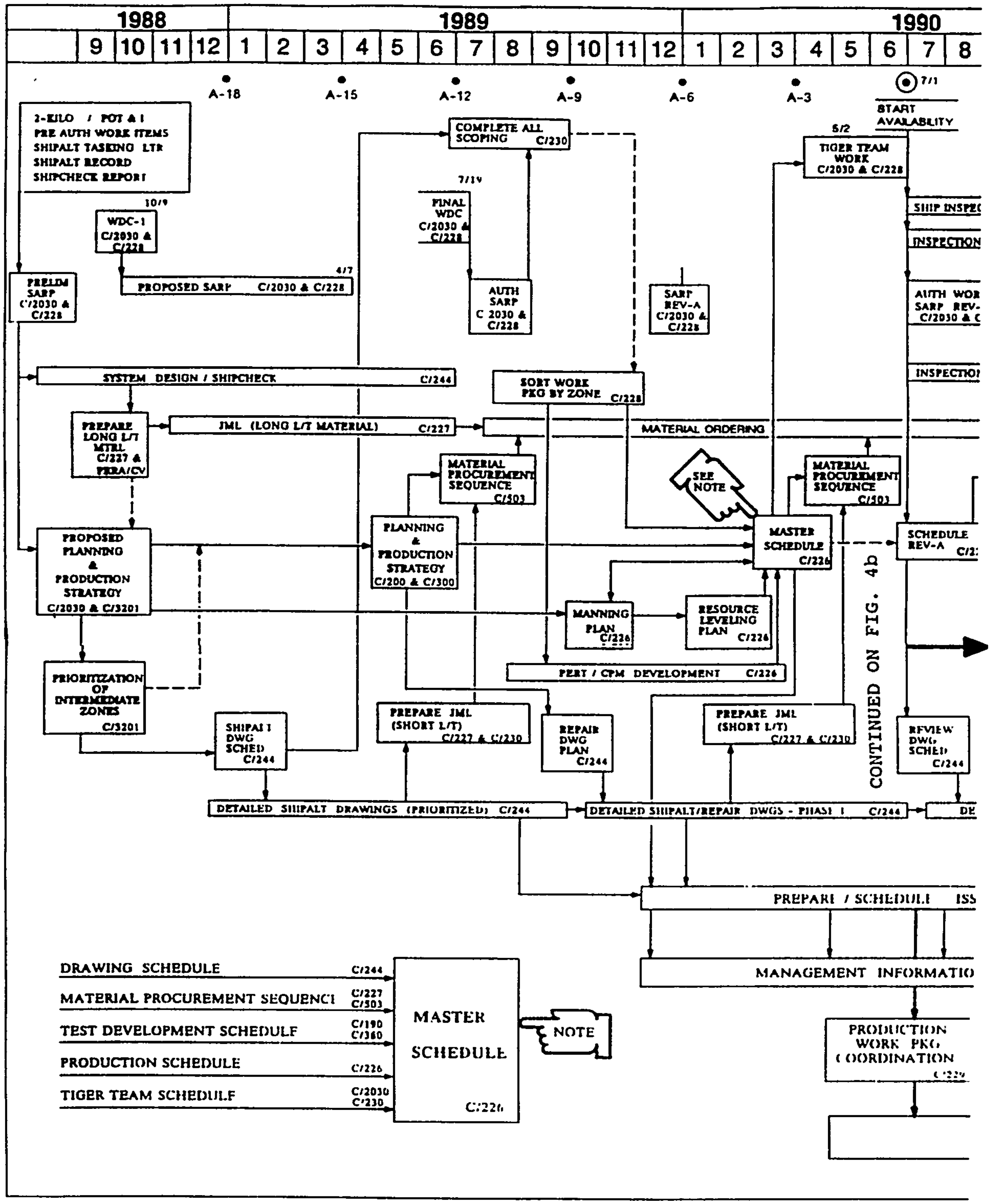


Fig. 4a USS CONSTELLATION AVAILABILITY STRATEGY

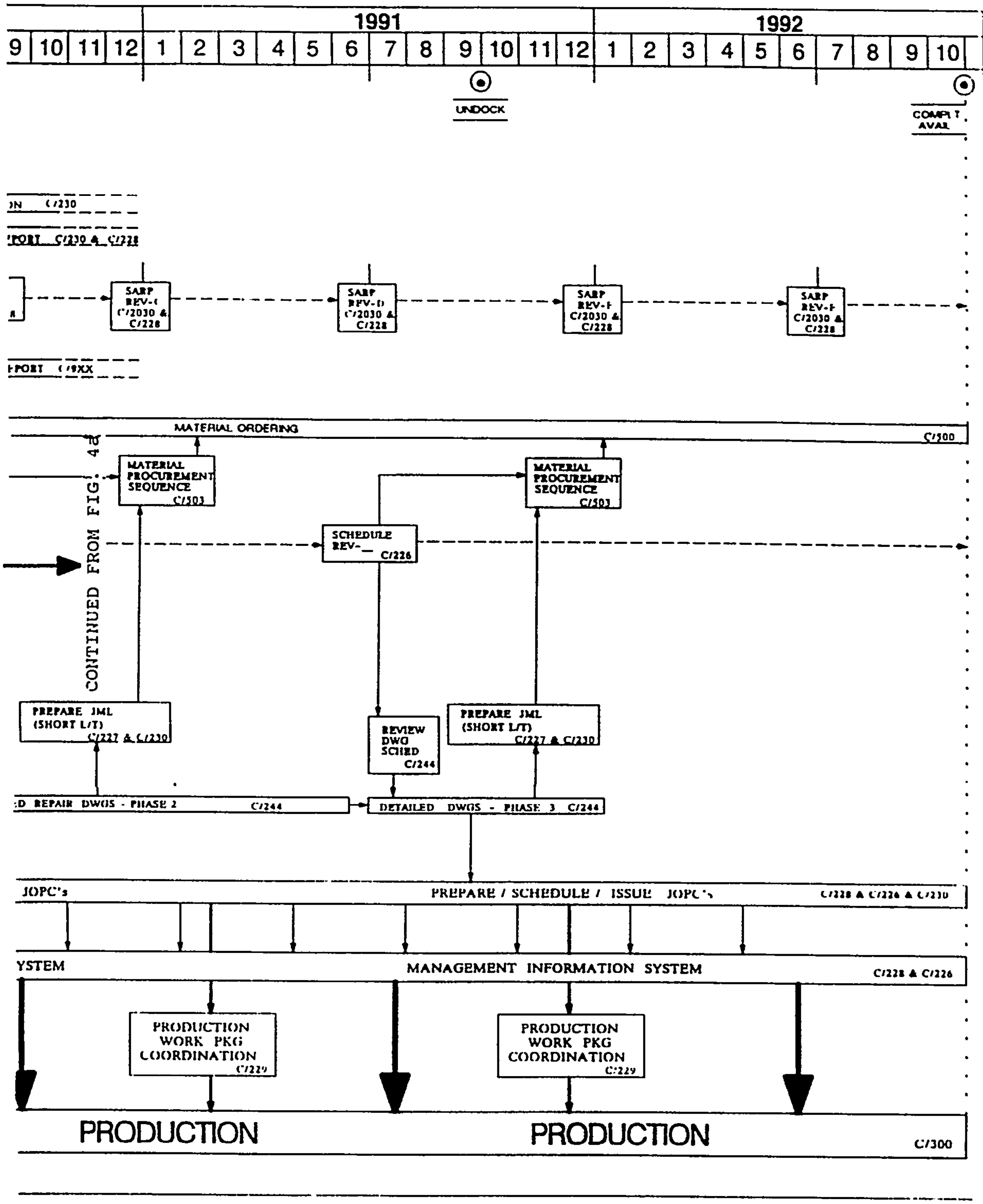


Fig. 4b **USS CONSTELLATION AVAILABILITY STRATEGY**

Work Packaging Utilizing Zone Logic

In order to simplify and organize the number of products which were being provided to production shops, a work packaging group has been established. Baba, et al (1) and O'Hare, et al (4) discuss the methodology used by the work packaging group. This group has two main functions listed below.

1) Organize the work according to the production schedule and grouping it using zone technology principles, that is: by phase. by trade, by area.

2) Provide to production all of the assets which production shops require to complete a job on schedule.

The difference in philosophy from Vraditional[11] means ofprovidingproducts to the shops to the "zone technology method" is illustrated by Figures 5 and 6.

The work packaging group [1]'product,[1V] the work vackaue, combines all of the information, authorization and material required of a shop to execute work. This includes scanned-in sections of process instructions, scanned-in portions of drawings, material lists including the location of the material, test specifications and, of course the job order process cards (JOPCs) which are the work authorizations and descriptions of work on specific RROPs contained within the work package. The job order process cards and the accompanying information/documentation is grouped and scheduled together to assure that a work package consists of similar work which is carried out pv vhase. bv trade and are in the same aeosravhic area. In order to assure that the product (work package) is delivered to production shops in sufficient time to execute, the work packaging group schedules individual work packages to be compiled and issued at least Go days prior to the scheduled start date of that work package. The ability, or inability to deliver the product on schedule is measured as shown in Figure 7.

As a [11]customer,[88] work packaging receives [88]products[1]* from their [81]suppliers[11] which make up the work package. These products may vary with the specific work package but, in general, they are:

- test specifications,
- material lists,
- Job Order Process Cards,
- material inspection certifications,
- drawings or design instructions, and/or
- other sources of information.

The ability of the work packaging 'suppliers" to meet their requirements is measured as a number of non-conformances which prohibit timely issue of work to production. Examples of these measures are discussed in the following sections.

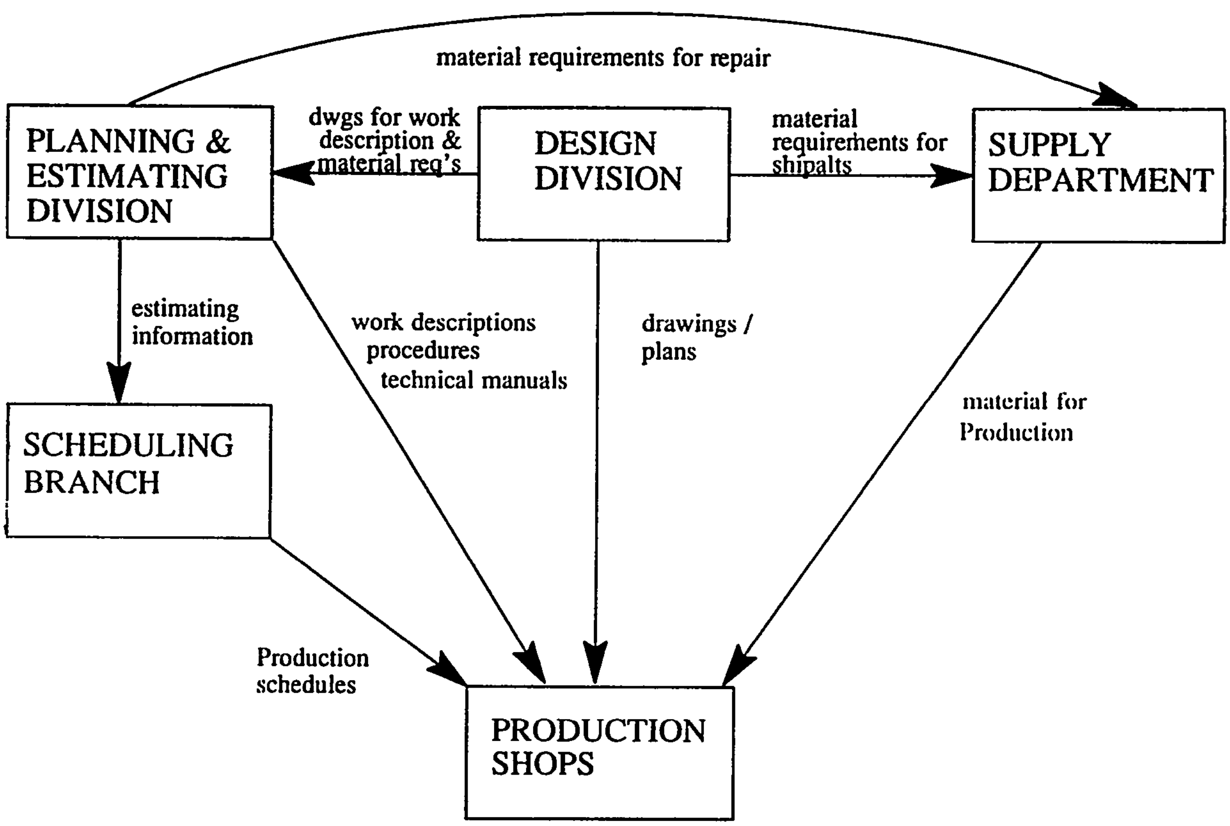


Fig. 5 "TRADITIONAL" PLANNING PROCESS

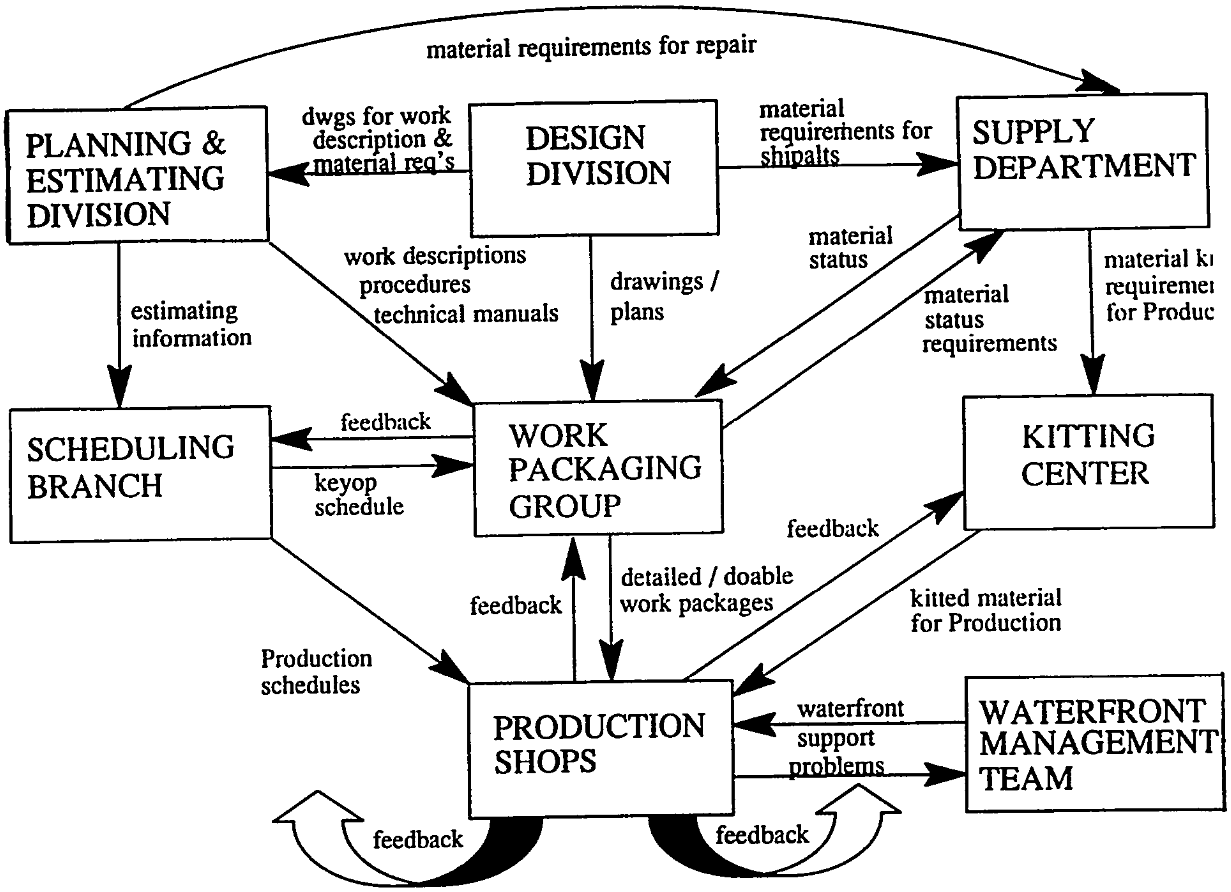


Fig. 6 ZONE TECHNOLOGY PLANNING PROCESS

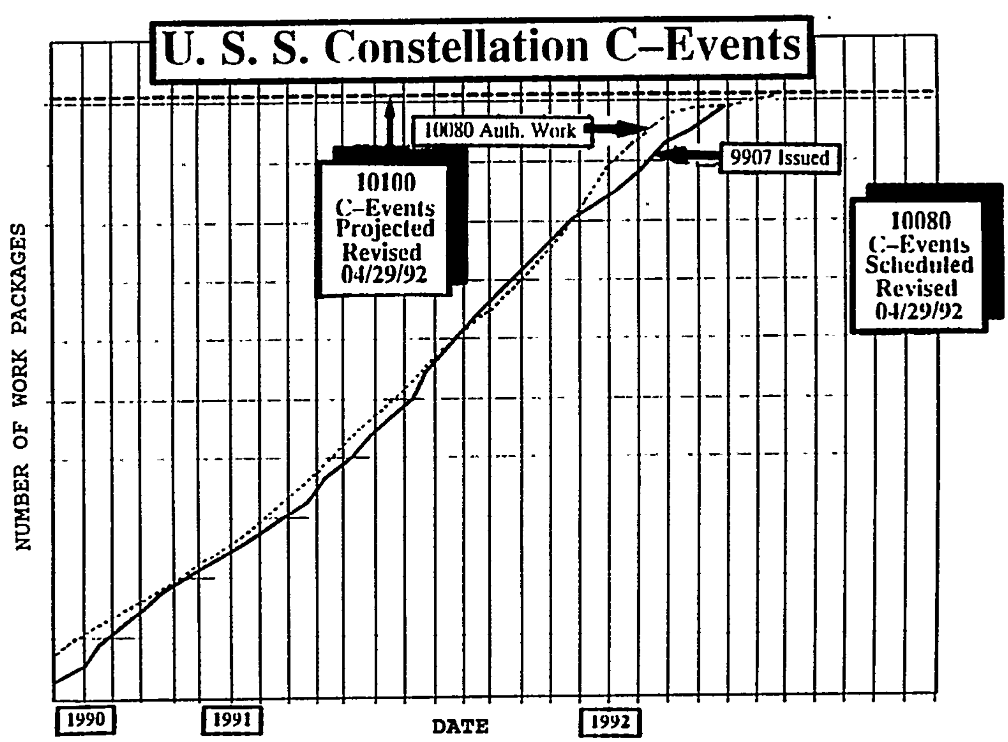


Fig. 7 WORK PACKAGE SCHEDULE ADHERENCE

Test specifications. The issuance of test specifications is required at least 150 days prior to the scheduled start of that test. This lead time allows planning adequate time to identify any additional repairs or materials required to allow the test specification to be met satisfactorily the first time. Figure 8 shows a number of non-conformances to this 150 day requirement on the part of the Hull, Propulsion and Auxiliary (HP&A) test writing branch. Here, non-conformances are measured against calendar time and indicate an improving trend.

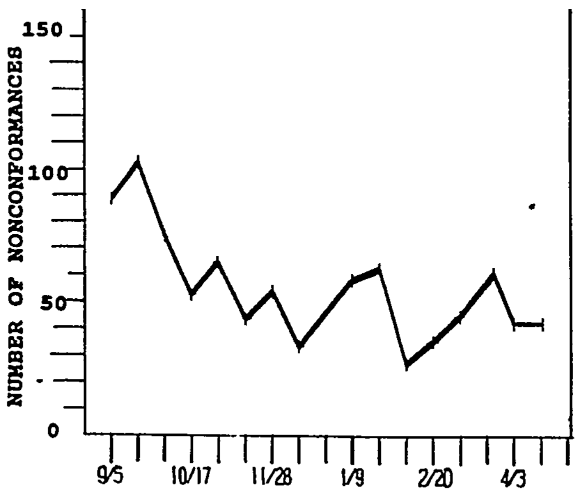


Fig. 8 **TEST SPECIFICATIONS ISSUED MEASUREMENT**

Material Dues. Through adherence to the integrated planning and production schedule and zone technology principles, <u>all</u> material ordered is assigned a <u>specific</u> job order and key operation (KEOP). This makes it possible to assign latest required delivery dates (RDDs) of all material ordered based on the date the work is scheduled to start. This allows the shipyard material ordering branch and supply department to know precisely when material is required. The RDD will not change unless the schedule should change. Since material orderers, purchasers and expediters know in advance when production requires the material, the "crisis management" approach to expediting material through the various steps of the procurement process has been significantly reduced. In order to identify potential material problems early on, a 120 day window has been selected to measure "material dues". Figure 9 shows a sample of this material dues measurement. Here, the solid bar indicates the number of material line items due with RDDs past due or RDDs within 120 days. The asterisks and connecting line indicates the number of material dues within this window which have a "bad" estimated delivery date (EDD), that is the EDD is after the RDD. The cross-hatched bar indicates the number of material dues which are assigned to KEOPs which are closed (completed) or canceled. Material dues on closed or canceled work are reviewed to determine if these orders should then be canceled.

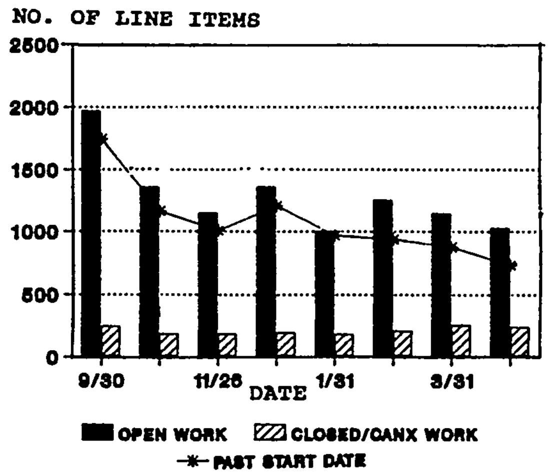


Fig. 9 **MATERIAL DUES MEASUREMENT**

Material Inspection. Among the lessons learned from the Kitty Hawk SLEP is that receipt inspection for quality assurance was frequently a bottleneck in getting material to production. Since RDDs were not tied to each material line item ordered, it was impossible for the receipt inspection branch to know in advance what material was needed immediately on the waterfront and what should have gone into temporary storage pending need. The priority of receipt inspections are now tied to KEOP and work package start dates. Receipt inspection is measured by viewing a 75 day window prior to the work package start date. All material requiring inspection for work packages past its start date or scheduled to start within the next 75 days are measured. Figure 10 shows a sample graph of receipt inspection measures. Here, the inspections pending are categorized as:

1) material not yet received in the shipyard,
2) material received but not on-site for inspection,
3) material in inspection backlog, or
4) material lost.

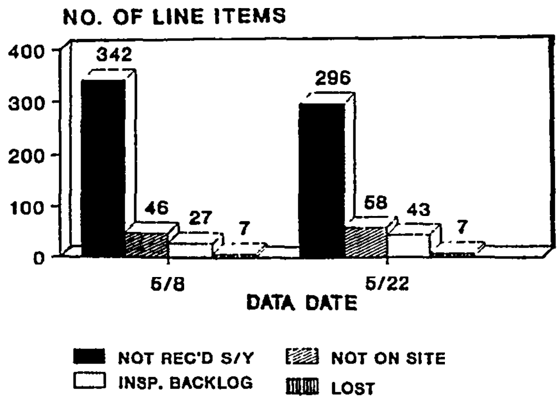


Fig. 10 **MATERIAL INSPECTION MEASUREMENT**

Work Package Hold-Ups. As previously discussed, the work packaging branch has a requirement of issuing work to production at least 90 days prior to the start date of that work package. In order to measure the non-conformances which are preventing issuance of complete work packages, the work packaging branch measures non-conformances and categorizes according to reason for hold-ups. These hold-ups are presented to responsible codes on a weekly basis for action, and are discussed by senior management on a bi-weekly basis. The categories of hold-ups and examples of causes are shown below:

1) Production Shops - due to late submission of an as-found condition report;
2) Type Desk - due to late release of reservation or funding by the customer for identified work;
3) Planning/Estimating - due to late issuance of an authorized job order;
4) Design - due to late issuance of design instructions or plan revisions;
5) Combat Systems Office- due to late issuance of test specifications; and
6) Hull, Propulsion & Auxiliary (H,P&A) - due to late issuance of test specifications.

Figure 11 gives an example of work package hold-up measures.

Measurement for Continuous Improvement

Thus far, measurements of the planning process have been discussed. Numerous other issues can cause work stoppages. Through the principle of measurement for continuous improvement, roadblocks and bottlenecks which delay the manufacturing process once production shops start work are identified, analyzed and corrected.

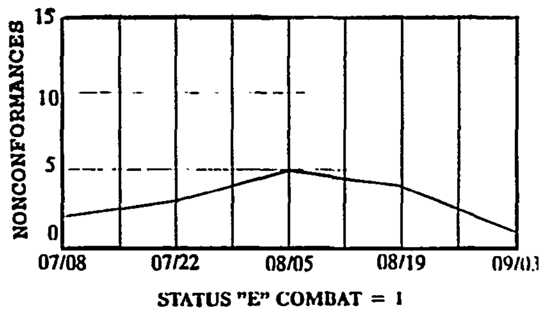


Fig. 11 **MEASUREMENT FOR WORK PACKAGING HOLDUPS (COMBAT SYSTEMS DIVISION)**

Some of the measures used in this analysis are:

1) reschedule action analysis;
2) shop report analysis; and
3) Design Service Request (DSR) analysis.

Reschedule Action Analysis. When work packages cannot be completed on schedule, a rescheduling may be justified. Shipyard management requires that each reschedule action be clearly categorized by cause for the reschedule. Causes are then studied to identify and correct systematic problems. Typical categories for rescheduling are:

1) production shops - worksite not available due to pre-requisite work not completed, sufficient manning or equipment not available:
2) planning - work package not issued:
3) supply - material not in yard: or
4) sequence - work improperly scheduled.

A sample measurement of reschedule actions is shown in Figure 12.

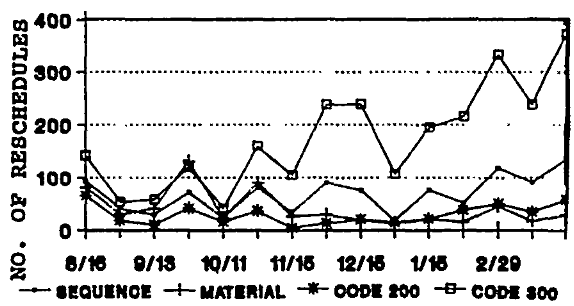


Fig. 12 **RESCHEDULE CAUSE MEASUREMENT**

Shop Report Measurement. Shop reports are used to identify as-found conditions or to identify inconsistencies in planning documentation. Total number of shop reports outstanding and the shipyard office responsible for answering are reported weekly. Managers are advised of outstanding actions they have and corrective action required. Figure 13 shows by office, where the outstanding shop reports are for action. Typical categories are:

Code 214 (Type Desk): requires authorization of work:
Code 300 (Production Shops): solicited shop report overdue for submission:
Code 503 (Supply): missing or incorrect material problem:
Code 225 (Planning and Estimating): requires estimate or routing of work: and
code 244 (Design): requires engineering analysis.

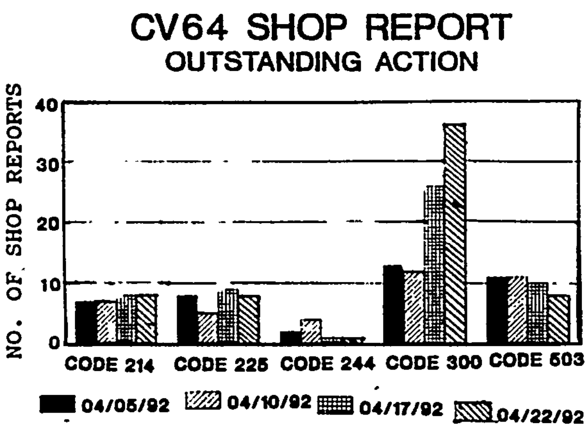


Fig. 13 SHOP REPORT MEASUREMENT

Design service Request Analysis. As many Design Service Requests indicate a work stoppage in a given job, design division is measured on its ability to satisfactorily answer DSRs in a timely fashion. Any DSR which is determined to be "urgent" or a work stoppage requires a 24-hour turnaround.

Project Management

Petersen-Cverton, (3) discussed the projectmanagementorganizationdeveloped for USS Constellation SLEP. Project management at the shipyard has since evolved to the point that the production department has divided into two separate departments. These are the production resources department (Code 300) and the operations department (Code 3300). This reorganization is a natural one given the emphasis and responsibility placed on project managers. The Operations Officer now reports directly to the Shipyard Commander on matters relating to the execution of projects at the shipyard. Each project is assigned a project superintendent, a senior group superintendent level or shop head level civilian manager. Assistant project superintendents each have several zones assigned as their areas of responsibility. Due to the size of the SLEP work package, zone managers are assigned to manage individual zones and report to an assistant project superintendent. Military or civilian ship superintendents are also assigned to each project. The role of the ship superintendent is essentially unchanged from that described by Petersen-Overton as the individual responsible for interface of shipyard work to ship's force work. Figure 14 illustrates the project management organization.

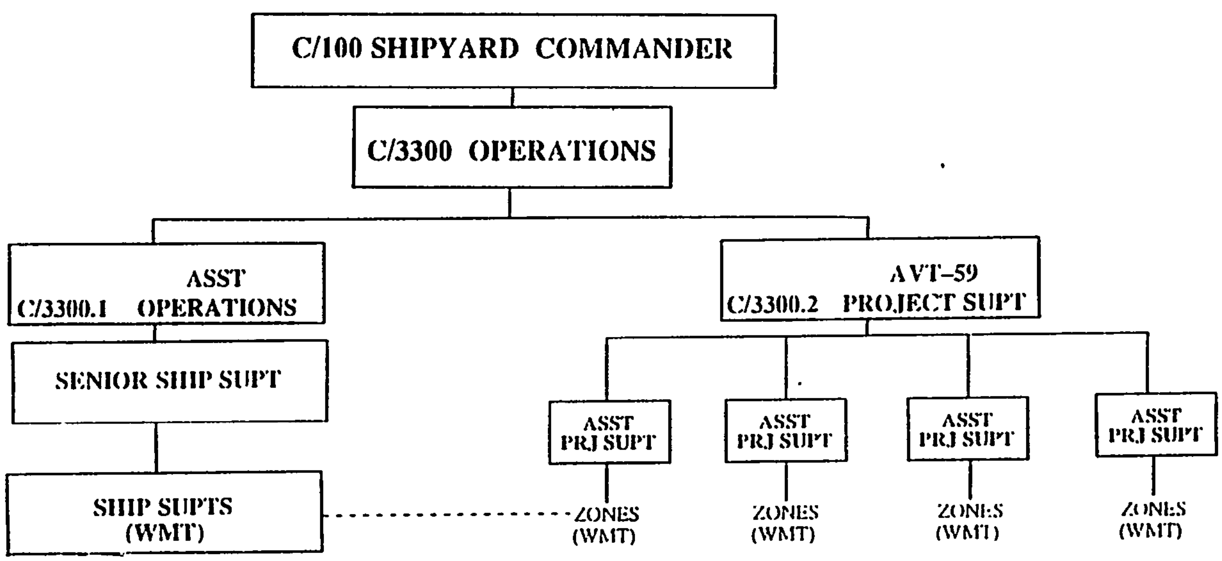


Fig. 14 **TYPICAL PROJECT MANAGEMENT ORGANIZATION (AVT-59 COH)**

The former production office (Code 300), now the production resources office, also reports directly to the shipyard Commander and is responsible for providing manpower and equipment to the project superintendents for their use. The production resources organization is shown in Figure 15.

It has been recognized that the project management approach to ship overhauls is much more efficient than the previous approach because it allows the senior civilian and military managers to focus on the project at hand. A senior civilian project superintendent will no longer have to be pre-occupied with the myriad of administrative duties which are time consuming and prevent him/her from spending the time needed the project execution. The project superintendents responsibilities are considerable: execution of the project within cost and scheduleconstraints. There-organization is proving to be the tool he/she needs to succeed. The project management organization discussed above is generic and is tailored for any sized project.

Waterfront Management Team

The philosophy of manning and outfitting complete Waterfront Management Tetm (WMT) to assist the project superintendent in his duties is unique. The WHT is staffed by members of all shipyard offices and departments which are required to keep the project flowing smoothly. While staffing a WRT may be more expensive than the "traditional" work out of the home office approach, the benefits in improved communication are enormous. It is nearly impossible to measure the efficiency gains made by staffing WRTs but it is accurate to say that, after going through 80% of a SLEP and numerous shorter availabilities with the WMT concept, no manager or office at the shipyard would be willing to operate without them. Each WHT works out of a common trailer or office situated as close as possible to the worksite. These offices are fully outfitted with the required ADP equipment, Local Area Network (LAN) fiber-optic connections, FAX machines, etc. to operate as autonomously as possible. The intangible benefit of the WMT has proven to be the improved communications made possible by the closerworking relationship. WMTmembers, due to their close proximity to the worksite, are also able to spend much more time at the worksite, anticipating and solving problems as they arise. Response time to problems has been greatly reduced as most of shop questions can be answered on the spot rather than waiting for phone calls, calling meetings, etc. Petersen-Overton, (3) has explained in detail, the duties and responsibilities of the individual WMT members. Increased use of computer-aided management tools has proven to be a time-saver for WNTmembers. Currently, the LAN allows on-line cost/schedule and material information, on-line daily status reporting and automation of routine reports. These all serve to allow the project superintendents and WMT members to spend more time "on the deckplates" solving and anticipating problems.

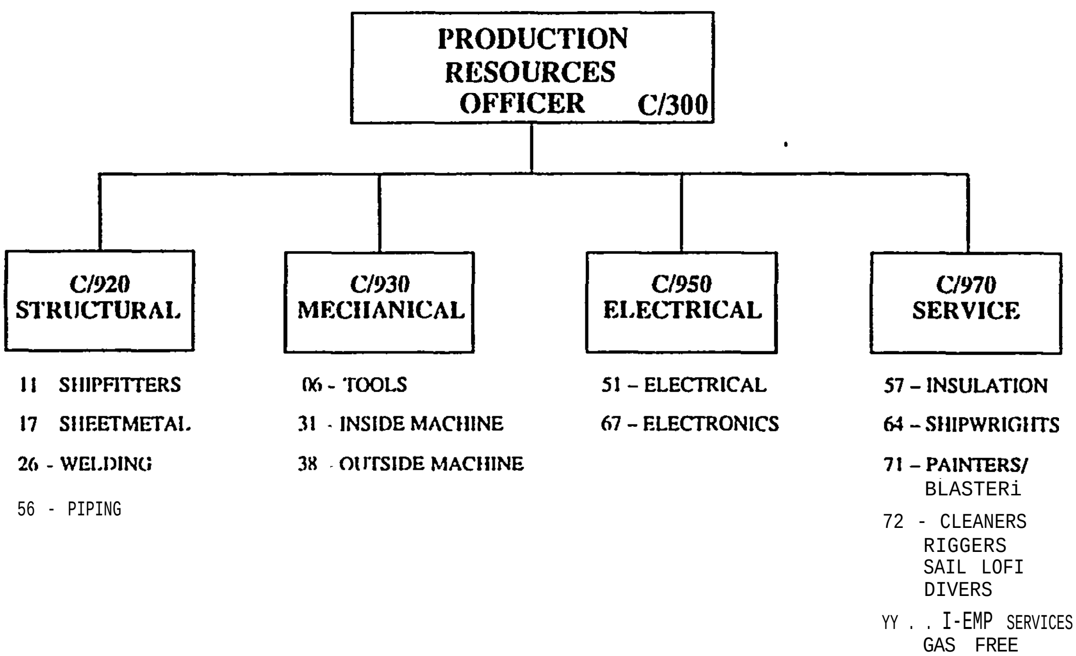


Fig. 15 PRODUCTION RESOURCES ORGANIZATION

Increased usa of Intograted Design Packages

Arguto, et al, (5) discuss the use of Computer-Aided Design (CAD) tools to provide Integrated Design Packages (IDP). These products have served to noticeably decrease the amount of interferences and resultant rework in those areas of the ship which are undergoing large scale renovation or re-design. As seen in Table II, there has been a matic increase in the use of IDP from CV-63 SLRP to CV-64 SLEP.

INTEGRATED DESIGN

US8 KITTY HAWK (CV-63)

Pump Room #5
A/C Machry Rm #3 & 4

US8 CONSTELLATION (07-64)

Pump Room #5
A/C Machry Rm #l
A/C Machry Rm #3 &4
Weapons Magazine
CAT Accum Rm #l
CAT Accum Rm #2
CAT Accum Rm #3 t4
TAS MK 23 Eqpt Rm
TAS Clg Eqpt Rm
Air Terminal Office
Radar Rm #5 (SPN-46)
Radar Rm #9 (SPN-46)
A/G Machry Rm #l C 2
A/G Machry Rm #3
A/G Machry Rm #4
AN/SPS-48E Clg Eqpt Rm
Radar Rm #6
Fan Rm
Radar Rm #8
RRE Machry Rm #l
RRE Machry Rm #2
RRE Machry Rm #3 &4
EW Eqpt Rm #l
EW Eqpt Rm #2
NTDS/ASWM CIC
NTDS/ASWM Cmptr Rm
NTDS/ASWM Aux Rdr Rm

Table II. INTEQRATED DESIGN ON Cv-63 vs. CV-64

Increased use of Design Aids for Producibility

Photogrammetry. CL'-64 SL?ZP has represented an increase in use of photogrammetry for shipchecks and fabrication information. Sparacino, eta1 (6) discuss in detail some of the photogrammetry applications and methods used on CV-63 and CV-64 SLEP. Table III shows total usage on CV-64 SLEP compared to CV-63 SLEP. The use of photogrammetry has increased the number of first time fits and significantly reduced the amount of field fitting and welding required on structural modifications.

PHOTOGRAMMETRY

USS KITTY HAWK (CV-63t

Bow Section Repair
Arresting Gear Bolt Holes
Terrier Missile Sponson
Jet BlastDeflector #2

USS CONSTELLATION (CV-64)

Arresting Gear Bolt Holes
Pump Room #5 Shipcheck
SLQ-32 Deckhouse
Jet Blast Deflector #4
Wet Accumulator Fnd #3 h4
Wet Accumulator Fnd #l
Wet Accumulator Fnd #2
Flight Deck Extension
A/C Plant #4 &5 Shipcheck

Table III. PHOTOGRAHMETRY USAGE on C'J-63 vs. Cv-64

Automatedcable Routing Instructions. USS Constellation SLEP was the first shipyard project to use automated cable routing. Approximately 260,000 m. (850,000 ft.) of new cable is being installed on Cv-64 using nearly 9000 local and thru-ships cable runs. Previous methods provided production Q&Y with termination points of cabling. The shops determined routing of the cables, resultant interference control, etc. This method did not conform to zone technology and resulted in excessive cost. By identifying specific compartments which cables are routed through, planning is able to provide for production not only more accurate cable length information but, more importantly, details where and what size penetratiors are to be installed and optimize cable hanger requirements. By establishing a separate job order to cover through-ship cable installations and cable collar installations, logic is applied to through-ship cab%: and rework is significantly reduced.

RBBULTB

Design Cost Improvements

Certainly, use of IDP, photogrammetry and automated cable routing represents increased up-front costs, but this investment is more than paid off in improved efficiencies. As an example, Figure 16 shows the level of activity of DSR submission on CV-63 SLEP and CV-64 SLEP. Since the CV-63 workpackage was larger than the CV-64 workpackage (1.7 million vs. 1.375 million mandays), the CV-64 numbers have been normalized. Recognize that every DSR submitted represents a problem, or perceived problem identified by production shops which may cause work to stop, and always requires design division investigation and answer. As Figure 16 indicates, approximately 2600 (normalized) DSRs fewer have been submitted at the 80% point of CV-64 SLEP when compared to CV-63 SLEP. Using the conservative figure of four mandays, as discussed by Burrill, et al, (2) to investigate and answer each DSR, this represents a 10,400 manday savings by design division alone! This 10,400 manday figure does not include all of the "rippling effects" of a DSR submittal such as work stoppage, Planning and Estimating (P&E) time to issue new work and material orders if required. This improvement cannotbetotally attributed to increased use of IDP, photogrammetry and automated cable routing but theses changes represent a significant portion of overall project efficiency gains.

Produotion Cost Performmce

As discussed earlier, Figure 3 shows cost performance information on all five cv SLEPS. In Figure 3, closed KEOP performance factor (CKO PF) is plotted against time expired. As previously discussed, the CKO PF is a measure of actual charges divided by budgeted charges on all KEOPs which are completed. At the 80% point a significant 11% improvement is indicated by CV-64 SLEP when compared to (X-60, CV-59, CV-62 and CV-63. The CKO PF chart shown in Figure 3 represents produciton costs only, non-production costs such as design division are not shown.

Production schedule Performance

Figure 17 shows the percent of planned work accounted for in completed KEOPs plotted against time expired. Here, CV-64 data is compared with like data for CV-62 and (X-63. The percentage of work in CKO at 80% is slightly less for CV-64 when compared to CV-63 at its 80% point in 1989 (approximately 67% vs. 70%) and equal to CV-62 at its 80% time expired point in 1987. A portion of the lag which developed at the 55% point was due to an

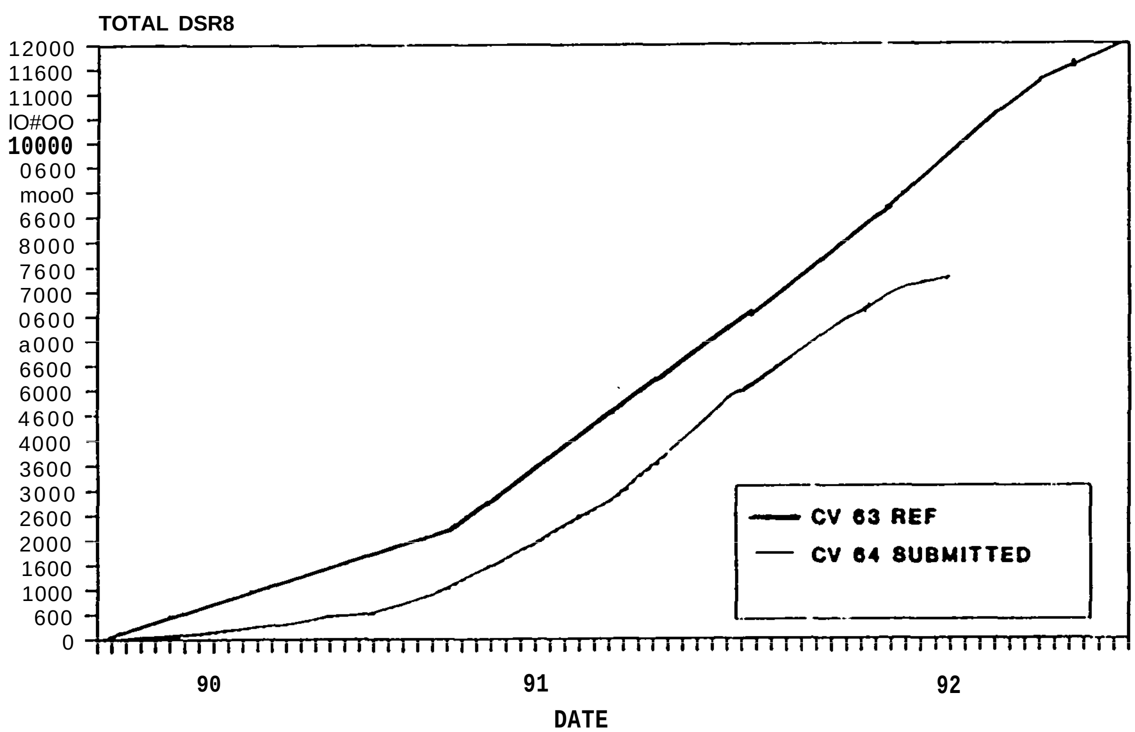


Fig. 16 DSR COMPARISON CV-64 vs. CV-63 (NORMALIZED)

increase in funding and subsequent increase in authorized work by 100,000 mandays. This increase represents a nearly 10% increase in the scheduled work for the CV-64 SLRP. It is not yet known what effect an increase of this magnitude will have on the final performance factor of the CV-64 SLRP. Generally, work picked up late in the scheduled availability is considered high risk and ttcoststl l0-20% more to execute. This may partially offset gains in efficiency which have been made.

Rework

Rework is measured by totalling mandays charged to established rework job orders. Figure 18 shows non-normalized curves for rework accomplishment on USS Independence (CV-62) SLEP, USS Kitty Hawk SLRP and USS Constellation SLEP to date. At the 80% point, the USS Constellation rework performance is encouraging and indicates additional payoffs as a result of zone logic and the corporate repair philosophy.

CONCLUSIONS

Utilizing a carefully developed strategic plan, an established quality process, and zone logic technology as a corporate repair philosophy, the shipyard has exhibited significant gains in the cost of doing business. Zone technology has become the accepted way of planning and performing work and, together with numerous improvements intheplanning and production process is beginning to pay dividends. There are always improvements to be made, however, and evaluation and changestothe manufacturing process must be continuous. As planning is currently underway for the USS Forrestal and USS John F. Kennedy COHs, "lessons learned" are being applied which will continue to streamline the manufacturing process and complete the shift to logical availability strategies, product-oriented work packaging and successful project execution.

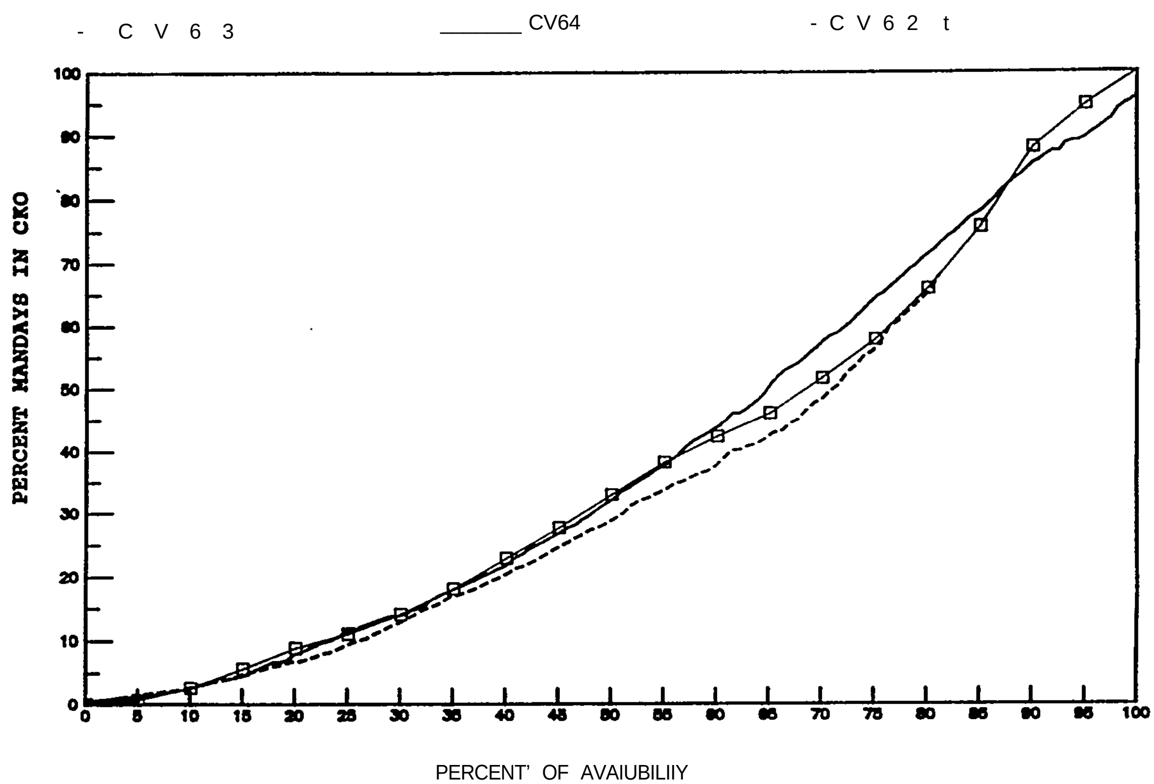


Fig. 17 CV-SLEP PERCENT OF WORR IN CLOSED REOPS

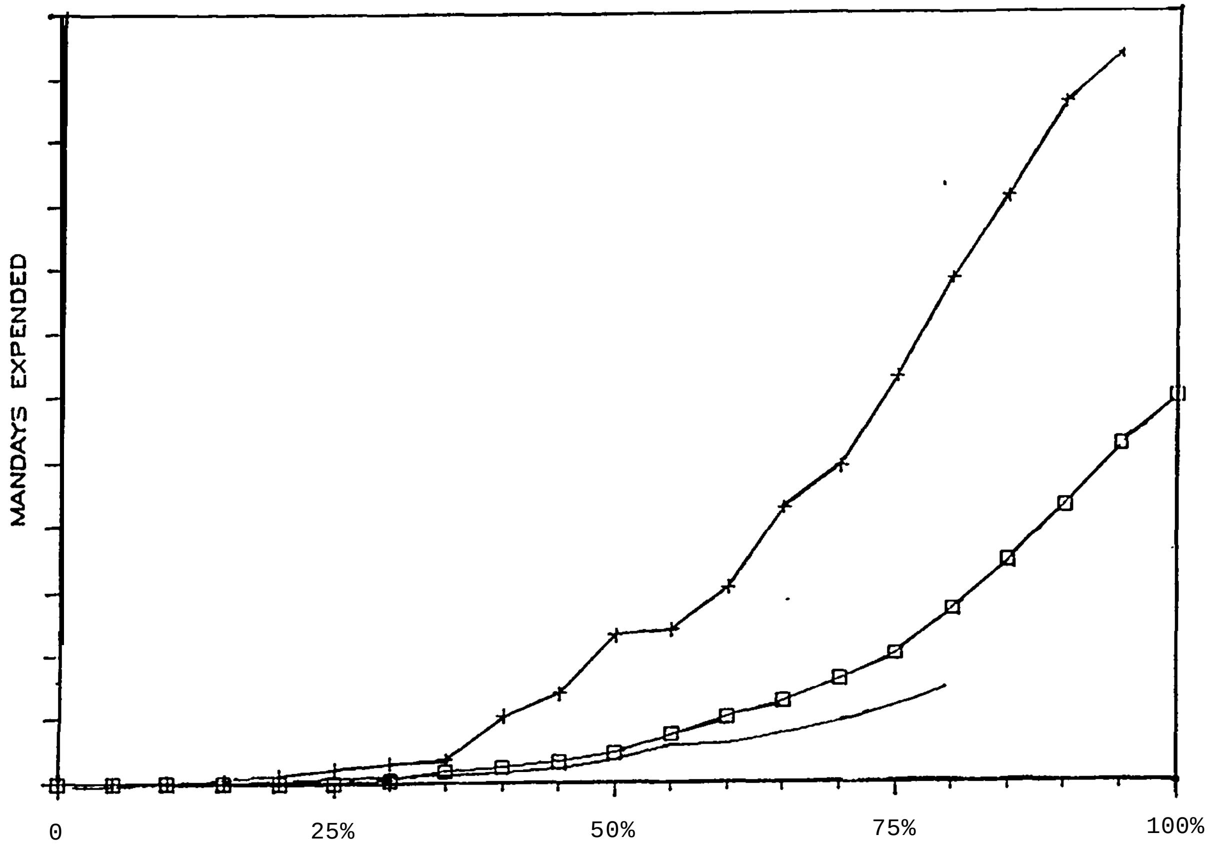


Fig. 18 MANDAYS EXPENDED ON REWORR, CV-64 VS. Cv-62 and Cv-63

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Defining the Shipyard's Engineering Requirements

No. 4B-2

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Dr. James R. Wilkins, Jr., Member, Wilkins Enterprise Inc

ABSTRACT

It is customary for a shipyard to subcontract with one or more design agents for at least some portion of the detail design of a ship to be constructed by the shipyard. Past experience with this process has demonstrated that it has the potential to be the source of inefficiencies, wasted efforts and deteriorated relations between the shipyard and design agent. The Society of Naval Architects and Marine Engineers (SNAME) Ship Production Committee Panel, (SP-41, Design/Production integration, sponsored a project to improve this process. This effort developed a list of the information which should flow from a shipyard to a design agent in order for the design agent to generate the calculations, drawings and other deliverables in a timely fashion and useable format to support the construction effort. This paper describes the methodology used to develop the required information and reviews the details of the list.

BACKGROUND

The specific information about the shipyard that is needed in order for the shipyard's "in house" engineering department to provide support for the ship construction process is normally resident within the engineering department. However, because of the cyclical nature of today's shipbuilding market, not all shipyards are able to maintain a full design staff. Some of these shipyards maintain a "core" engineering group capable of managing a preliminary or detail design effort prepared by an outside design agent. In that case, designs for products which are to be built and/or assembled in the shipyard will be prepared by design agent personnel who may have little or no history and knowledge of the shipyard's design and construction capabilities and practices. Simply stated, the shipyard's problem is how to identify and communicate the vast amount of information which must flow across the interface, in both directions, to enable the outside design agent to prepare a usable design product at a cost efficient price.

The permanent shipyard engineering staff who manage the contract, have to bridge the interface between the shipyard and the "temporary" design personnel who will be doing the design work. To obtain a product from the design agent which is usable by the shipyard production departments, the permanent shipyard staff must have a thorough knowledge of the shipyard's specific requirements based upon the shipyard's capabilities, facilities and past practices, as well as a solid understanding of the "process" of how a ship is designed and built at their yard. Not only must the shipyard personnel have the information, but they have to communicate it to the design agent in a timely fashion to avoid rework and increased costs. The design agent needs to know certain information about the shipyard, the details of the current ship construction project, how the shipyard plans to build the ship, the design output required and when the deliverables are required in order to properly support the shipyard.

Although each shipyard's requirements may vary in some details, a set of generic requirements for an engineering support contract has been developed. These generic requirements are available for the shipyard to modify and use as required in developing the specific requirements for each contract. The listing of generic requirements is intended to assist both the shipyard and the design agent in assuring that the required information has been discussed and either has or will be transmitted between their organizations in a timely fashion.

The purpose of this paper is to report on the methodology used to develop the list of generic requirements and provide the contents of the resulting list for the use of the shipbuilding industry.

THE GOAL

The goal of this project was to identify the information which needs to be provided by the shipyard to the design agent. This information must be sufficient to ensure that the product of the design agent is directly usable by the shipyard, with negligible rework generated as a result of the shipyard's review of the design agent's products. By being able to identify the information to be transmitted, by as early as the initial stages of negotiation between the two parties, not only will adequate information flow be ensured, but more accurate cost estimates for the design agent's efforts should be possible. The timeliness of information flow will also be enhanced, since schedules can be developed and managed throughout the process.

THE APPROACH

The approach followed in performing this task was to divide the work into the four steps which are described in detail in the following sections. The assistance of a number of shipyards and design agents was enlisted to participate in the project. Some of the shipyards and design agents provided copies of contracts and other documentation used in previous projects to serve as a starting point in developing the questionnaire. All of the participants contributed valuable time and effort to the project and made significant comments and suggestions which improved the value and completeness of the final product.

First, a number of shipyards and design agents were contacted and invited to participate in the project. In depth inquiries were made with several of the shipyards and design agents to obtain and compile sufficient information to prepare the basic questionnaire which was to be sent to the larger group of participants.

Then, the questionnaire was mailed to all of the participating organizations. Follow up visits and phone calls were made as necessary to clarify the information requested and to establish a common understanding of each item.

Next, the responses received from the participants were tabulated and reviewed. Additions and deletions were made to the listing based upon the numerous comments received with the completed questionnaires. The tabulated and revised responses were then mailed to the various participants for any additional comments.

In the last step, following receipt of the final comments, a report including the final listing of engineering data which should be provided by a shipyard to a design agent providing engineering and design support services was distributed to the participants and other interested parties.

THE PARTICIPANTS

The following organizations participated in the project. Many individuals within each group made valuable contributions of both their knowledge and time.

Shipyards

Avondale Industries Inc. (ASI)
Bethlehem Steel Company (BSC)
Bath Iron Works (BIW)
Ingalls Shipbuilding Division (ISD)

McDermot (McD)
National Steel and Shipbuilding Co. (NASSCO)
Peterson Builders Inc (PBI)
Textron Marine Systems (TMS)

Design Aaents

CDI Marine
Gibbs and Cox (G&C)
JJH Inc.
John J. McMullin & Assoc. (JJMA)
M. Rosenblatt and Son (MRS)

THE QUESTIONNAIRE

Questionnaire Structure: Top Level

The questionnaire was prepared as a draft of a checklist for statement of requirements (SOR) for engineering support services.

The check list was structured in a work breakdown format with the top level being the five major elements of information which should be provided in a SOR. The five major elements of the listing were:

1. shipyard specific information,
2. project specific information,
3. shipyard imposed project specific requirements,
4. required deliverables, and
5. required schedule of deliverables.

Questionnaire Structure: Second Level

The five major elements of the top level were broken down into a second level as follows:

Shiovard Soecific Information
1.1 Shipyard Organization,
1.2 Shipyard Facilities,
1.3 Shipyard Capabilities, and
1.4 Shipyard Standards and Practices;

Proiect Soecific Information
2.1 Contract,
2.2 Specifications,
2.3 Contract Drawings,
2.4 Contract Guidance Drawings,
2.5 Project Peculiar Documents,
2.6 Third Tier References,
2.7 Approval Procedures,
2.8 Owner Data Requirements, and
2.9 Other Owner Requirements;

Shiovard Imoosed Proiect Soecific Reauirements
3.1 Build Strategy,
3.2 Proposed Construction Plan,
3.3 Proposed Construction Schedules,
3.4 Proposed Test Program,
3.5 Drawing Format and Content,
3.6 Computer Aided Design, Engineering and Manufacturing (CAD/CAE/CAM),
3.7 Other Production Information,
3.8 Liaison Procedures,
3.9 Change Procedures,
3.10 Design Reviews,
3.11 Quality Assurance, and
3.12 Work Tracking and Status Reports;

Reauired Deliverables
4.1 Design Calculations and Studies,
4.2 System Drawings,
4.3 Composite Drawings,
4.4 Installation/Assembly Drawings,
4.5 Fabrication Drawings,
4.6 Schedules, List/Booklets,
4.7 Other Drawings,
4.8 Vendor Drawings,
4.9 Work Packages,
4.10 Test Program Documentation,
4.11 Material Procurement Documents,
4.12 Vendor Documentation,
4.13 Technical Documentation, and
4. 14 Samples Provided;

Reauired Schedules of Deliverables
5.1 Design Calculations and Studies,
5.2 System Drawings,
5.3 Composite Drawings,
5.4 Installation/Assembly Drawings,
5.5 Fabrication Drawings,
5.6 Schedules/Lists/Booklets,
5.7 Other Drawings,
5.8 Vendor Drawings,
5.9 Work Packages,

5.10 Test Program Documentation,
5.11 Material Procurement Documents,
5.12 Vendor Documentation, and
5.13 Technical Documentation.

Questionnaire Instructions

The following information and instructions were transmitted to the participants as guidelines for their responses:

"This document is the first draft of a listing of information that a shipyard should convey to a design agent with the Statement of Requirements (SOR) for Engineering Support Services to insure that the products received by the shipyard are of the desired quality and are directly usable. The purpose of this questionnaire is to test the checklist against existing practices and to identify those items of information which you believe should be added or deleted from the list."

"For a shiovard resoondent:
Please review the following check off list and:
1. check whether your organization currently provides the information indicated with the Statement of Requirements (SOR),
2. check whether you believe that the item should be provided, and
3. add any additional items that you believe should be included with the listing."

"For a desian aaent respondent:
Please review the following check off list and:
1. check whether you normally receive the information with a SOR,
2. check whether you believe that the item should be provided with the SOR to facilitate your performance, and
3. add any additional items that you believe should be included with the . listing."

Questionnaire Follow-UD

Rather than passively waiting for the questionnaires to be returned for analysis, the authors visited as many of the respondents as practicable and discussed both the questionnaire and their responses. This turned out to be most valuable, since it allowed the team to resolve questions that arose in interpreting the questionnaire. It had the additional benefit of providing valuable feedback in comments that went beyond the scope of the questionnaire but were directly related to the efficiency and effectiveness with which shipyards can overcome information flow deficiencies, changes, and other obstacles to production support.

THE RESULTS

The following is a summary of the responses received from the questionnaire.

ResDonses

The responses to the questionnaires were very positive. None of the items listed in the draft questionnaire were rejected as unimportant, unnecessary or extraneous. The key problem that affected the shipyard's responses was the direct result in a lack of clarity in the wording of the questionnaire. When answering the question about their current practices, those shipyards which are not currently farming out a specific type of work answered "No" to that question even if they thought that the answer should be "yes" if the work were farmed out. The actual intent of the questionnaire was to find out whether they agreed that the information cited would be needed IF the shipyard were to farm out that type of work. Fortunately, the follow-up visits by team members were able to clarify this matter in many instances. Reference 1 contains a complete summary tabulation of the responses received to the original checklist items.

Additions

A number of suggested additions to the original list of information items required were received from the respondents. Some of the original items were found to require additional description. All of these additions and modification were made and included in the final listing, which is provided in the Appendix.

THE ANALYSIS

The following are some of the significant findings based upon a review of the completed questionnaires and meetings with shipyard and design agent personnel.

Data DiscreDancies

Review of the summary data revealed what appeared to be considerable divergence in the responses between shipyards and design agents for the current situation. For instance, there are numerous items such as for "1.2.9 Burning Machines", where more than half of the shipyard responses indicated that the data is now being provided, but none of the design agents said that it was. Much closer agreement was obtained in responses to the questions whether the data should be provided.

As a result of the discussions that took place with some of the respondents, it was determined that some of the differences in the responses was due to the fact that some of the shipyards felt that the data was available to the design agent if it was found to be necessary to the design agent's efforts, while the design agents were indicating that they did not get the data without specifically asking for it. The significance of this is that if the data is not available at the time the design agent needs it, the design agent's work is interrupted and delayed. Both shipyards and design agents agreed that it would be much more efficient to identify data needs as early as possible and to have the data available when needed.

Reauired Data

The responses indicate a high degree of agreement that all of the items in the questionnaire would be necessary if the associated type of work were farmed out. In the vast majority of those cases where the shipyard answered "no"and the design agent answered "yes", it was because the shipyard was not presently farming out that type of work. When asked whether that data would be necessary if they did farm out that type of work, the shipyards answered "yes" in almost every case.

ADolication to Current Contracts

In most cases, the percentages of "Should Provide" answers were greater than for the "Now Provide" responses. This indicates that the shipyards and the design agents both agree that the design agents are not now receiving all of the data that they need in order to efficiently provide the shipyards with high quality products that require minimum rework. This is a significant finding that indicates that the list in the Appendix can be used immediately by all shipyards and design agents to identify data needs that have not yet been satisfied under existing contracts.

Amount of Data

There were no indications of any reluctance by the shipyards to provide information to the design agents,, as long as the information was believed to be really relevant to the management or effectiveness of the design agent's efforts. However, there is not total agreement on exactly what information is required by the design agent. There was overwhelming agreement, particularly during discussions with shipyard and design agent personnel, that a check-off list such as that provided in the Appendix would be of great assistance in achieving understanding of, and agreement on, what really is needed and that there is a need to do so. Further, there does not appear to be any significant downside risk to the shipyard in providing more data to the design agent than is absolutely necessary.

Desian Aaent Role

Without complete data, the design agent is limited to the traditional design role and is unable to provide products which make maximum use of the capabilities of the shipyard. The improved productivity and efficiencies which could be achieved from concurrent engineering can not be realized without the full range of data.

ADDITIONAL COMMENTS

Respondents provided additional written comments, as well as many other comments during follow up discussions, that were related to when and how to use the check-off list. They also provided many comments on the management of farm-out engineering efforts. These are summarized in the following paragraphs.

Use of Check-off List for Reauests For Quotes (RF&)

The check-off list in the Appendix, should be used as a part of the initial request for quote for engineering services, by both the shipyard and the design agent. The shipyard should indicate what data will be made available. “There is an absolute need, both at the proposal stage as well as the contract stage, to have a mutual understanding of the constraints or degree of detail required by the client. For example, if the shipyard does not have pipe bending capabilities, the design agent must maximize the use of fittings. Similarly, if a shipyard has extensive in-house standards for foundations, pipe hangers, ventilation spools, etc., the design agent, if not knowledgeable of these standards, will incur unnecessary expense and provide the shipyard with an unusable product.” The design agents believe such data should be made available with the RFQ so that they will know the scope of work they are bidding on more precisely. In their responses, the design agents can use the list to identify what information they need and tie their quote to the availability of the data indicated.

Use of Check-off List for Neaotiationq

The check-off list can be used during negotiations prior to the award of the engineering services contract to further define information needs, as well as to establish a schedule by which the information will be provided. This schedule would be integrated with the schedule for drawing submittal.

Timeliness of Data

Design agents stressed the need for the information to be delivered in a timely manner in order to reduce time wastage and cost. One noted that even though they had indicated on the questionnaire that the information was now being provided, some of the information was only being provided after the design agent identified the need and asked for it. Several design agents indicated that although all of the necessary information normally was received by the end of the contract, it was not necessarily provided when it was needed. This is particularly true in obtaining vendor information. Late information results in wasted effort and/or incomplete drawings being provided to the shipyard.

KeeDina Data Current

Information provided to the design agent must be kept current during the course of the contract. In particular, changes in the ship construction contract and specifications or shipyard construction schedule, should be conveyed to the design agent without delay.

On-Site Representatives

The focus of most of the discussions with the shipyards and design agents was on how to most effectively manage the engineering services contract. It was universally agreed that it is essential to have at least one representative from the shipyard on-site at the design agent’s facility. Experienced personnel added the following considerations.

The shipyard representative must be very knowledgeable about at least one of the areas of work being accomplished by the design agent, so that he can provide as much direct response to questions as possible, without having to refer back to some other individual in the shipyard first. He must have commensurate decision making authority from his shipyard.

For those issues to which the on-site rep is not able to provide direct answers, it is better to have the design agent engineer/designer, rather than the on-site rep speak with a designated point of contact (POC) at the shipyard to get the answer that he needs. This requires that the designated point of contact for each discipline at the shipyard be identified in advance. The POC's should be aware of the limits of their authority. Both the POC contacted and the design agent engineer/designer should record the contact and the decisions made.

Qualitv Assurance Plan

The design agent's Quality Assurance plan should be compatible with that of the shipyard, so that the shipyard's system will not be examining for items that were not covered by the design agent's system.

File Translation

The shipyard and the design agent should have the same or a compatible system of computer data files to readily permit data translation and transmission.

Desian Aaent Standards

An individual from one shipyard who had been that shipyard's on-site representative at a design agent, made the highly unusual suggestion that shipyards should review the design agent's standard drawing practices and standard design details. In some cases, the design agent's standards, based on experience with many shipyards, might be superior to the those in use at the shipyard and should be adopted. In other cases, it might be less difficult and expensive for the shipyard to revise the design agent's drawings to the shipyard's standard rather than to have the design agent learn the shipyard's preferred approach.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are provided.

Use of Check-off List

The checkoff list contained in the Apapendix should be used in the preparation of a shipyard's engineering support contract with prospective design agents. This will ensure that all of the requisite data is identified during the design agent's proposal preparation. Further, the checkoff list can then be used to ensure that the requisite data is prepared by the shipyard and provided to the design agent when required following contract award.

Need for Direct Liaison

Use of the list provided in the Appendix will not preclude the necessity to establish good liaison, effective communication paths and manageable techniques for establishing responsibility for controlling data transmission between knowledgeable personnel in the shipyard's and design agent's organization - but it will be an invaluable first step. The need to have knowledgeable, responsive shipyard personnel available, either on-site at the design agent's facility or through an on-site shipyard representative, was stressed by every shipyard and design agent who participated in this project.

Current Contract Reviews

Shipyards should meet with their current engineering support contractors to identify all data that is considered useful for the design agent to have and to ensure that the design agent either has the data or will be given it by an agreed upon date.

Acknowledgments

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References

1. "The Definition of a Shipyard's Engineering Requirements to be Met by a Design Agent", NSRP Report 0333 dated July 1991

APPENDIX

ENGINEERING SUPPORT SERVICES CHECKLIST

This Engineering Support Services Contract Checklist is intended to assist the shipyard to insure that the shipyard has provided or will provide the design agent with the requisite information in a timely fashion to enable the design agent to produce the contracted design services in a useable format, at the proper time and at the least cost.

SHIPYARD SPECIFIC INFORMATION

This section addresses information which applies uniquely to the specific shipyard and includes both physical characteristics and limitations, as well as established practices and standards.

- 1.1 Shipyard Organization
- 1.1.1 Organization plan
- 1 .I .2 Organizational responsibilities
- 1.1.3 Project organization, responsibilities
- 1.1.4 Telephone directory
- 1.2 Shipyard Facilities
- 1.2.1 Maximum lift capacity
- 1.2.2 Water depth at launch and pier side
- 1.2.3 Type of building ways /slab/drydock
- 1.2.4 Laydown area
- 1.2.5 Plate handling /bending/rolling limitations
- 1.2.6 Unit/assembly size limitations
- 1.2.7 Climatic conditions
- 1.2.8 Paint facility
- 1.2.9 Burning machines
- 1.2.10 Welding equipment
- 1.2.11 Machine shop equipment
- 1.2.12 Pipe bending machines
- 1.2.13 Robotic equipment
- 1.2.14 Temporary Services available
- 1.2.14.1 Staging, lighting, HVAC

1.2.15 Geographic constraints
1.2.15.1 Channel depth & width
1.2.15.2 Bridge clearances
1.2.15.3 Material transportation limitations
l-2.16 Computer programs in use
1.2.17 Material ordering limitations
1.3 Shipyard Capabilities
1.3.1 Size of workforce
1.3.2 Skill level of workforce
1.3.3 Subcontractors
1.3.3.1 Joiner
1.3.3.2 Electrical
1.3.3.3 Combat System
1.3.3.4 Insulation
1.3.3.5 Painting
1.3.3.6 Major equipment
1.3.3.7 HVAC
1.3.4 Other capabilities and limitations
1.3.4.1 Union labor constraints
1.3.4.2 Interface required with other vendors & suppliers
1.4 Shipyard standards and practices
1.4.1 Drafting practices and conventions
1.4.1 .I Dimensional control criteria
1.4.1.2 Piece marking
1.4.1.2.1 Steel, pipe, electrical, outfitting
1.4.1.3 CADICAEICAM
1.4.2 Material standards and practices
1.4.2.1 Material ordering conventions
1.4.2.1.1 Plates/shapes ordering standards
1.4 -2.1.2 Pipe ordering standards
1.4.2.1.3 Stock material
1.4.2.1.4 Catalog material
1.4 2.1.5 Special order material
1.4.2.1.6 SY fabricated standard parts
1.4.2.2 Long lead/advance material procedures
1.4.2.3 Matenal list format
1.4.2.4 Hazardous material
1.4.2.5 Make/buy criteria
1.4.2.6 Material Procurement Documents
1.4 -3.6.1 RF0
1 .4.2.6.2 Purcllase technical specification
1.4.2.6.3 Purchase order
l-4.2.6.4 Bulk material lists, steel list, valve list
1.4.3 Structural standards and practices
1.4.3.1 Metal forming and cutting
1.4.3.2 Welding procedures and details
1.4.3.3 Holes control
1.4.3.4 Bulkhead/deck sleeves
1.4.3.5 Foundations and foundation reinforcement
1.4.3.6 Pipe hanger supports
1.4.3.7 Cable way supports
1.4.3.8 Standard structural details
1.4.4 Lofting standards and practices
l-4.4.1 Conventions
1.4.4.2 Tolerances
1.4.4.3 Nesting criteria
1.4.4.4 Extra stock
1.4.5 Mechanical/Machinery standards and practices
1.4.5.1 Shaft alignment procedures
1.4.6 Electrical standards and practices
1.4.6.1 Wireways
1.4.6.2 Cable supports
l-4.6.3 Testing
1.4.7 Piping standards and practices
l-4.7.1 Fabrication practices
1.4.7.2 Bend radius
1.4.7.3 Hangers
1.4.7.4 Cleaning/flushing/testing
1.4.8 HVAC standards and practices
1.4.8.1 Manufacturing/fabrication criteria
1.4.8.2 Hangers
1.4.8.3 Testing
1.4.9 Painting/coating standards and practices
1.4.10 Jigs and Fixtures standards and practices
1.4.11 Tests and Trials standards and practices
1.4.12 Work Packages standards and practices
I .4.12.1 Work package size limitalioris
1.4.12.2 Work package format

1.4.12.3 Work package contents
1.4.12.4 Work package numbering system
1.4.13 Engineering change standards and practices
1.4.13.1 Producibility
1.4.13.2 Value engineering
l.4.13.3 Error correction
1.4.14 Fitting and accuracy standards and practices
1.4.15 Any other standards and practices

PROJECT SPECIFIC INFORMATION

This section addresses that information which applies uniquely to the specific project due to the requirements which the owner has imposed by the ship construction contract and specifications.

2.1 Contract
2.1.I CDRLS, DIDs
2.1.2 Copy of contract
2.2 Specifications
2.3 Contract Drawings
2.3.1 List of drawings by drawing number, title and revision
2.3.2 Reproducible copy of each drawing
2.3.3 CAD/CAE/CAM data files
2.4 Contract Guidance Drawings
2.4.1 List of drawings by drawing number, title and revision
2.4.2 Reproducible copy of each drawing
2.4.3 CAD/CAE/CAM data files
2.5 Project Peculiar Documents
2.6 Third Tier References
2.7 Approval Procedures
2.7.1 Shipyard approvals required
2.7.2 Owner approvals required
2.7.3 Regulatory body approvals required
2.7.4 Correspondence and distribution procedures
2.8 Owner Data Requirements
2.8.1 Integrated Logistics Support (ILS)
2.8.1.I Provisioning technical documentation
2.8.1.2 Spare parts
2.8.1.3 Selected record data & drawings
2.8.2 Commercial data information
2.8.2.1 Procurement information
2.8.2.2 Technical manuals
2.8.2.3 Booklet of General Plans
2.8.2.4 Spare parts list
2.8.3 Test and trial data
2.8.4 Training and instruction
2.8.5 COSAL
2.9 Other Owner Requirements
2.9.1 Models
2.9.2 Design briefings
2.9.3 Ceremonies
2.9.4 Certifications

SHIPYARD IMPOSED PROJECT SPECIFIC REQUIREMENTS

This section addresses the information which applies uniquely to the specific project which the shipyard has imposed.

3.1 Build Strategy
3.1.I Description of building plan
3.1.2 Establish Unit and assembly breaks - drawing
3.1.3 Product Work Breakdown Structure
3.1.4 Preoutfitting sequence
3.2 Proposed Construction Plan
3.2.1 Shipyard Master Construction Plan
3.2.2 Ship construction plan
3.2.3 Unit erection plan
3.2.4 Subcontracting plan
3.3 Proposed Construction Schedules
3.3.1 Time phased construction plan
3.3.2 Engineering and design schedule
3.3.3 Material/equipment required in yard dates
3.3.4 Vendor information required dates
3.3.5 Long lead time materials
3.4 Proposed Test Program
3.4.1 List of tests required

3.4.1.2 Required sequence of tests
3.4.2 Test procedures required
3.4.2.1 Test Procedure format and content
3.4.2.2 Test procedure numbering system
3.4.2.3 Sample test procedure provided
3.4.3 Test reports required
3.4.3.1 Test support required/ personnel/equipment
3.4.4 Trials agendas
3.4.4.1 Dock trials
3.4.4.2 Builders trial
3.4.4.3 Owner's trails
3.4.5 Trial reports required
3.5 Drawing Format and Content
3.5.1 Drawing size
3.5.2 Title Block layout and data
3.5.3 Drawing numbering system
3.5.4 Drawing layout
3.5.5 Bill of material format
3.5.6 General Notes
3.5.7 Drafting Standards
3.5.7.1 DOD-STD-1OO/DOD-DI OOO
3.5.7.2 Commercial
3.5.7.3 Level 1,2,3
3.5.8 Sample provided
3.6 CAD/CAE/CAM
3.6.1 Required CAD/CAE/CAM application
3.6.2 Shipyard CAD/CAE/CAM system
3.6.3 Degree of compatibility required
3.6.4 Control of CAD/CAE/CAM file
3.7 Other Production Engineering Informatlon
3.7.1 NC tapes
3.7.2 Nesting sketches
3.7.3 Template information
3.7.4 Spool sketches
3.7.5 Pipe details
3.8 Liasion Procedures
3.8.1 Responsible SY personnel
3.8.2 SY approval procedures
3.8.3 SY personnel at Design Agent
3.8.3.1 Facilities required
3.8.4 Design Agent personnel at SY
3.8.5 Responsibility for meetings
3.8.6 Responsibility for reports
3.8.6.1 Frequency of reports
3.8.7 Contact with owner
3.8.8 Contact with regulatory bodies
3.8.9 Contact with vendors and subcontractors
3.9 Change Procedures
3.9.1 Change orders
3.9.1.I Changes to basic ship construction contract
3.9.1.2 Changes to Engineering support contract
3.9.2 Engineering changes (ECNs)
3.10 Design Reviews
3.10.1 Responsibility
3.10.2 Procedures
3.10.3 Location
3.10.4 Schedule
3.11 Quality Assurance
3.1 1. I Responsibility
3.11.2 QA plans
3.11.3 Shipyard procedures
3.11.4 Design Agent procedures
3.12 Work Tracking and Status Reports
3.12.1 Responsibility
3.12.2 Report content
3.12.2.1 Technical
3.12.2.2 Schedule
3.12.2.3 Financial
3.12.3 Reporting schedule

REQUIRED DELIVERABLES

This section addresses the information which the design agent is required to deliver to the shipyard under the terms of the engineering support contract between the shipyard and the design agent. This section addresses whether the shipyard and the design agent have clearly identified all of the deliverables required by the shipyard from the design agent.

4.1 Design Calculations and Studies Identified
4.1.1 Weight Estimate
4.1.2 Inclining Experiment Report
4.2 System & Arrangement Drawings
4.2.1 Structural Scantling

drawings
4.2.2 General Arrangement Drawings
4.2.3 Machinery Arrangement Drawings
4.2.4 Control Space Arrangement Drawings
4.2.5 Diagrams
4.2.6 Diagrammatic Arrangements
4.2.7 Advanced material list
4.2.8 Material List
4.2.9 Compartment and Access Drawings
4.3 Composite Drawings
4.3.1 Composites/multisystem drawings
4.4 Installation/assembly Drawings
4.4.1 Unit drawings
4.4.1.1 Outfitting Lists
4.4.2 Machinery packages
4.5 Fabrication drawings
4.5.1 Pipe details/spool pieces
4.5.2 Piping hanger support details
4.5.3 Ventilation details
4.5.4 Foundation list
4.5.5 Foundation drawings
4,5.6 Hole list
4.5.7 Key List
4.6 Schedules/lists/Booklets
4.6.1 Paint schedule
4.7 Vendor Drawings
4.7.1 Vendor Geometry Drawings
4.7.2 Vendor Compliance Drawings
4.7.3 Vendor MilSpec Drawings
4.8 Other Drawings
4.8.1 Closure Lists
4.8.2 Label Plates
4.8.3 Cableways
4.8.4 Lighting
4.8.5 Shafting
4.8.6 Joiner
4.8.7 Insulation
4.8.8 Deck Covering
4.9 Work Packages
4.9.1 Work package master list
4.10 Test Program Documentation
4.10.1 Test procedure master list
4.10.2 Test reports master list
4.10.3 Testing support required
4.10.4 Trial support required
4.11 Material Procurement Documents
4.11.1 Material ordering master list
4.11.2 Spare parts list
4.12 Vendor Documentation
4.12.l Master list of vendor documentation required
4.12.2 Number of copies required
4.13 Technical Documentation
4.13.1 Master list
4.13.2 Training
4.13.3 Safety
4.14 Have samples of above items been provided?

REQUIRED SCHEDULE OF DELIVERABLES

This section addresses the schedule on which the design agent is required to provide the deliverables to the shipyard under the terms of the engineering support contract between the shipyard and the design agent. The items in this section address whether the shipyard and the design agent have established the required dates for the deliverables to the shipyard in order to perform to the contract and specifications.

Required Dates for:

5.1 Design Calculations and Studies
5.2 System and Arrangement Drawings
5.3 Installation/Assembly Drawings
5.4 Fabrication Drawings
5.5 Schedules/Lists/Booklets
5.6 Other Drawings
5.7 Vendor Drawings
5.8 Work Packages
5.9 Test Program Documentation
5.10 Material Procurement Documents
5.11 Vendor Documentation
5.12 Technical Documentation

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An Approach for Improving White-Collar Productivity

No. 5A-1

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ABSTRACT

The bastion of the white-collar segment within the typical shipyard has rarely been penetrated by outside influences, especially under the banner of productivity improvements. This paper will discuss enlisting the talents of both white and blue collar employees to gain some advantages in this area.

The technique espoused here is the empowerment of selected employees at the operational level through the use of Action Teams. This is the level at which daily shipyard operations are conducted, above the worker level and below the management level. A recent project sponsored by SNAME Ship Production Committee Panel SP-5 on Human Resources, and performed under the National Shipbuilding Research Program (NSRP), conducted a hands-on application of this theory in a small shipyard with favorable results. This project will be discussed in some detail, including:

(1) the rather extensive preparations conducted at the management level before any other efforts were expended;

(2) the formulation 01 two separate Action Teams of representatives from nearly all of the white-collar segments of the shipyard, along with carefully selected members of the blue-collar community;

(3) the implementation activities that. occurred over 8 months; and

(4) the overall results obtaincd.

This initial project was sufficiently successful that. a follow - on project was immediately prosecuted by Panel SP-5. Although the second project was not completed prior to the preparation of this paper, an update will be provided so that the audience may stay abreast of this fast-moving scenario, which promises to provide anothcr practical tool for- developing shipyard productivity improvements.

INTRODUCTION

The magnificent Grand Canyon bears a striking resemblance to a common problem in our shipyards. How immense this natural wonder really is - so wide, long, and deep. By analogy, one is reminded of the dimensions 0f a major difficulty found in nearly every shipyard, except perhaps for the smaller ones with less than 500 people. This difficulty is the communication gap that exists between the white-collar people and the blue-collar production work force. Such an observation is not the off-hand opinion of a chronic skeptic, but the distillation of many first-hand observations in both areas over quite a few years. There simply IS NOT A close working relationship between these two shipyard groups - with each side freely announcing that the other is the one at fault.

One Perspective

In one admittedly biased view of a shipyard, there is a production work force (the blue-collar segment) that performs the basic functions of that enterprise. All the rest of the people are there to provide support to that production work force. This latter group constitutes the white-collar segment - engineering, material procurement, estimating, accounting, human resources, data processing, central planning and scheduling, and management. Certainly the white-collar people have their own interests and concerns, but ultimately they MUST align their efforts so that the production work force can best utilize the support provided to them. This challenge does not rest with the white-collar segment alone, hut i:; shared equa1ly by the production work force. There is no contradiction in terms here, because the key to success is TEAMWORK. All of the players must make their best contribution to the common good. The term TEAM WORK is receiving much attention these days, and hopefully it is here to stay.

Response to the Request for Proposal

It was in this frame of mind that a response was prepared to a Request for Proposal issued by SPC Panel SP-5 on Human Resources in October 1989. The project called for some relatively fearless person to penetrate the bastion of the white-collar world in a selected shipyard, establish a beachhead, pick out one or more promising targets, and set about the task of improving the productivity of those white-collar segments through the use of employee involvcmcnt techniques. There was not much experience on the books concerning forays into the white-collar community within the shipyard industry, and this project was attractive to one who has been active in several segments of the white-collar world during a busy professional career.

The proposal noted that this project would be a challenging effort. The white-collar regimen would be formidable, and breaking the paradigm of white-collar attitudes and activities firmly entrenched over many years of ostensibly satisfactory service would not be easy. As an added difficulty, visibility into the arena of the white-collar people has been hazy at best, with the haze growing more dense as the overall size of the shipyard increases. White-collar inefficiencies and their associated expense to the shipyard are often invisible to management, who simply see the production work force as not producing adequately. A common reaction is to throw more production workers at the problem, and to step up the application of overtime in order to meet the delivery schedule. These actions treat the effect, but not the cause. And since the production worker portion of the shipyard is the largest and most expensive in terms of total manpower cost per day, the impact of such a reaction can be devastating.

Specific Considerations

The proposal contained two rather severe conditions, which were recognized as potentially difficult for the Panel to accept, but which had to be voiced up front. The first was that the task should be carried out in a small shipyard, where representative conditions existed but where the added problems attending the larger white-collar organizations were minimal. This would allow the investigation to treat several different full segments of the white-collar work force, rather than being limited to only pieces of the larger groups that are found in the bigger shipyards. In addition, the subsequent test application of work redesign techniques could be applied to a whole white-collar function in a small shipyard, rather than only to a segment of that function in a large shipyard. Later on, the techniques developed here could be adjusted to suit application in a large shipyard environment. The first condition, then, would allow the task to proceed more effectively in a small shipyard were the problem areas could be surrounded and treated in a reasonable length of time.

The second condition was that the members of the production work force at the shipyard would be involved in the activities designed to improve white-collar productivity. That is:, the white-collar segment of the shipyard would NOT be the only group treated, as had been the case in other industries. The task would recognize and build on the communications and operational relationships needed between whitc-collar workers and blue-collar workers in order to improve the productivity of the white-collar group. The rationale behind this approach was quite simple, and was based on fundamental information feedback. The white-collar segment produces a product. The principal user of that product is (ultimately) the production work force. The producer must have information feedback from the user on whether the product is producing the results desired, so that adjustments can be applied as necessary. This feedback mechanism ensures that the overall process is carried out in the best interests of all participants.

Communications in Both Directions

Two points are of immediate concern.

(1) The white-collar producer needs to understand clearly the basic capabilities of the user, and the specific procedures and operations throuqh which the white-collar product will be applied to produce the ship. This information (blue-collar to white-collar) is essential to the initial creation of a product that will be usable and can be readily applied. It might be assumed that the white-collar segment already knows all about the production side of the shipyard, particularly since many of the people in the white-collar segment may have previously worked in production areas. Experience tells us, however, that this is NOT usually the case. White-collar people tend to concentrate (and rightly so) on their own part of the overall effort, which often demands single-minded determination to resolve one onerous issue after another. At the same time, developmental changes in production techniques, and the dynamic nature of production activities, -gradually move the sensitivitv of the white-collar people further away every day from the pulse of production. Soon the information gap grows to surprising proportions, and continues to widen as

each new production situation presents itself. Unless there is some sort of bridge, regularly traveled by all of the participants, the hope for true progress is dimmed.

(2) The white-collar producer must stay in close touch with user problems and concerns as they develop so that problems can be resolved quickly and decisively. The ostrich technique for avoidinq difficulties does not work in an industrial atmosphere. What you don't know WILL. hurt you, eventually if not sooner. For the white-collar segment to gain the needed degree of intelligence about everyday activities in the production work area requires a system of timely and FAITHFUL communications among all of the people involved. And even this is not enough! Problems must be identified BEFORE they impact production work, causing costly delays and disruptions in the ship production processes. This requires careful and complete communications in the OTHER direction (white-collar to blue-collar), so that the production side can understand white-collar intentions, and can assist in identifying potential problems while there is still tine to correct them with minimal cost in time and money. Again, it might be assumed that our informational networks and problem-handlinq paperwork will obviate this dilemma, and well they might. But since most of this brand of intelligence is generated after the fact, the PEOPLE involved must illuminate such judgmental information before the fact. This is the really tough part of the problem, because it demands an operational closeness among the team members that will survive the rigors of the workplace and allow the stream of communications to continue IN BOTH DIRECTIONS, a condition that is absolutely vital to a successful effort.

Arena Selection

Finding a small shipyard with an on-going workload sufficient to support this investigation was recognized as difficult enough in the prevailing economy. Finding one with a disposition to attempt this sort of improvement effort, and willing to share the findings with the rest of the industry, would be doubly difficult. An agreement, however, was secured with Peterson Builders, Inc., Sturgeon Bay, Wisconsin, to serve as the participatinq shipyard for this project .This shipyard would have an adequate workload over the several months of project performance, a progressive and responsive management team, a dedicated and effective work force, and a wi11ingness to share NSRP task findings with the rest of the industry.

Proposal Features

The proposal offered to develop a four-phased program for performing this task over a period of about 12 months:

(A) measurement of base-line productivity in several white-collar functional areas;

(B) identification of those whitc-collar functional areas most amenable to improvement through cmployee involvement techniques, and other work redesign avenues;

(C) development of work redesign innovations, through employee involvement techniques and other-industrial engineering procedures, for direct application in one of' more specific functional areas; and

(D) test application of' actual improvement efforts in as many white-collar functional areas as the project could support.

A competitive award was made in April 1990, and work began promptly.

PREPARATIONS

The approbation of most senior shipyard management was recognized as absolutely essential to success. Initial preparations, therefore, were carried out to ensure that such support was both present at the shipyard, and was advertised to the workers involved before any measurements were made or discussions were held with the work force. Each senior manager associated with the personnel who might be involved in the task was briefed in complete-detail as the very first step of the project, and thereafter before any other specific actions were carried out. These briefings were done by the project director, usually one-on-one with the-senior manager involved. This portion of the project required a considerably amount of time, but was absolutely essential to successful performance. There must be NO surprises at this senior management level, which included the General Manager, the Vice President of Manufacturing, the Vice President of Operations Support, and the Vice President of Human Resources.

This point of preparation is made first and foremost to emphasize the important of this action. These senior managers were NOT expected to take any specific actions themselves during the project, but would be kept fully appraised of activities as they unfolded, and made aware of each significant new action to be taken before it was attempted. Having these senior manager:: aware of project details, albeit de1iberately distant from the participant::

themselves, created an atmosphere of agreement and support without which the combined efforts of all the players could not have been so successful.

DISCUSSION OF PROJECT ACTIVITIES

Assessment of Initial-Conditions

Comprehensive interviews were conducted with selected personnel from several segments of the shipyard. The participants were carefully selected through consultation with two knowledgeable and established members of the work force, in order to cover a representative cross section of the shipyard. Both white-collar and blue-collar workers were interviewed. Each interview was set up for 1 hour, one-on-one. The same questions were asked each person interviewed to aid in subsequent analysis of the answers. All interviews were completed before any analysis of results was made. This point helped to ensure that bias was not inadvertently introduced during the interview discussions which, because of the number of individual interviews involved, took place over a period of several days. Although shipyard senior management was made aware of who was being interviewed, they did not influence the selection of interviewees or the questions asked of them.

The interviews revealed that the shipyard had committed a large amount of effort to employee training under the Transformation of American Industry (TAI) format, and also to Total Quality Management (TQM), which was renamed and redefined as Continuous Quality Improvement (CQI). It was immediately clear that this project should capitalize on the training already carried out, since A large number of workers had completed these courses and were familiar with many of the techniques espoused. Building on this base of knowledge was expected to improve the likelihood of success.

After all of the interviews had been completed, the results were analyzed and assessed. The overwhelming message was that people were not communicating effectively with each other. Often the only time that common problems were addressed was after an equipment interference was encountered, material was unavailable when needed, or a sequencing problem arose that a trade could not resolve independently. In such cases, the production people were stuck with the problem, which usually occurred well into the ship construction period and with essentially NO time for working out a solution. The white-collar segment would be involved in problem resolution only on request. This condition appeared to be most troublesome in two functional areas; structural, and electrical. The other functional areas of the shipyard appeared to be in a similar but 1ess severe condition.

Establishment of a Productivity Baseline

Several ideas were explored in an attempt to set up a reasonable baseline tot- productivity assessment, as lo:-lows:

First, the number and content of Product ion Change Requests (PCR's) was examined. These documents are generated by production workers as a vehicle with which to communicate with engineering (most often) and occasionally with other support people. It was clear that PCR's were being used only by certain groups in the shipyard, and then only after other avenues had been exhausted. PCR's were clearly not a popular way to communicate, and were often used only as a last resort. Even the name of the form was a problem to some workers, since it suggested that the change was something that production was requesting to satisfy their own interests. In fact, the PCR was simply reporting a problem that needed a resolution so that construction might continue.

Second, the number and content of drawing revisions was examined. These revisions, made by in-house engineering people, were found to be quite dependent on the quality of the basic design drawings received from the outside design agent. This fact may have caused bias in the message gained from analysis of drawing revisions, so this potential baseline indicator was abandoned.

Third, the population of Engineering Change Notices was examined. ECN's are used when problems arise in carrying out the basic design. Since they might reflect the closeness of in-house engineering people with production activities, they would be trackcd further.

Fourth, the mobility of the engineering people was examined to see whether they were personally going to the production sites within their assigned areas of concern frequently, often, or rarely. This indicator might reflect the working relationships between engineering people and production people, and might shed some light on the nature and degree of communication actually taking place.

Fifth, the general attitudes exhibited by the various players were examined. These would be a valuable indicator of just how well things were going, and how close the working relationships were among the several groups involved in carrying out daily operations. If, indeed, improvements could be obtained through employee involvement techniques, an early indicator would be a change in the personal attitudes of those closest to the pulse of the shipyard.

Determination of Areas to be Treated

The decision on what functional areas to treat was not a difficult one to make. The structural area and the electrical area clearly were most in need of improvements in working relationships and communications. Each area had its own unique problems, but both shared the common need for better and more timely understanding of problems as they developed, and for closer cooperation in resolving matters of mutual interest before a major snag was encountered. It appeared from the start that each of the white-collar groups enjoyed the basic capability to do their jobs correctly and efficiently once they fully understood the details of the problems. What was missing, though, was the faithful exchange of detailed information from production people to white-collar people, and from white-collar people to production people. This gap in communication was the direct cause of an unproductive atmosphere. It was therefore decided to tackle the problem of communication first, followed closely by working relationships in both of these functional areas.

Creation of Action Teams

An Electrical Action Team (EAT) and a Structural Action Team (SAT) were set up as the vehicles through which improvements would be attempted. The composition of each team was established with great care through extensive discussions involving the two shipyard people who assisted in setting up the interviews mentioned earlier. The aim was to include on each Action Team the optimum mix of white-collar people and production people, so that all elements of daily operations in that area were represented. It was desired that each team member be able to recognize the action needed in a particular area, be it engineering, planning, material, or production. In many cases, the Action Team member would be able to carry out that action alone. *in* the more extensive cases, however, the member would carry the message back to the parent organization, discuss the details with those responsible for resolving the matter, and follow up on the corrective activities until the basic need was satisfied to the satisfaction of the Action Team. This arrangement would provide the capability to develop improvements, as might be identified later on, with only an occasional need to invite others to join directly in the deliberations of the Action Team. It was also desired to keep the size of each Action Team from growing too large. About 15 people was set as the maximum number, with 10 to 12 as the preferred range. The initial composition of the two Action Teams was as follows:
(* = white-collar)

Electrical Action Team -

* Electrical Engineering Section Head
* Electrical Engineering Staff Member
* Electrical Engineering Staff Member
* Material Control Group Member
* Planning Supervisor
* Planning Group Member
Electrical Superintendent
Electrical General Supervisor
* Facilitator (Human Resources Group)
* Task Director

Structural Action Team -

* Hull Engineering Supervisor
* Hull Draftsman/Designer
* Material Identification Group Member
* Planning Supervisor
* Planning Group Member
* Materials Management Representative (Purchasing)
Shipfitting Superintendent
Shipfitting General Supervisor
Shipfitting General Supervisor
Shipwright General Supervisor
* Facilitator (Accuracy Control Group)
* Task Director

It is important to recount the process of selection Action Team members There was absolutely no attempt to exclude an individual because of an ominous personal attitude or expressed opinions. On the contrary, every potential member was assessed *on* the basis of position in the shipyard, assigned responsibilities, and ability to influence the activities of others. This resulted in the creation of Action Teams representing the true life blood of the shipyard at the operational level, with members who should be able to handle the down-stream improvements when they became apparent.

Final selection of the Action Team members received the approbation of senior management in each case. Then, and only then, was the information on Action Team members made known to the personnel involved, and to their immediate supervision.

Meetings of each Action Team were established as once-a-week, for a duration of not more than *one* hour. Unfinished business was carried over until the following week. This arrangement established a known commitment of time for each attendee, minimizing the disruptive effect on other activities. Meeting minutes were kept, and an agenda was published *prior* to the following meeting. The atmosphere during the meetings was kept informal, but control of the discussions was exercised by the facilitator or the task director until their involvement could be lessened, and later eliminated.

Implementation of Action Teams

Both Action Teams followed the same pattern for the first three meetings, as follows:

Meetings No. 1. A kickoff meeting, where the purpose of the Action Team was explained, the meeting set-up was described, and the members began to interact with one another. This initial experience was tense, with considerable apprehension noticeable among the members. Their contributions to the general discussion were minimal and guarded, with several members clearly relieved when the meeting was adjourned.

Meeting No. 2. A brainstorming session, where problems of every description were brought up under carefully controlled general rules. These rules were as follows.

- Each member could bring up only one item at a time.
- The turn would then pass to the next member, moving around the table until everyone had run out of problems (or the meeting time had run out).
- No member could make any comment on another member's item when it was brought up, pro or con.
- Every item would receive equal consideration.
- An existing item could be modified or clarified by another member when his turn came, but the original item would stay the same.

Following this format, and with two facilitators writing down the items two flip charts, the Electrical Action Team generated 66 items, and the Structural Action Team generated 99 items, each in the space of ONE HOUR.

Member attitudes during these second meetings were essentially unchanged from the first ones. The atmosphere was still heavy, with member participation only as required. These sessions were designed to get each of the members to express, but not discuss, items of common interest, which would continue the process of getting the members to feel more comfortable just being in each other's presence. Progress in this regard was slow, but in the right direction.

Meeting No. 3. A categorization session, where each of the problem items brought up were assigned to one of 12 categories. Once each item had been assigned to a category to the satisfaction of all members, a VOTE (using Nominal Group Technique) was conducted to see which category should be pursued further as the highest priority concern of the members. Results were as follows.

For the Electrical Action Team, Material-.Identification was the big winner. This reflected the dire and continuing need for improvements in the timeliness and quality of electrical material deliveries to the work site.

For the Structural Action Team, Material Availability and Communications came in as a tie. It was therefore agreed to discuss both items, which probably had a common thread anyway.

These sessions began the process of developing positive interaction among the members. Member attitudes and participation during these third sessions were improving, with a noticeable decrease in atmospheric tension. Some apprehension remained, particularly in regard to whether any improvements could realistically be achieved despite the need for them. Generally, however, barriers were beginning to break down and the future looked more promising.

Meetings Nos. 4 through 6. These were working sessions where individual concerns within a previously selected category were discussed. By the end of Meeting No. 6, open exchanges were taking place among the members, and several possible avenues of resolution *were* being explored for the main items on the agenda. The facilitators were active in controlling the discussions, but the need for their involvement was beginning to decrease.

Meeting No. 7. For both Action Teams this meeting included the development and acceptance of a Mission Statement, and the selection of an Executive Sponsor. Now the two Action Teams were getting formally established within the shipyard framework for this type of group. Both Action Teams decided to elect, at the next meeting, a Chairman and a Note Taker from among their members. A volunteer Note Taker emerged on the Electrical Action Team, and was promptly accepted by the group.

Meeting No. 8. This meeting saw the election of a Chairman within each Action Team. and also the election of a Note Taker-for the Structural Action Team. The role of the facilitators was now reduced to the point that each Action Team was essentially running by itself as directed by the Chairman.

Meetings Nos. 9 through 24. For both Action Teams, these meetings addressed a regular pattern of items, with different specifics in each functional area but with similar types of agenda items. Both Action Teams treated two generic types of problems: 1) short-range problems within the resolution capability of the Action Team members; and 2) larger and longer-ranged problems that required the involvement of others outside of the Action Team members. A few specific items are described below.

Summary of Action Team Activities

A few of the specific items accomplished by the two Action Teams are as follows.

Electrical Action Team. The principal thrust of several meetings was concern about electrical material identification and availability information. The members were distantly aware of an in-house white-collar effort to improve overall shipyard operations through a technique called Integrated Business Systems (IBS). A modeling technique (IDEF) was being used by the IBS Group to capture the as-is situation for later use in developing the to-be arrangement. In the material area, three specific items were being treated by the IBS Group: the Material Ordering System; the Material Management System; and the computerized Bill of Material. These three items were of special interest to the EAT members, several of whom were regular users of this information.

Several meetings were therefore devoted to articulating particular concerns in these three material system areas for later transmission to the IBS Group for their consideration. The intent was to provide the IBS Group with first-hand user concerns and suggestions that might prove beneficial during the deliberations of the IBS Group. Eight separate and specific items of concern were generated, developed, and carefully described by the EAT. A decision was then made to send these descriptions to the IBS Group, along with an invitation for representatives of the IBS Group to attend an upcoming EAT meeting where two-way communications about these items could be carried out. The invitation was accepted by the IBS Group, and an excellent exchange of information was held at the next EAT meeting (#19). The atmosphere was positive and enthusiastic on both sides, with the expectation that future modifications to these three material systems would reflect the information exchanged. This will clearly enable an improvement in white-collar productivity to the benefit of the *user* community.

During subsequent discussions, the IBS Group decided to seek the agreement of the EAT to be the window into the electrical area through which IBS ideas and intentions might be initially presented sometime in the near future. Following such a presentation, these items might be discussed so as to provide feedback to the IBS Group on how these initiatives might work out in actual usage. Furthermore, the TBS Group voiced their support for similar additional windows through the creation of Action Teams in other functional areas. Clearly, this posture constituted a strong endorsement of the value gained by the white-collar segment from the information exchanges that took place through the EAT.

In another specific area, the EAT members addressed the contractual requirement for calibrating meters in electrical panels. Practice had been to remove the meters from the panels, transport them to the shipyard calibration laboratory for calibration verification, transport them back to the ship, and reinstall them into the panels. This practice was time consuming, costly, and fraught with opportunities for meter damage. Several shipyard support people were invited to attend an EAT meeting to discuss the possibility of in-place calibration verification of panel meters, a practice that would require some equipment purchase and training, but which would potentially save the shipyard a substantial amount of time and money. As a direct result of the EAT involvement in this matter, a procedure for in-place calibration verification of meters in electrical panels was established through the cooperative efforts of people in engineering, material procurement, quality assurance, and production. Once again, a white-collar product was better able to satisfy the overall interests of the shipyard because of the communications provided through the EAT. Working relationships were strengthened through the cooperative discussions that took place, and enough money will be saved by this one item alone to pay for all of the EAT meetings held during this project.

Structural Action Team. A major thrust of the SAT was to investigate the cause of time-consuming problems in the flow of small fabricated wood parts for the minesweepers (MCM). The internal information system covering these parts would show that fabrication of certain parts was complete, but when the downstream installing shop would try to draw these parts out for installation, they were not available in the warehouse or in the fabrication shop. Delays were commonly encountered while a search was made for the supposedly available parts.

A flow chart was made to show every step in the laminating and fabricating process. Representatives from these two shops were invited to attend the SAT meetings so that agreement might be obtained on the details. Despite several tries at improvements, and at least one substantial change in the software for the information system, the problems persisted. Finally, one seemingly small step was found to be missing from the flow chart, and this step turned out to be the key to establishing when a part was truly completed. Once this point was brought to light, the communication problem that had plagued this particular area on every MCM constructed over the past several years was now resolved. The savings in installation shop man-hours through drastic reductions in parts chasing activities will be several times greater than the cost of all of the SAT meetings held during this project. The white-collar product that was improved in this case was a computerized tracking system, now adjusted to reflect the true status of the parts being tracked.

This particular problem endorses the importance of having a process flow chart that covers ALL aspects of an operation. Such a complete flow chart discloses four types of activities:

Type 1 - part of the process + value added to the final product;

Type 2 - part of the process + no value added to the final product;

Type 3 - not part of the process + value added to the final product;

Type 4 - not part of the process + *no* value added to the final product.

Careful examination of each activity on the process flow chart will disclose the exact nature of that activity (Type 1, 2, 3, or 4). This will promptly reveal those activities that are candidates for modification, or even outright elimination. It may even be the activities that are not a part of the basic process that are causing the problems in the first place.

One other regular feature of the SAT meetings was a brief presentation by the SAT members from the shipyard engineering group on what directions were going to be issued to production in the immediate future. At first the only information volunteered was for those items that had been fully researched and were considered firm by engineering. That is, there was no discussion of items that were indefinite and still under technical consideration. As the meetings progressed, the working relationships among the SAT members became closer and less uncertain, and confidence grew among the members. Then the engineering members were more Willing to volunteer information even if it was still under development. This produced a virtual breakthrough in communications (at about meeting #19), which allowed the regular discussion of potential problems to take place at each subsequent meeting. Although the effect on white-collar productivity of these more open discussions was not quantifiable, there is no doubt that the benefits are large and in the right direction.

Attitude Changes

The appearance of changes in the baseline indicators selected for measuring improvement in white-collar productivity did not materialize as soon as was expected, with one exception. That exception was the general attitudes exhibited by the various participants. Within the Action Teams membership, noticeable changes in personal attitudes were seen as early as the 5th or 6th meetings, with major changes apparent by about the 9th or 10th meetings (that is, after the meetings had been running for about three months). Thereafter, steady improvements were seen, with positive working relationships continuing to develop among the Action Team members.

Outside of the Action Team members themselves, changes in the attitudes of those interfacing with the Action Teams were seen shortly after these invites had participated in the meetings. First among this segment was the IBS Group, whose prompt reaction was to endorse the EAT as a way for IBS efforts to be introduced into the shipyard processes, and from which feedback on implementation of these ideas might be gained. In addition, the IBS Group quickly supported the potential for establishing similar Action Teams in the other functional areas of the shipyard, so that the same advantages might be gained in those areas also.

The attitudes of senior shipyard managers followed a similar vein. These senior managers (identified earlier) were briefed on a continuing basis. As the end of the project drew near, the task director raised the possibility of abandoning the Action Teams, since they were no longer needed to support the project. The consensus of the senior managers, however, was that the two Action Teams already in place should continue to operate. Since these two Action Teams had been institutionalized (during the 7th meetings), having them continue in operation would not require any additional or special action. This senior level of management also indicated that consideration would be given to setting up similar Action Teams in the other functional areas of the shipyard. To date this action has not been taken because of an unfavorable workload.

Specific Baseline Indicators

In regard to the other baseline indicators selected for this Task, the following observations apply.

The population of Production Change Requests (PCR's) appeared to be unchanged during the performance period of this project. The PCR system itself continued to be supported in some areas and not in others, apparently unaffected by activities of the two Action Teams.

The situation surrounding Engineering Change Notices (ECN's) was somewhat different, since these items were now being discussed freely during the SAT meetings. To the extent that this noticeable improvement in information exchange was taking place, the ECN system was gaining credibility. However, the number and nature of ECN's showed no significant change.

The mobility of the engineering people, along with white-collar material people and planning personnel, seemed to show more activity due to the Action Teams, but definitive data to support that observation was not available. Similarly, visits and discussions by blue-collar workers with their white-collar counterparts seemed to be more prevalent as the end of the project performance period was reached, but firm data to support this condition was not in evidence.

Questionnaire Results

After the Action Teams had operated over a period of 6 months, each Action Team member was asked to fill out a questionnaire to provide some insight into how this project had proceeded. Although this information sample of 15 replies, 5 from production members and 10 from white-collar members, was too small to be statistically sound, the results were interesting.

93% felt that meeting for 1 hour per week was about right.

80% of the production members felt that engineering (and other white-collar) matters were the best topics discussed.

44% of white-collar members felt that the best topics discussed were those that could be resolved by the Action Team members. One white-collar respondent stated that ALL topics discussed were important.

66% felt that problems beyond the capability of the Action Team members to resolve were the worst topics discussed. However, 2 respondents stated that there was NO worst topic discussed.

The EAT/SAT was value rated by all respondents at 6.9 (on a scale of 1 to 10 (high)). However, the production members value rated the EAT/SAT at 7.8.

73% felt that white-collar productivity had stayed the same during the 6-month period of EAT/SAT operation. One respondent added that 6 months was too short a time period to reveal any major improvements. 40% of production members, but only 20% of white-collar members, felt that white-collar productivity had improved during the 6 month period of EAT/SAT operations. No respondent indicated that white-collar productivity had dropped.

80% supported the idea of Action Teams in other functional areas.

93% felt that better cross-functional communication was needed.

Termination of Phase I

At this point it was decided not to wait any longer for the baseline productivity indicators to change. The 12-month performance period of this task was exhausted. In view of the fact that Phase II of this task would be performed at the same location with little or no interruption in activities, it was decided to continue tracking the results of these two single-function Action Teams into Phase II. This would provide additional opportunity for these indicators to show changes which may reflect on the nature and magnitude of white-collar productivity.

APPLICATION OF FINDINGS

The results of this Task have demonstrated that white-collar productivity in a shipyard environment can be treated effectively with the Action Team technique. From-the lessons learned during Phase I, the following guidelines are suggested for use by other shipyards interested in developing this approach.

Step 1: Gain the Confidence of Most Senior Shipyard Management

This action is clearly the most important to a successful operation. This level of management must be kept in close touch with the activities of each Action Team on a frequent and regular basis. The amount of time needed to effect changes in the attitudes of the workers must have up-front recognition and acceptance, because it is not an overnight evolution. Attempts at short-cuts, particularly in the early going, can devastate the fragile balance being nurtured among the participants, and send progress back to square one. In addition, the subject matter selected for discussion at the Action Team meetings must be selected by the members themselves. They must feel empowered to control their own destiny in regard to the topics being treated. Senior management needs to know what is going on at the meetings, but must resist the temptation to get directly involved.

Step 2: Recognize the Need to Involve Production Workers

As users of the white-collar product, production workers hold two important keys to achieving success:

(1) detailed and up-to-date information on actual performance of the many procedures and operations that will create the shipyard product, which information is essential to the original development of a good white-collar product; and

(2) information on how well (or how poorly) the white-collar product is actually supporting the various production activities, which information forms the valuable feedback needed by the white-collar faction to truly improve their contribution to the total effort.

Failure to recognize and treat the full scope of white-collar impact may result in improving the quantity and timeliness of the white-collar products, while ignoring the actual usability of them. Such an oversight could make matters even worse by more fully masking the real cause of shipyard difficulties.

Step 3: Assess Initial Conditions within the Shipyard

A series of l-hour interviews with selected workers will provide a suitable profile of existing relationships among the groups involved, and will also generate information on training and operational capabilities upon which to build the overall effort. It is important to recognize that deliberate interviews of this type should be conducted, even though current information appears to be already in hand. It takes only a short while to conduct the interviews, and when properly done they can reveal a wealth of information on how things are perceived by the workers themselves. Recent attention to the idea of Action Teams is quite extensive throughout the shipyard community. This approach will therefore find familiarity in most locations.

Step 4: Establish Baseline Productivity Indicators

Even though this step fell short of the mark during Phase I of this project, the need to carry it out was not diminished. Several indicators should be selected and measured to provide the starting points for later assessments of white-collar productivity. Once established, these baselines should not be changed as developments occur, but rather should remain as stable reference points against which to assess progress.

Step 5: Select the Functional Area(s) to be Treated

In most cases, this determination will be straightforward. The smaller the area, the better the chances of success (at least initially). In a large shipyard, the area to be treated may be limited by the sheer numbers of workers involved (both white-collar and blue-collar). The composition of the Action Team should include enough workers to permit reasonable discussion of the problem area, while staying at about 12 to 15 total people. If the area selected for treatment turns out to be too large to handle, the scope of the function should be reduced until a reasonable accommodation is reached. In the smaller shipyard, treating a full function should not be a problem.

Step 6: Create the Action Team(s)

The members of each Action Team should be selected carefully. Individuals who have a good grasp on their own activities, and show evidence of ability to influence others, will be good choices. The total team membership should encompass nearly all aspects of the functional area to be treated. Prospective members should not be rejected because they are too busy, or too noisy, or too difficult to control. Selection criteria should include the capability to communicate, the ability to recognize that changes are both needed and are usually difficult to achieve, and the probability that the candidate will ultimately make a meaningful contribution to the team. Selections should not be announced until senior management has been made aware of them, and the supervisors affected have voiced their agreement.

Step 7: Implement the Action Team(s)

Limit the Action Team meeting duration to one hour per week, preferably at the same convenient location so that the members will become familiar with the surroundings. The use of a facilitator is recommended, someone who has no particular vested interest in specific topics, but rather someone who will keep conversations alive and member interest up. Do not try to hurry the process along, at least initially. Time is a tool to be applied carefully in first developing a viable communications network among the participants, and then in creating a strong working relationship that will withstand the unrelenting and always urgent demands of the workplace. Once these two attributes are firmly established, perhaps three to four months downstream, the time element will become less sensitive, and more latitude will be available for adjusting Action Team meeting dates and durations. Early agenda items should be designed for team building rather than for treating specific subjects. After a few meetings, the team should select a Chairperson and Recorder from within their ranks, so that eventually the role of the facilitator can be reduced or eliminated. These duties can be rotated on a reasonable basis (several months) if desired. Each meeting should have a printed agenda, and meeting minutes should be kept and published to the members.

Step 8: Assess the Value of the Action Team(s)

After an Action Team has been in operation for several months, a deliberate assessment should be made to help in deciding whether or not the Action Team should stay in operation, and whether any membership adjustments should be made. If advantages are accruing based on the perspective of the Action Team members or on management assessments, and there are a reasonable number of concrete results in evidence, then continuation is indicated. Otherwise, it may be better to abandon the team, recognizing that it will suffer some startup problems if it is reinstated later on. Changing one or two of the team members may strengthen the overall effort, and invigorate the remaining team members to new heights of achievement.

The effectiveness of this step will be improved if management focus is maintained on the TEAM rather than on the projects being treated by the team. There is, of course, a continuing need for feedback to management on team activities, and there may be an occasional need for management follow-up on a specific item. Generally, however, the team will continue to function effectively once the members can see their own successes, and realize that they have been empowered to make the necessary changes by themselves. The management role becomes one of supporting the TEAM, and allowing it to operate as a cooperative entity. This is also a good time to evaluate whether additional teams in other functional areas might be helpful, recognizing that the startup times for the new teams must be accommodated.

OVERALL ASSESSMENT OF RESULTS

Performance of this project produced results that were better than anticipated. The Action Teams that were established, one electrical and one structural, both functioned extremely well. The Action Teams demonstrated that favorable worker attitudes and working relationships can be strengthened through employee involvement techniques. Several instances of white-collar improvements were seen, with more developing almost daily. Three segments of the white-collar community at PBI - as it applies to these two specific functions - were treated: material support, planning, and engineering. All three segments were responsive, and show promise of continuing improvements.

After Phase I, the attitude among the senior shipyard managers was to continue the two Action Teams beyond the end of the project, and also to promote the idea of establishing more Action Teams in other functional areas of the shipyard. Such intentions clearly endorse the advantages gained from this approach.

Other shipyards should consider the establishment of Action Teams, following the guidelines above. An additional inducement to try this approach will be found in the success achieved at General Dynamics Corporation/Electric Boat Division through the use of Union Driven Safety Action Teams (1). The composition of the Action Teams at GD/EB was similar, although the focus was on safety rather than on white-collar productivity. Nevertheless, the Action Team approach can be a versatile tool in the shipyard improvement arsenal.

WHAT HAPPENS NEXT?

During this project little, if any, regular and deliberate inter-functional communications were apparent. This symptom is common to many shipyards, where cross-functional communications are usually weak at best, and may be missing entirely until forced by inopportune production interferences and sequencing problems that occur downstream. Improvements in this area are needed to create new opportunities for the white-collar product to better match the needs of the overall production effort, while avoiding costly impacts during the construction period.

Phase II of this project has been addressing this problem area for several months, investigating and developing innovations for cross-functional communications as a logical extension of the first project. It has expanded upon the Action Team approach proven successful during Phase I, with a focus on the shipyard engineering group where cross-functional improvements probably should originate. A multi-functional Action Team has been organized and allowed to operate for several months. It is composed of white-collar and blue-collar representatives from the three main functional areas: electrical; structural; and piping. This team has been addressing ways to establish and develop inter-functional improvements at the operational level before inter-trade problems arise. Although the results of this effort were not available in time to be printed here, they will be discussed informally during the presentation of this paper at the Symposium in September 1992.

EPILOGUE

The concepts of team building and employee empowerment were not entirely unknown in October 1989 when this project was conceived, but first-hand experience with these ideas, and the associated reference material available at that time, were both minimal. This project therefore proceeded on the basis of good judgment, coupled with the rather basic belief that both white-collar people and blue-collar people are capable, that they understand their own areas better than anyone else, and that they will contribute beyond expectations if only they are made aware of what is needed. They form the very core of our shipyard community, and nearly EVERY ONE of them truly wants to help the others improve. During the past three years these ideas have been developed and strengthened throughout the industry. The experience gained through this project, coupled with the growing availability of excellent references on this subject, should inspire more attempts at narrowing the communications gap.

At the 1991 Ship Production Symposium, a superb paper was offered by James Rogness (2). It challenges the shipyard community to consider a revolutionary approach toward breaking the chains of tradition and fantasy which constrain attempts at improving productivity. His paper presents a strong case for unlocking the capabilities of workers at virtually every level in the shipyard. Although the attempt at improving white-collar productivity presented here has not broken those chains decisively, perhaps it has created an interdendritic separation in the base metal that will propagate with usage and create a weakening of those bonds sufficient to qualify these ideas as a herald for future achievements.

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Human Factors: An Initiative in the United States Coast Guard

No. 5A-2

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ABSTRACT

Although the concept of human factors is not new, it is new within the marine system. Ship design and operations are just a part of the marine system. The marine system is everything and anything associated with the marine community, environment, industry, etc.; whether it is public or private. Human factors is a means to improve and maintain a better quality of life in both the workplace and the home. Human factors is compatible and complimentary with good managerial practices, and is back by sound engineering. The aim of this paper is to expose the reader to human factors.

INTRODUCTION

Ships' machines can do a lot of the work required of humans. There are unmanned engine rooms, there can be bridge consoles that need only a single operator, and there can be damage control systems that provide decision support. Such systems, if designed and operated properly, can reduce the likelihood of mishaps. The engineering called for to build these systems is not complex by today's standards. The challenge is moving the marine industry to this technology. This requires a systems approach.

The current marine system is missing data. This is why there is a knowledge gap. From marine statistics kept by the Coast Guard, nearly 80% of commercial maritime casualties and nearly 80% of Coast Guard vessel mishaps have human related causes. However, these marine statistics do not capture the underlying causes of human error. Some examples are: improper training, under the influence of alcohol or drugs, fatigue, workload too high on the bridge, or the ship's design. The Coast Guard's taxonomy of human related causes of casualties has been changed, as much human factors' data can be entered into a Coast Guard database by investigating officers. This new taxonomy will enable the Coast Guard to analyze human error and eventually, focus near-term human factors efforts on the areas to be identified. For example, if the findings are that many casualties happen when the mariner is over-worked, then there is a need to examine the factors contributing to mental overload and physiological tasking, and perhaps consider changes to the appropriate regulations.

The need for marine specific human factors research was one of the main recommendations by the National Academy Sciences, Marine Board in a report entitled Crew Size and Maritime Safety. The Marine Board points out that human factor applications are not being addressed in the issue of minimum manning. The recommendations are to undertake: a reduced manning study, and more development and application be conducted on a variety of human factors issues, such as; an analytical tool that guides ship staffing decisions that accounts for human factors.

Global competition is the major hurdle for the marine industry. Keeping labor costs down would help make the United States Merchant Marine more competitive. The manning requirements may be constraining. However, there are no manning alternatives that advocate a safe reduction in crew size. The Coast Guard is drafting its first Human Factors Plan. The plan is intended for the Office of Marine Safety, Security and Environmental Protection and has virtually tapped all aspects of the marine system. The Human Factors Plan contains a specific task of conceptualizing a manning model. In late 1992, the plan will be introduced. Although global competition is not part of the Coast Guard's mission, it is a recognized reality.

AN EXECUTIVE SUMMARY OF HUMAN FACTORS

Human factors and ergonomics are synonyms. A working definition for Human Factors is making machines such as computers, products. and places (e.g., ships, building, etc.) fit the user. Humans are part of the system. The system is the environment in which human behavior influences specific outcomes. Therefore, Human Factors Engineering (HFE) is a multi-disciplinary technology.

An objective of HFE is to enhance working conditions in a way that encourages productivity in the workplace. This can be accomplished by improvement of equipment design that will make it compatible with human use. Improvements in health, safety, satisfaction, and quality in the work places will be windfalls from a system designed with HFE. Other benefits will be accident reduction, increased productivity and extended equipment life. There are abundant benefits in using human factors.

Human .Factors can be simplified to four basic factors: perception, judgment, motor ability and internal stress.

Perception **is** the ability to be aware of objects, movements or changes of energy occurring outside the human body. One must be aware that an action is called for. This is done yia any of the natural senses. The perception ability involves consciousness. Perceptions are arbitrarily classified as high; medium and low, and based on the sense affect. The senses are not in direct contact with the events being sensed. However, they are a convincing basis to interpret the reality. The importance appears in failures versus successes attributed to difficulties using the correct control or understanding the correct signal. The designer's goal for the perceptual factor is to generate displays to ensure the most reliable interpretation of signals. Interpretation calls for vigilance, and humans are not ideal sensors. Machines can monitor, sense and control better than humans. However, humans have several advantages. Humans can adapt easily and are very efficient in detecting signals in the presence of high levels of noise. Lastly, training has an important role in enhancing the perceptual factors in humans. If an outcome requires a perception then training is required.

The second factor considered is judgment. After a human has perceived that an action is required, he or she must then decide what action is required. In essence, judgment is a cognitive voluntary activity. Humans learn from both created and prevailing data, commonly referred to as training and experience, to respond successfully to situations. Usually, the decision making process is based on choosing the best option, and often, choosing one option prevents choosing all others. The concept is based on the 'value of anticipated outcomes' multiplied by 'important weights.' This results in a numerical value for each choice. Obviously, the desired choice has the highest value. Outcomes do not necessarily result directly from the human decision. Several factors, usually not under human control, contribute to human decision making. Decisions count on memory ability. Many decision-making problems are memory related. A complete database required to make the right choice usually exceeds an individual's memory. Again, training will enhance the decision-making process in humans, but the training must be routine, frequent and thought provoking.

Motor Ability is the capacity to make the muscular contractions required to perform a task. Motor ability is included in areas of study in anthropometry and biomechanics. Many aspects of the human body are unmeasured, unclassified and unaccounted in human factors. Humans are limited by speed, force, displacement and accuracy. Human duty cycles are limited and life support in a hazardous environment is costly. The best advantage is the human ability to adapt to new situations. Instead of standards and guidelines, humans are required to adapt. The challenge is to provide guidelines regarding the best distribution of functions between operator and machine.

Internal Stress is internal conflict resulting from certain qualities of the task. Any of the other factors affecting human performance is considered a stress agent. The internal stress effects can be catastrophic, in the right place at the right moment. There are two arbitrary stresses, based on the source: psychological and physiological. The social environment at work and leisure are typical sources of psychological stress. The task itself has mental-loading and pacing. The organization has supervisor style, boredom, and motivation. The individual has personal attributes and preferences. The other source of stress is physiological. Age and lack of sleep are examples. Changes such as day-night, natural cycle, and physical fatigue are antecedents to physiological stress. Temperature, noise or illumination will effect performing a task. The task itself forces demand. There are myriads of sources. Prevention is difficult but management is attainable; such as physical exercise. Some level of physical activities will improve both, psychological and physiological stress. Stress levels are related to one's health, and can be related to the health or well-being of others.

One common mistake in the implementation of human factors is the methodology. Most people think one does not have to be a human factors specialist to implement this concept. Scientific methods must be used to validate human factors' data. The data is obtained under controlled conditions. Independent and dependent variables must be taken into account. Biomechanics and anthropometry are available for most applications. However, methods are needed to account for stress, judgment and perceptual factors in any part of the marine system, e.g., ship's operation, fleet operation, maintenance, standards, etc. The method must deal with vagueness in quantitative and qualitative ways.

HFE plays an important role in prevention and response. Human factors contribute to accidents and are the means of avoiding accidents. It is possible to quantify the combination of factors and sequence leading to an accident. It is more challenging to forecast the factors and events that would prevent the accident. Human factors are based on events, and prevailing or created data, including those using simulators. Poor design of equipment, fatigue, over-load, too much information required for a decision, vigilance and environment may be all in the critical path leading to an event. These factors can be foreseen. Checklists are used to ensure the correct action is taken. However, the improper use of checklists will increase the risk of failure. So, the ideas in this summary are an over simplification of a complex matter. To show the complexity a checklist of twelve domains follows. Linkage among the domains is not included and will be the topic of another paper.

A HUMAN FACTORS CHECKLIST

In 1991, a checklist was considered by members of the Coast Guard's Human Factors Coordination Committee (HFCC). The checklist was not all inclusive in nature, nor is the expanded version presented below. To develop a checklist for a specific situation, a discreet analysis of the related variables must be performed. Since the HFCC had a time constraint and variables were questioned, the HFCC checklist is not available. The checklist presented is the author's attempt to foster human factors in the marine system. Several more questions from "The Biology of Work" (1) were added and several words and sentences constructions were changed as well. This is presented for the reader's consideration.

1. Physlcal capabilitles required for effective human performance

a. Are there any physical conditions that will disqualify the individual?
b. Are there any useful characteristics (e.g., strength or endurance) required to accomplish the task?
c. Are any of the five senses a critical ability(ies)?
d. Is the work space adequate?
e Are the characteristics of the hand controls compatible with the forces required to operate them (e.g., shape, size, surface) and are the forces acceptable?
f. Can the subject be seated for all or part of the time and complete the task?
g. Are there provisions for the subject to sit, and is the available chair satisfactory in its design?
h. Are hand tools used or required?
i. Can the speed of the machine equipment or device be adjusted according to the skill of the operator dedicated to the task?
j. Are personal protection devices required?
k. Does the task impose excessive visual demands on the individual?
l. Is high illumination required or local artificial light needed?
m. Are there visual signals, and are they placed in a central area?
n. Is color discrimination required?
o. Does the task require tactile discrimination?
p. Does the task require a good sense of balance?
q. Does the task require a good sense of smell or taste?
r. Does the task require high accuracy of movement?
s. Is the muscular load dynamic or static?

2. Mental capabllitles requlred for effective human performance

a. To what extent is alertness considered critical?
b. To what extent is reaction time considered critical?
c. To what extent is concentration considered critical?
d. To what extent is ability to think under stress considered critical?
e. How complex are the decision-making requirements (i.e., do the decisions require consideration of many variables to determine the most effective alternative)?
f. What mental conditions should be considered disqualifying?
g. Are high levels of motivations, alertness and power of concentration required?
h. Is there any data to be processed before the required action can be taken?
i. Are there different sets of data to be compared before action can be taken?
j. Are standards of comparison available and used?
k. Can signals be confounded?
l. Are there any rest pauses during monitoring work?
m. Are fear or repulsion evident?

3. Minimum required training or experience

a. Is perception required?
b. Are there any special training requirements related to the specific task?
c. is on-the job experience required before an effective performance can be expected?
d. Is supervision required during performance?
e. What is the training period, e.g., one week, month, etc.?

4. **Critical informatlon requlred for effective human performance**

a. Is essential data readily available when **needed?**

b. Must any data be located before proceeding with the task? Must data be assessed before used?

c Is the rate of data likely to exceed the mental capacity of the operator and to overload the user?

e. Do identical or similar signals occur for a long time and are they frequently repeated?

f. Are all the factors applicable to a decision presented at the right time and sequence?

5. **Associated events related to workload**

a. Are several related events that require attention by the same individual taking place simultaneously?

b. Will other events continue to develop unattended?

c. Can a critical point develop if other events are permitted to proceed unattended? **d** Must other important tasks be postponed while attention is devoted to a task that the individual has determined is more important?

e. Do surrounding events distract the individual who must focus attention on a single task?

f. If any of the sensory channels is likely to be overloaded, can the load be more evenly spread?

g. Does the subject have to make a choice in response to a signal, and does he know immediately if the choice is wrong?

h. Can feed-back be given of the effects of adjustment to a system?

6. **Degree of precision required for effective human performance**

a. Do conditions normally allow for a wide margin or error?

b. Are some errors in the situation under study likely to undermine accuracy, reliability, validity of later events?

c. Does the task demand very fine visual judgment?

d. Can auditory signals be easily detected and distinguished from each other?

e. Is the accuracy of the instrument compatible with the required reading accuracy inherent on the task?

f. Are reading errors minimized by the design of the instrument?

g. Can signals from different sources occur simultaneously?

h. Can preferred signals be distinguished easily?

7. Communication skills

a. Does performance require an ability to read?

b. Does performance require an ability to communicate orally in a particular language?

c. Does performance require an ability to communicate by non-verbal means?

d. Does performance require an ability to use technical vocabulary or technical formulation?

e. Can lack of opportunities of communication with other individuals affect performance?

f. Is verbal communication needed in the task, and does noise level permit it?

8. Time-critical factors

a. Must judgment be exercised within specific time limits?

b. Must a series of interdependent steps or instructions be performed rapidly?

c. Does the event recur periodically?

d. Can the performance become so routine that the individual's level of concentrations begins to drop?

e. Can performance involve a response to emergency conditions (i.e.. is the individual likely to be confronted with unexpected situations requiring immediate attention to avoid major adverse consequences)?

f. Does performance significantly influence other events?

9. Is the time lag between changes in the system and indication of it in the dials optimized?

9. Procedural considerations

a. Can the entire process or sequence of events be accomplished by one person or machine?

b. Can it be commenced by one person and completed by others?

c. Does effective performance require more than one person to work together?

d. Must the process or sequence of events be completed in a specific series of steps?

e. Does performance depend on reliable performance of automated equipment?

f. Does the process include warning or imminent failure that requires immediate attention?

g. Does the process depend on accurate record-keeping?

h. Can the process be standardized?

i. Does the process include safeguards such as redundancy, review, observation or inspection by others?

j Are there any circumstances under which advancement to the net state of the process will be turned back if permission to continue is not granted by someone not involved directly with the task?

k. Does the process require a positive confirmation to be given to others and an affirmative acknowledgement that the performance has been effectively completed?

l. To what extent must individuals responsible for one part of the process be familiar with other parts of the process?

m. Are there any procedures so complex that they require frequent consultation with written instructions?

n. Are those instructions provided in a form that is adequately clear for those who are likely to consult them?

o. Is the task rigidly paced? (What are the pacing systems?)

10. Design Considerations

a. To what range is the distribution if instruments, equipment, machinery inflexible?

b. To what extent is physical access to equipment, controls, spaces, work station, etc., required?

c. Does effective performance require rapid or emergency access? d Does effective performance require random access?

e. Does effective performance require concurrent access to more than one location?

f. Does effective performance require concurrent access to more than one person?

g. Is there a wide variation in the available designs for performance capabilities?

h. Does the design arrangement allow for adjustment to accommodate individual preferences, abilities and physical characteristics?

i. Are instruments, equipment, machinery often installed as a modification to an existing arrangement?

j. Are security features or safeguards needed to discourage improper or unauthorized use?

11. Other relevant factors

a. What position does the practice or procedure under examination occupy as a component within a larger, more comprehensive system?

b. Are there any conventional standards in the maritime or other transportation industry that might apply to the practice or procedure?

c. Is any written guidance available on the above matters to assist decision makers who are responsible for implementing the particular practice or procedure most effectively and practical?

d. Is additional information needed to allow an assessment of the extent to which human ability or behavior may be involved in the practice or procedure?

e. How can reliable current information be collected most expeditiously?

12. Environment

a. Are conditions within the comfort zone?
b. Is the individual exposed to rapid environmental changes?
c. What is the noise level; does it interfere with performance; is there any risk of hearing loss?
d. Are personal protective devices needed?

This checklist is for insight and by no means totally inclusive. Furthermore, this checklist does not provide the linkage for the entire system/solution. A system's analysis is required that must include task and network analysis. The next step is to determine where in the design, maintenance or operation process the domains need to be considered.

SUMMARY

Though humans will make mistakes, there is a lot that can be done to minimize their short comings. Humans play an active role in the marine system and the maritime community needs to integrate human factors into the design, maintenance and operation of the marine system. Many came to realize there are methods and techniques that can be applied to the marine system that will improve human performance and reduce casualties and errors.

To ensure human factors principles are applied as widely as possible the United States Coast Guard is incorporating human factors considerations in its research and development, design, and operational efforts. The integration of human factors into these efforts will be a major undertaking for the maritime community. By understanding why humans err and understanding how to design systems to minimize human error the maritime community will have a safer marine system.

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Note: The opinion(s) expressed here are that of the author and not necessarily that of the United States Coast Guard.

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NIDDESC-Enabling Product Data Exchange for Marine Industry

No. 5B-1

James Murphy, Visitor, Naval Sea Systems Command

The opinions expressed herein are those of the author and not necessarily those of the Department of Defense, the Department of the Navy, the National Ship building Research Program or NIDDESC member organizations.1

ABSTRACT

The use of Computer Aided Design (CAD) technology in the U.S. Navy and Marine industry has evolved from a drafting based design tool to a 3-Dimensional(3D) product oriented information base, used for design, production and service lift support. One of the most significant enhancements to current CAD technology has been the incorporation or integration of non-graphic attribute information with traditional graphics data. This expanded information base or product model has enabled the marine industry to expand CAD use to include such activities as engineering analysis, production control, and logistics support. While significant savings can be achieved through the exchange of digital product model data betwccn diffcrent agents. current graphics based CAD data exchange standards do not support this expandcd information content.

The Navy/Industry Digital Data Exchange Standards Committee(NIDDESC)wasformcdasacooperative effort of the Naval Sea Systems Command (NAVSEA) and thcNationalShipbuilding Research Program to develop an industry consensus on product data and to ensure these industry requirements arc incorporated into national and international data exchange standards. The NIDDESC effort has rcsuitcd in the development of a suite ofproduct model specifications or Application Protocols (AP's) defining marine industry product model data. These AP's have been submitted for inclusion into the next generation of data exchange standards.

NOMENCLATURE

ANSI	American National Standards Institute
AP	Application Protocol
CAD	Computer Aided Design
CALS	Computer aided Acquisition and Logisitics Support
HVAC	Heating. Ventilation. & Air Conditioning
IGES	InitiaI Graphics Exchange-Specification.
PO	IGESlPDES Organization
IS0	International Standards Organization
IWSDB	Integrated Weapon Systems Database
MIL-D-28000	DOD Specification for Digital Data Exchange.
NIAM	Nijssen's Information Analysis Method.
NIST	National Institutes of Science and Technology
PC	Personal Computer
PDES	Product Data Exchange using STEP.
STEP	STandard for the Exchange of Product data.

INTRODUCTION

The U.S. marine industry has been progressively expanding the use of Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) technology for both Naval and commercial ship design and construction. More recently, these 3D CAD/AM implementations have expanded the traditional graphics oriented applications to include associated non-graphic attribute information such as weight, material, and production control information (1).

This combination of graphic and non-graphic information known as product or product model data has become the basis of current CAD/CAM use by many in the U.S. Navy and marine industry. Several shipyards have developed design and production systems on the integration of traditional CAD/CAM systems with other informational databases. The recent NAVSEA CAD 2 system acquisition has enabled the Navy to pursue the implcmcntation ofa product model architecture for design, construction, maintenance. and modcmizuion of naval ships.

The trend toward the integration of previously separated at a base systems for design, material, fabrication, etc., has resulted in a need for better and more complex data exchange mechanisms capable of handling this expanded information base. This need is being met by the efforts of thcNavy/lndustry Digital Data Exchange Standards Committee (NIDDESC).

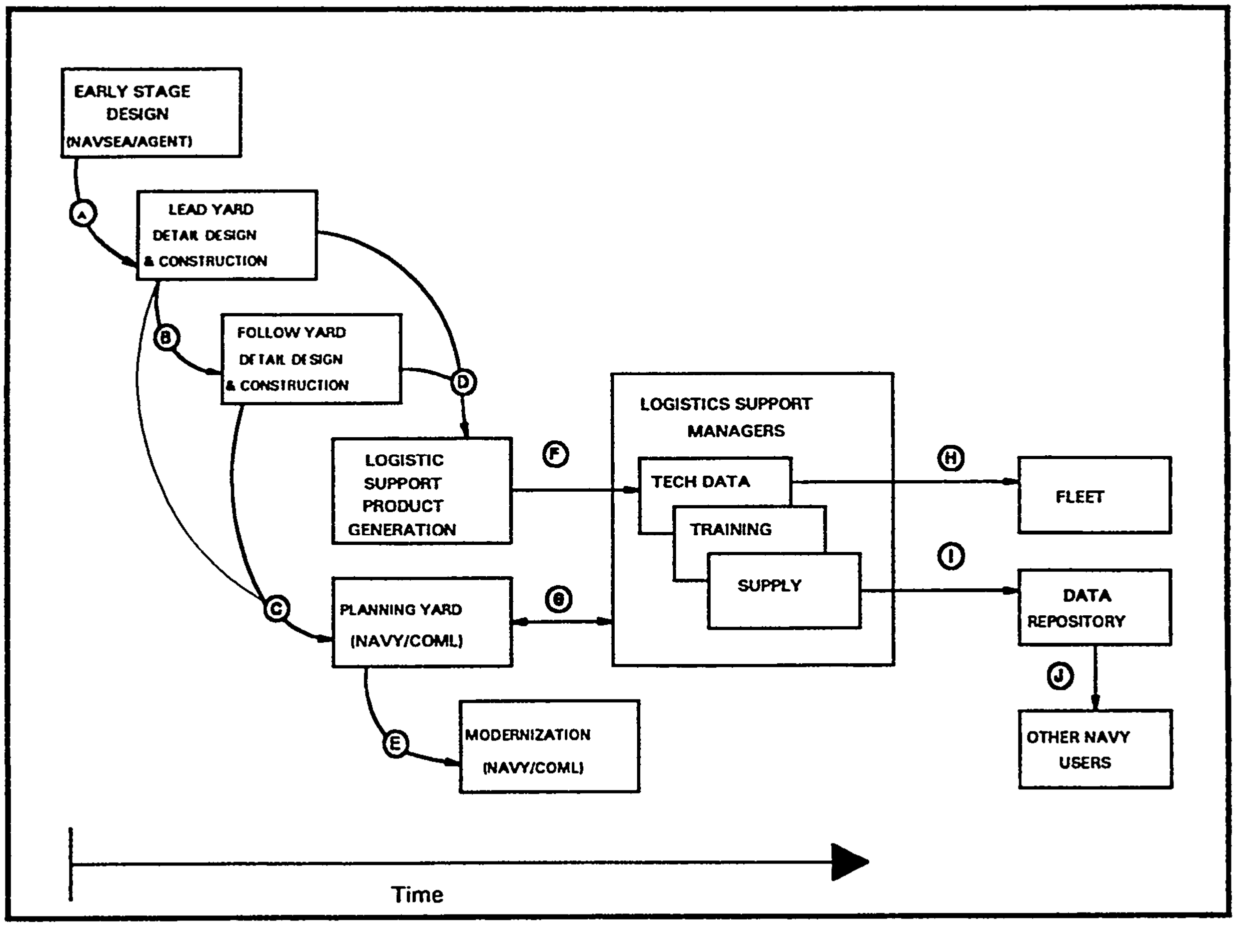

Fig. 1 Principle Data Transfer Interfaces During a Ship's Life Cycle

BACKGROUND

One of the most significant benefits associated with CAD/CAM use, is that once captured, data canbere-used at significant savings. Savings can bc accrued through the rc- use of data for design developments as well as in transferring existing data from one activity to an-other. In addition to savings accrued through there-use of digital data, further bcncfits can be achieved through the reduction of errors associated with regeneration of data and reduced time required to enter data. As most marine industry organizations have made significant investments in information technologies, the focus has begun to shift from whcthcr todevelop products in digital form to how to accomplish this goal in the most effective manner. This paper will focus on the exchangc of digital data betwccn diffrerent organizations and different computer systems.

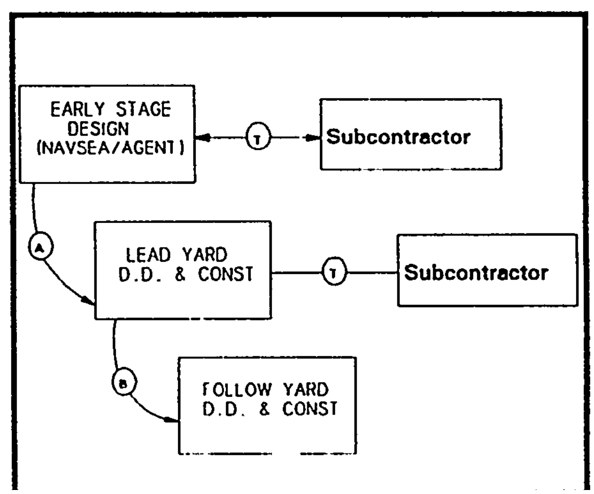

Fig. 2 Subcontractor Transfer Interface

There are in general two different digital data transfer interface types within the marine industry. The first type is between successive organizations responsible for different aspects of a ship's life cycle such as design, fabrication or service lift support Figure 1 depicts these principle cxchange interfaces for the life cycle of U.S .Navy ships. This depiction of transfer interfaces has been used extensively by NAVSEA and others in determining requiremcnts and priorities for data exchange.

The second type of digital exchange occurs between an organization and its subcontractors for such purposes as design support or fabrication. This interchange enables an organization to send and/or receive digital data from supporting design contractors or to exchange digital fabrication instructions for use in Numerical Control (NC) machining. Figure 2 expands the previous figure to include this second exchange interface.

DATA EXCHANGE MECHANISMS

Several CAD Data exchange standard have been in use in the marine industry for the last a number ofyears. These standards arc based on the exchange of neutral file descriptions and have met with varying success. As with most CAD system databases, these exchange standards are primarily graphics oriented, concentrating on the transfer oflines, arcs,splines, text,etc.. There remain some options to enhance existing standards to incorporate additional attribute information thus enabling more of a product data transfer, but in general full product model transfer will require a next generation standard designed to handle graphic and non-graphic attribute data. A summary of existing and developing standards for digital data exchange is provided below:

IGES

Most current CAD data exchange is via the Initial Graphics Exchange Specification (IGES). IGES is the approved ANSI standard for neutral tile transfer of CAD' graphic data and is used through out the industry. Initially developed for graphics, IGES has been enhanced or expandcd to include some limited attribute information. IGES tmnsfers however, have not been without

DXF

DXF is a proprietary cxchangc format developcd and maintained by Autodesk, Inc. Primarily used in the exchange of personal Computcrbascd CADsystcmsgraphits data. It has been used successfully for the exchange of wireframe geometry. but is not suitable for complex 3D surface and solid model cxchangcs. There is no formal revision process associated with updating or enhancing DXF as an exchange mechanism.

MIL-D-28000

MIL-D-28000 is the Computer aided Acquisition and Logistics Support (CALS) standard for the acquisition of technical data in CAD processable vector format. This military standard defines the use of IGES for Department of Defense (DOD) data acquisitions.

STEP (STANDARD FOR THE EXCHANGE OF PRODUCT DATA)

STEP is the international Standards Organization (ISO) standard for product data exchange currentIy under development. This next generation standard is targeted to replace IGES providing for a more robust exchange of product information.

PRODUCT MODEL ACTIVITY IN THE MARINE INDUSTRY

Several U.S. Navy ship acquisition programs have developed 3D product model databases to support the detail design, fabrication, and assembly functions. The SEAWOLF submarine and the DDG 51 class destroyer programs have made significant use of the product model approach and have exchanged this data between lead and follow shipyards. The SA'AR 5 design, developed by Ingalls shipbuilding utilizes a combination of 3D CAD and relational database technology in developing product model data.

The SEAWOLF data exchange between Newport News Shipbuilding and General Dynamics Electric Boat Division is based on the Initial Graphics Exchange Specification (IGES). The SEAWOLF program enabled the exchange of significant product data through the use of IGES for graphics and project specific translation of non-graphic attribute or list type data. Limitations of the IGES specification required that both Newport News and Electric Boat establish CAD modeling and data exchange procedures to ensure successful data exchange. Production transfers of piping, heating ventilation and air conditioning (HVAC) and drawing data have been achieved on this program.

TheDDG 51 class destroyer acquisition program has made extensive use of 3Dproduct model data for detail design and fabrication purposes and planning has begun for the use of this product data for service life support. As with the SEAWOLF program, the DDG 51 exchanges product data between lead and follow builders, Bath Iron Worksand Ingalls Shipbuilding. The exchange is accomplishcd through the transfer of a neutral tile description developed specifically for the DDG 51 program. This project specific transfer mechanism enables the transfer of additional attribute information and was developed because of the inability of current exchange standards to handle the range of product data necessary fo r the DDGS1 program.

The SA'AR 5 design, developed recently by Ingalls shipbuilding was accomplished using 3D CAD models Iinkcd to other databases containing non-graphic attribute data. This product model data has been used for interference detection. weight calculation and material take-off. (1)

With the award of the CAD 2 contract to Intergraph, NAVSEA has expanded its development and implementation of CAD systems, based on a product model architecture (3). This product model architecture will provide the foundation for the implementation of phase 3 ofthe DOD CALS program. Phase 3 CALS, orthe implementation of Integrated Weapon Systems Data Base (IWSDB). describes a 3D product model information enviromnent containing information for design, construction, maintenance, and modernization of Naval ships.

There is an increased emphasis on the ability to exchange digital information, as NAVSEA and the U.S. Marine Industry continue to develop and utilize 3D product model data. While savings associated with the exchange of data has justified the development of project specific translation capabilities, the need for a single definition of product data and improved transfer mechanisms has been recognized. This need led to the formation of NlDDESC.

HISTORY OF THE PROGRAM

NIDDESC was formed in 1986as ajoint effort of the U.S. Navy and the National Shipbuilding Research Program (NSRP). Work activities, approved by the NIDDESC Steering committee are performed by a working group consisting of industry technical experts.

NAVY	INDUSTRY
NAVSEA 04	Bath Iron Works
NAVSEA 05	General Dynamics, E.B. Division
NAVSEA 06	Ingalls Shipbuilding
David Taylor Research Center	NASSCO
SEACOSD	Newport News Shipbuilding
Puget Sound Naval Shipyard	Angle, Inc. ’
PMS 400	Gibbs & Cox
PMS 350	The Jonathan Corporation
NAVSEA 9 1	JJH, Inc.
	Lovdahl & Assoc.
	NIST

Table I NIDDESC Member Organizations

NIDDESC member organizations participate on a cost Sharing basis with funding provided by the Navy NIDDESC member organizations include five major shipyards, several design agents, and NAVSEA representatives from different activities. The current NIDDESC member organizations are shown in Table I.

Most if not all of the member organizations have been with the program since its inception. In a cost sharing environment, this represents a significant commitment by the industry to the development of improved standards. Additional significant support and technical guidance has been provided by the Center for Building TechnoIogy at the National Institute for Standards & Technology (NISI).

CURRENT PROGRAM PLAN

The technical working group is currently completing work on the third NIDDESC program plan. This effort will result in the identification of marine industry product model content and the development of specific neutral tile format documents for incorporation into the current IGES specification and the emerging STEP standard. These documents known as application protocols AP’s) define requirements, content, and format of marine industry product data and arc required for incorporation in data exchange standards. In addition to product model information,NIDDESC has developed an AP for enhancement to the current IGES specification for the transfer of CAD drawings. Drawings remain a key document and the current IGES standard must bc further defined to ensure unambiguous transfer of this type of information.

PROGRAM PLAN # 3

The bulk of the effort of program plan#3 has been in the development and testing of STEP Application protocols. Six application protocols defining shipsproduct model data submitted for inclusion into STEP have been developed by NIDDESC. The Ship’s AP’s are for:

1. Piping,
2. Heating, Ventilation, and Air Conditioning (HVAC),
3. Electrical Distribution and Wireways.
4. structural Systems,
5. Outfit and Furnishings, and
6. Standard Parts.

In addition to STEP AP development, two additional application protocols have been defincd for the enhancement of the IGES specification. The IGES AP’s arc for:

I. Drawings, and
2. 3D Piping (submitted and approved).

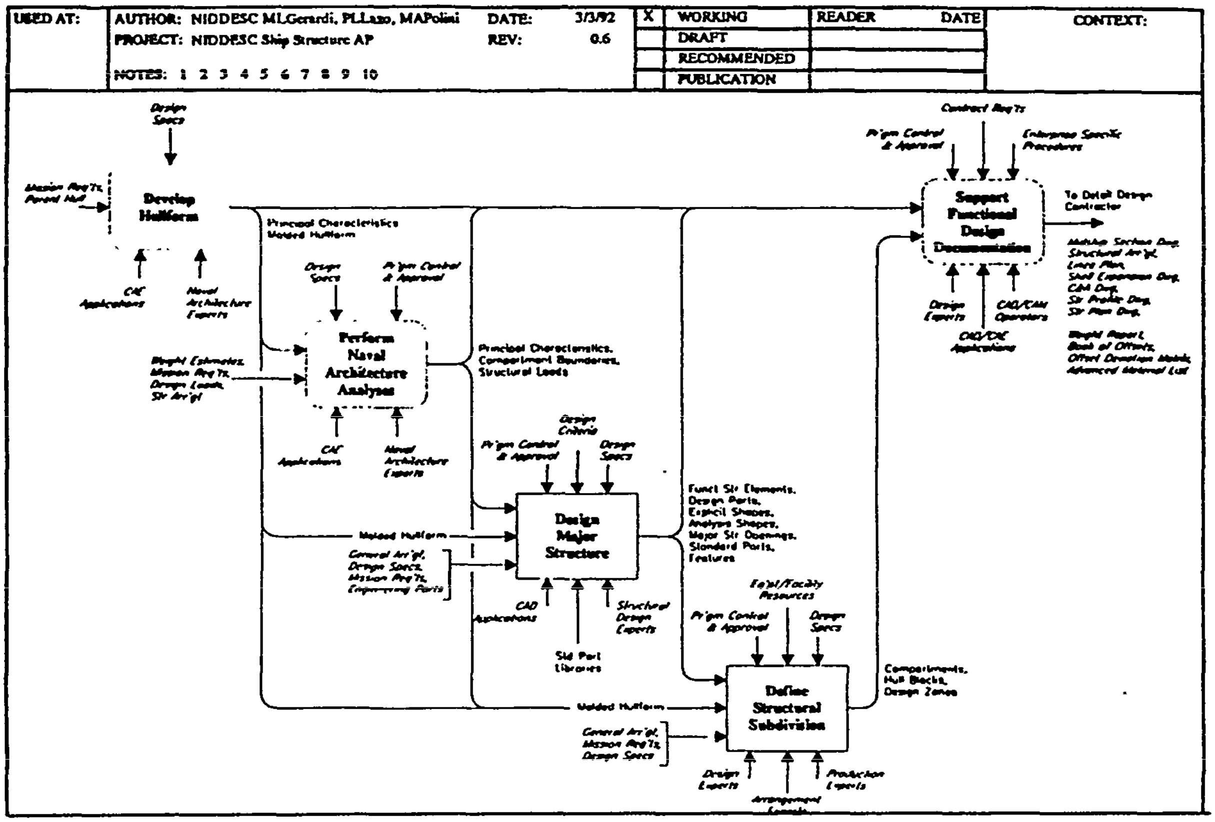

Fig. 3 Structural Functional Design Activity

IGES continues to be the primary exchange mechanism in the marine industry and it is expected be in use over the next 5 to 10 years. It is doubtful that acquisition programs initiated within the next 5 years will have any other choice but IGES, to acquire data. It may also besome time before the availability and acceptance of product data replaces the drawing as the deliverable. This expected need to exchange drawings via IGES prompted the steering committee to approve the development of an IGES drawing AP. Such an effort was required to ensure the near term exchange of drawings using IGES.

The IGES 3D piping AP was previously developed under program plan # 2. but has required extensive effort to push it through the standards process. This effort has now been included in current revision of MIL-D-28000A. While NIDDESC still pursues the development of a piping exchange within STEP, the IGES piping AP development and approval process has provided significant benefit to both NIDDESC and the IGES/PDES Organization (IPG). This document remains the only approved application protocol developcd for IGES or STEP, and currently, the only mechanism to exchange piping product model data conforming to national standards.

NlDDESC DEVELOPMENT PROCESS

The first and perhaps the most important step in the AP development process is the determination of the requirements for ship's product model data. This has been accomplished through the evaluation of the needs of the various participating organizations and on the extensive review of existing data exchange programs such as SEAWOLF and DDG 5 1.

From the assessment of industry requirements, NIDDESC determined the specific processes involved in the design, construction and life cycle support of ships. From this process evaluation, the scope and requirements for each application area is agreed upon. The IDEFO methodology is used to evaluate and define the various processes involved in a particular application area. Figure 3 provides an example of the process evaluation process using IDEFO.

This evaluation results in a defined set of functions and the products developed. For example, for the

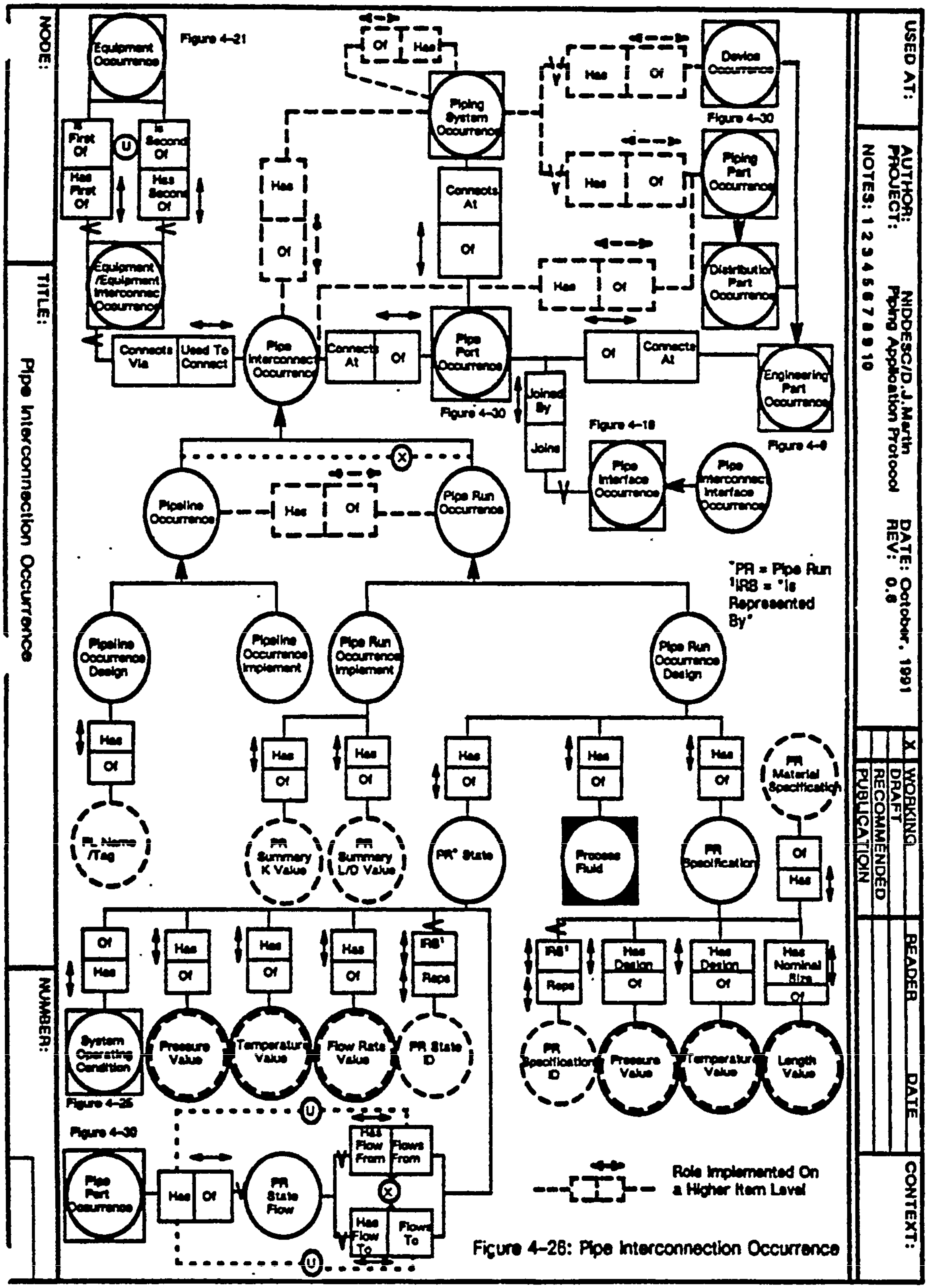

Fig 4. NIDDESC Piping Application Protocol

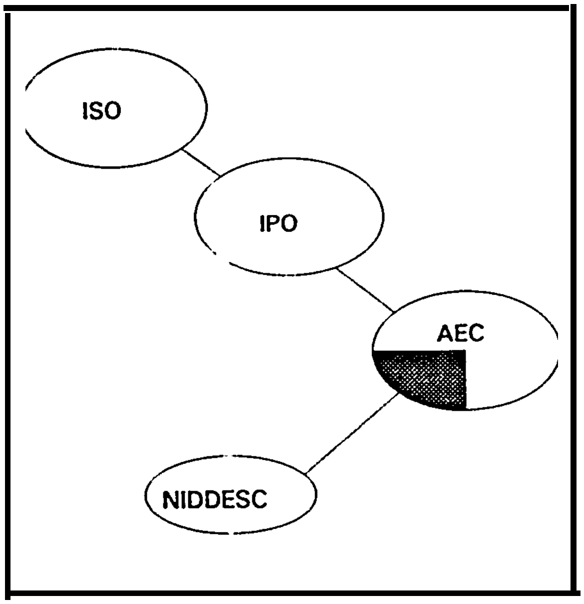

Fig. 5 Interaction Between NIDDESC,
IPO & IS0

piping application these functions and products include:

- Flow Analysis,
- Equipment Arrangement,
- Piping System Test Definition,
- Interference Analysis,
- Bill of Material, and
- Pipe Stress Analysis. Etc.

From this process evaluation specific data elements and their relationships arc defined. This is accomplished through the use of Nijssen's Information Analysis Method (NIAM). This formal information modeling approach was chosen based on the functionality of NIAM to define information and its relationships found in the marine industry. Several different methods are inuse for other information modeling efforts including the IDEFlX approach. Information models define information and their relationships in terms understandable to both application and computer systems experts. Figure 4 depicts a typical NIAM model of a portion of the ship's structural information.

This marine industry development and review

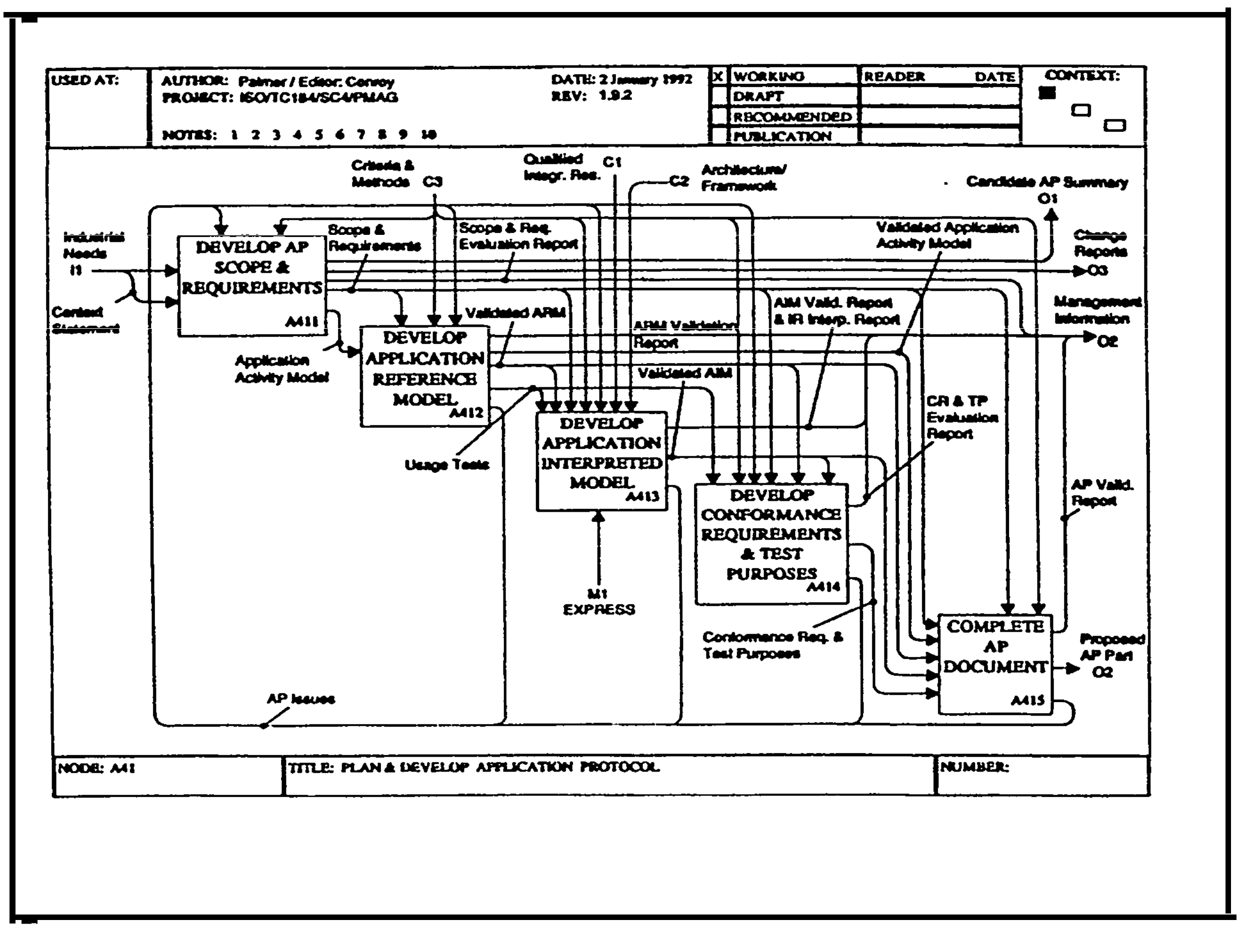

Fig. 6 STEP Application Protocol Development Process

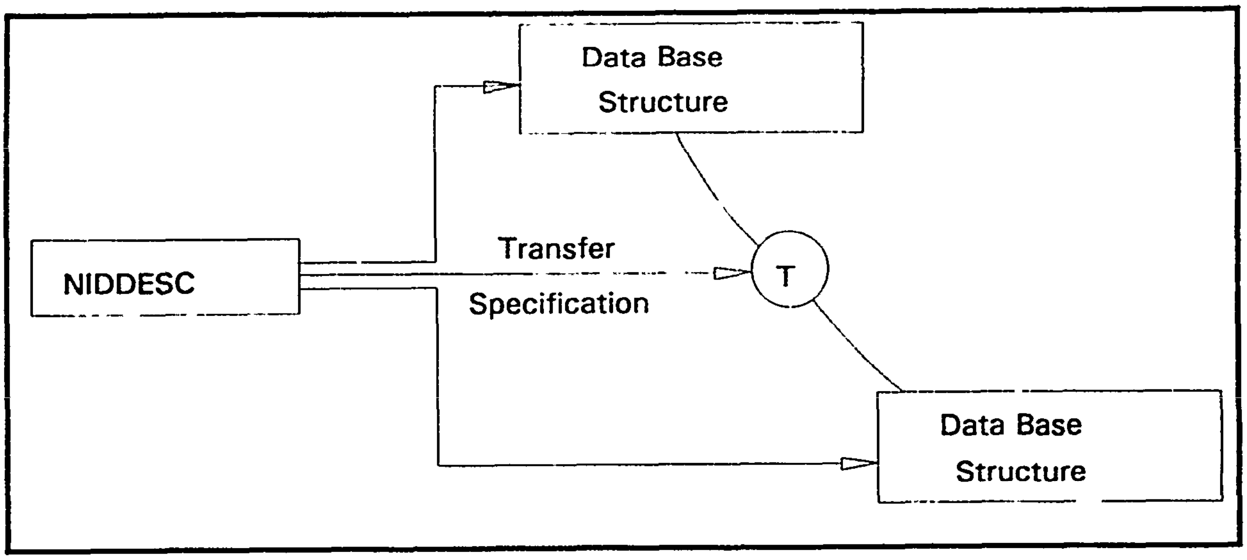

Fig. 7 Benefits of NIDDESC AP Developments

process has enabled NIDDESC to define a single product model description which will support broad industry and organization specific exchange needs. This industry agreement is key to influencing changes to national or international standards.

STANDARDS DEVELOPMENT/APPROVAL PROCESS

Once an industry's product model content is defined, an exchange standard must be developed or enhanced to incorporate this information. The United States product data standards organization is the IGES/PDES Organization within which NIDDESC works through the Architecture, Engineering Committee (AEC) sub-committee. The AEC sub-committee was chosen because of marine industry similarities between building & process plant product information, such as piping. HVAC, structures, electrical and furnishings.

Changes to the IGES specification are approved at this level by the IP0, while exchange requirements to be incorporated into STEP must be further approved by ISO. Incorporation of industry data exchange requirements into STEP requires the additional requirement of international approval. Figure 5 depicts the relationship between NIDDESC and the IPO and IS0 standards organizations.

The product data exchange standards development process is a time consuming, dynamic environment with development and approval procedures continuously changing. In particular, the STEP development and approval process is till evolving. Changing requirements placed on the participating organizations, have resulted in additional expense and have increased the uncertainty of both the timing and the actual functionality of the initial version of the standard.

Within this dynamic environment, NIDDESC strives to the maximum extent possible to adhere to the evolving guidelines for STEP development defined by the National Institute of Standards and Technology (NW') (6). Figure 6 depicts the major steps involved in the application protocol development process.

The six MDDESC application protocols have been submitted by the IPO for inclusion into the STEP standard. This represents a major milestone for the Navy and the marine industry. It is critical to long term U.S. shipyard competitiveness, that the product model exchange for ships product data be via international standards. U.S. industry must be able to communicate digitally on an international level with other organizations.

PRODUCT MODEL IMPLEMENTATION

The NIDDESC AP's will serve many purposes. In defining ships product model information, the AP's form the basis for the development of data exchange standards as well as the basis for developing or acquiring computer systems capable of dealing with this product data. Figure 7 shows this relationship.

NIDDESC has taken abroad view of the information developed during a ships life cycle and the applications to be supported in defining the scope of product model definition. Most current computer systems are not configured to utilize this information. The NIDDESC Ap's provide the information content and relationships necessary to implement product model systems. The NlDDESC product model descriptions will enable the marine industry to share a common definition of this information.

CONCLUSION

As the standards approval process continues, the navy and marine industry can now begin the integration and enhancement of current systems to acheive the benefits associated with product model exchange. With the NIDDESC standards defining product model definition, organizations can begin to plan for the exchange of 3D product data. While information systems within the industry remain different, with each organization choosing the most appropriate tool for their use, the information developed remains the same. In order to acheive the benefits of product model exchange, each must be capable of generating and utilizing this information. With the continued development of CAD systems and the enhancement of data exchange, the marine industry continues to be a leader in the product model development arena.

ACKNOWLEDGEMENT

The standards development *process* is a constantly evolving process requiring patience ,determination and a long term commitment to achieve success. The success of the NIDDESC program can be attributed directly to the individual efforts of the members the Working Group and long term commitment of the Steering Committee members. Those individuals contributing significantly to the development of NlDDESC products include: William Becker, Newport News Shipbuilding, Jack Brainin, CDNSWC, Bruce Calkins, SEACOSD, Lisa Deeds, CDNSWC, Mike Gcrardi, Bath Iron Works, Dr. Burton Gischner, General Dynamics,EB Div., Ben Kassel, CDNSWC, Dave Kinne, Bath Iron Works, Pete Laze, Newport News Shipbuilding, Rick Lovdahl. Lovdahl & Assoc., Doug Martin, NASSCO. Greg Morca, General Dynamics, EBDiv., MikePolini,JonathanCorp., Suhhash Ramachandran Angle, Inc., Virgil Rinehart, Maritime Administration, Tom Santicapita, Gibbs & Cox, Inc., Richard Shields, Ingalls Shipbuiding, Randy Stegemeyer, Puget Sound Naval Shipyard, Ron Wood, Ingalls Shipbuilding, Dan Wooley. Newport News Shipbuilding

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NIDDESC - IGES Developments -Today's Solution

No. 5B-2

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ABSTRACT

Thc Initial Graphics Exchangc Specification (IGES) was first developed in 1980. it has cvolvcd with continual improvcmcnts to the current version 5.1 which was published in October, 1991 (I).

Although IGES has proved to be a very valuable tool, difficulties have been encountered in using it for sophisticatcd transfers, such as for product models or complicated drawings. The primary problems have revolved around the fact that the spccification allows for multiple forms of rcprcscnting the same data, which results in difficultics in transferring that data between varied CAD (Computer Aided Design) systems.

The long range solulion to thcsc difficultics is the cmcrgcncc or STI31' (Standard for the Exchange of Product Model Data). The Navy/industry Digital Data Exchange Standards Committee (NIDDRSC) has been a leading playcr in the dcvclopmcnt of this international standard. However, in the interim, NIDDESC is also spcarchcading the efforts to cnhancc the use of' IGES by dcvcloping application protocols.

Application protocols are required becausc IGES allows for multiple ways of rcprcsenting the same data, and few implcmcntations support all of the IGES Specification. An application protocol dcfincs a logical subschcma of the spccificalion. and dcscribcs the usage of that subschema as well as the ncccssary benchmarks for testing implementations

NIDDESC has led the efforts to develop IGES application protocols for 3D Piping and Engineering Drawings. Thcsc two application protocols arc the first ones to be developcd by the IGES/PDES (Product Data Exchange using STEP) Organization (I.P.O.), and will lcad the way to more productive data transfcr before the development Of STEP'. They will bc referenced by the DoD (United States Department of Defense standard for digital data transfer. MIL-D-28000(2), and should greatly facilitate the occurrence of effective data transfer in these two disciplines. Furthermore, the use of these IGES application protocols is expected to provide significant guidance in the developmcnt of application protocols for the emerging STEP standard.

This article will focus on the development o; these two application protocols, the involvement of NIDDESC and the shipbuilding industry (a; well as the participation of other industry users and vendors), and the significant benefits to be derived from the adoption of these standards.

NOMENCLATURE

AEC =Architecture, Engineering, and Construction Committee
- Committee of the IGES/PDES Organization through which NIDDESC efforts are submitted

AP = Application Protocol
A specification for representing product model data from an application area in the format of a given data exchange standard

AVM = Application Validation Methodology Committee
- Committee of the IGES/PDES ORGANIZATION which sets criterion for and approves format of application protocols

CAD = Computer Aided ***Design***
Describes computer methods and symbols used in the design process

CALS = Computer--aided Acquisition and Logistic-Support
Program of the Office of the Secretary of Defense
Objective is to establish an integratcd set of standards and specifications for the creation, management, and exchange of product development and logistic data by computer

DoD = United States Department of *Defense*
Issuing organization for MIL-D-28000 to specify standards for digital data exchange

DoE' = United States Department of Energy
- Developcd an IGES based plan for exchanging drawings among its own sites

DOEDEF = Department of Energy Data Exchange Format
Project to establish rules and guidelines to enable production drawing exchange within the DoE

IGES = Initial Graphics Exchange Specfication
First developed in 1980
Currently in widespread USC in American industry
- Primarily designed to transfer graphics betwcen existing CAD systems

I. P. 0. = IGESIPDES Organization
- United States committee that publishes IGES Specification and is coordinating U.S. effort toward development of STEP

I. S. 0. = International Standards Organization
Parent organization of committee that is developing STEP Standard

MIL-D-28000 = DoD Specification for Digital Data Exchange
- References the 3D Piping IGES Application ProtocoI as Class V
Eventually plans to supplement Class II with the Engineering Drawings IGES Application Protocol

NIDDESC=Navy lndustry Digital Data Exchange Standards Committee
- Joint, cooperative effort of Navy and industry to develop data exchange standards and procedures for use in the shipbuilding industry

PDES = Product Data Exchange using STEP
- Unilcs States effort in support of development of STEP Standard

SEA WOLF = SSN2 I
New Class of submarine being developed for the United States Navy by Newpon News Shipbuilding and General Dynnamics/Electric Boa1 Division. whose design and construction have pioneered in the production USC of electronic data cxchange

STEP = Standard for the Exchange of Product Model Data
- Proposed international standard for the exchange of product models
Version 1 is currently in I.S.O. balloting process
Current version is very restrictcd in scope and will be of limited USC in man;, application areas
- It will be years before STEP is in widespread production use

INTRODUCTION

General use of IGES

The importance and benefits of electronic data exchange have long been recognizcd, and the difficulty of developing and maintaining direct translators betwcen CAD systems led to the concept of a neutral filc transfer, and the subsequent development of the Initial Graphics Exchange Specification (I) with Version I being published in 1980.

In the last decade, IGES has been expanded and improved greatly with Version 5.1 being published in October, 1991. Despite the expansion in the scope of IGES (for instance, it now includes solid geometry and attribute table representations), and its vast improvement in recent years, there arc still many organization.. that have had difficulties in using the specification to successfully accomplish digital data transfer.

One problem frequently encountered, is that because of the breadth of the IGES Specification, thcrc may be several correct ways to represent certain entities from a CAD system, and an exchange will only be successful if both systems choose to USC the same implementations. Documents such as the "IGES 5.1 Recommendcd Practices Guide " (3) have helped reduce these problems by giving guidelines for the best way IO implement the specification in certain instances. However, to insure the best possible transfer between diverse CAD systems, the IGES processors must be written IO conform to a much more rigid set of requirements. It is this lightly controlled environment (which will lead to successful and productive digital data transfers) that the development of application protocols is designed to create.

Specific Projects

Aside from the general attempts to usc IGES successfu1ly. Severall organizations or projects have developed task forces or working groups to use IGES to implement their specific data cxchange requirements.

The Navy/Industry Digital Data Exchange Standards Committee (NIDDESC) was formed in 1986 as a joint cooperative effort between the Navy and corporate participants from the shipbuilding industry because of the realization as to how valuable effective electronic data exchange could be to the marine industry. It is largely because of the efforts of NIDDESC and its member companies that the application protocol development projects discussed in this article wcrc Undertaken

The SEAWOLF Digital Data Exchange project provides another example of the successful usc of IGES for exchanging data. This project was a joint effort of NAVSEA, General Dynamics/Electric Boat Division, and Newport News Shipbuilding and used IGBS successfully to transfe- engineering drawings as well as structural and piping models. In fact, the SEAWOLF piping Product Model transfer provided the basis for the development of the 3D Piping IGES Application Protocol (4). A more detailed description of the SEAWOLF Digital Data Exchange Project is available in Reference 5.

The DOEDEF Project of the U. S. Department of Energy (DOE) successfully set Up rules and standard format **for** the transfer of' drawings via IGBS among many **DoE** sites using different CAD systems.

The success of these project specific implementations demonstrates that digital data exchange using IGES can be productive in today's environment when the scope, formats, and implementation of the transfers arc rigidly controlled. These experiences have led to creation of the concept of IGES application protocols. and their development and implementation through efforts led by NIDDESC.

Throughout this article mcntion is made of several 0rganizations and Specification. Thc IGES/PDES Organization (I.P.O.) is a body composed of volunteers from industry and government agencies (primarily in the United States) who have developed the IGES Specification and are participating in the development of STEP' under the auspices of the International Standards Organization (I.S.O.). IGES has been primarily used to transfer graphics data between existing CAD systems. STEP is being developed to provide an international standard for the exchange of product models.

NIDDESC is a joint cooperative effort of the U. S. Navy and the marine industry to develop data exchange standards and procedures for usc in the shipbuilding industry. NIDDESC participates actively in the I.P.O. and is making major contributions to both the IGES and STEP standards.

All of these activities fall under the umbrella of the Computer-aided Acquisition and Logist;: Support (CALS) Program of the United States Department of defense, and arc heavily supported and enthusiastically endorsed by the government .

APPLICATION PROTOCOLS - CONCEPT AND IMPLEMENTATION

Background

The Initial Graphics Exchange Specification (IGES) was first developed in 1980 as a neutral file format to facilitate digital data transfer between CAD systems existing at that time. Despite the extensive efforts that went into developing the specification, many attempted data transfers wer unsuccessful or encountered problems, especially in the first few years of the standard.

Some of the problems were caused by the IGIB Specification not having an adequate representation for all constructs within a CAD system. Thcsc were addrcsscd in later versions 01 the standard, and ongoing enhancements arc still underway

More difficulties, however, were caused by opposite problems: that IGES allowed multiple correct representations of thc same information. and that vendors would each implemcnt a unique subset of the specification. Additional complications were caused by the lack of validations procedures for translators and the translation process.

It is the above class of problems that the concept of an application protocol was designed to solve.

Structure of an Application Protocol (Ap

Thc basic problem in digital information exchanges can bc exprcsscd as agreeing on the meaning and purpose of exchange data. The resolution of this problem is achieved by providing the methods for developing, testing, and implementing information models that define unambiguous sets of data elements.

Application protocols are the means to this solution. They provide a method to achieve consistent and reliable exchange of product data within a specified application area. The key concept is to explicitly link the application's information content to the entities and data structures to be exchanged. An AP defines the context for the use of product data, and specifics the use of the standard (i.c. IGES) in that context to satisfy an industrial need.

There arc four key components to an application protocol:

1) Application Scope and Requirements - defines the realm and applicability of the type of data to be exchanged;
2) Application Reference Model (ARM) - defines the supported information and application domain in an information modelling language that is independent of the specific transfer specification being used;
3) Application Interpreted Model(AIM) - specifies the data constructs used fog rprcsenting the application information defined in the ARM in the selected neutral file format (i.c. IGES); and
4) Conformance Criteria and Test Purposes - specifies conformance testing to increase the confidence that different implementations of the AP will be able to exchange information successful1y.

A more detailed description of the structure and requirements for an IGES application protocol is available in the "Guidelines for tl:1[8] Specification and Validation of IGES Application Protocols". by R. Harrison and M. Palmer (6).

Implementation Efforts

The STEP Standard, which is being developed as an international specification for the exchange of product model data, will depend heavily upon application protocols basis for its successful implementations. However, in the interim period until STEP is an approved international standard with production translators to support it it. there is a need for IGES application protocols.

The urgent need for application protocols and the extensive time required for STEP to become a workable standard has caused NIDDESC lo lead development efforts for two IGES application protocols: one for three dimensional (31)) Piping, and the other for Engineering Drawings. Along with the extensive marine industry participation, the AP 'efforts have received significant help lion: CAD vendors and members of process plant and other industries. This voluntary participation demonstrations the wide spread need for these documents.

THE 3D PIPING IGES API'LICATION PROTOCOL

Background of the Piping AP

The 3D Piping IGES Application Protocol represents an attempt to use IGES in ways that arc beyond the original scope of the specification) Whereas IGES was primarily designed to enable the transfer of graphical data as it is captured oil current CAD systems, the Piping AP is using IGES to transfer product model information. To facilitate this use of IGES, several enhancements were required to the specification in order to support the piping model transfer. enhancements were approved by theI.P.O.. and arc included in Version 5.1 of the IGES specifications(1)

The scope of the 3D Piping IGES Application Protocol is discussed in the abstract of the. document itself (4). As explaincd there:

> "The 3D Piping IGES Application Protoco! (Al') specifies the mechanisms for declining and exchanging 3D piping system models in IGES format. The AP defines three-dimensional arrangement data of piping systems which includes definition data types of geometry (shape and location), connectivity, and material characteristics. The scope of this Al' includes only piping System and 1101 drawings or

internal details of equipment. The specified piping model is sufficiently detailed to supper: the fabrication and final assembly of a piping system.

IGES is designed to support a broad range of applications and information, and it is recognized that few implementations wil! support all of the specification. An application protocol defines a logical subschcma of the IGES Specification, the usage of the subschema, and the necessary benchmarks for testing implementations.
The 3D Piping IGES Application Protocol is the first IGES AP to be delivered to industry and is an important example for the development of STEP (Standard for the Exchange of Product Model Data) application protocols."

Historical Perspective on Development Efforts in Pining Data Transfer

Discussions about using IGES to transfer piping product model data began in the IGES/PDES Organization's AEC Committee in the mid-1980s. These led to the incorporation of a 3D Piping Example as an appendix to IGES Version 4.0. The AEC Committee also participated in development of a Distribution Systems Model. The IGES example was a forerunner of the SEAWOLF Piping Data Exchange Procedure and the 3D Piping IGES Application Protocol, while the Distribution Systems Model was a pre-cursor to the STEP Piping Application Protocol (being developed by NIDDESC) as well as the ARM used in the 31) Piping IGES AP.

The real impetus for a 3D Piping IGES Application Protocol, however, came from the SEAWOLF Digital Data Exchange Project. This new class of submarine is being jointly designed for the U. S. Navy at Newport News Shipbuilding and General Dynamics/Electric Boat Division with the potential for construction at both shipyards. The SEAWOLF Piping Data Exchange Procedure was developed in a cooperative effort between Newport News Shipbuilding, Electric Boat Division and NAVSEA, and was designed to use an IGES neutral file format to transfer piping product model information between Newport News' VIVID' system, and Electric Boat Division's PIPER system. Both of these were. in-house developed CAD systems that were being used to support SEAWOLF piping design and fabrication. Most of the IGES constructs that were later used in the 31) Piping IGES AI' were first implemented in translators developed for SEAWOLF Piping Data Exchange.

The formal project to develop the 3D Piping IGES Application Protocol was sponsored by NIDDESC, although it also had significant participation from members of the process plant industry as well as the vendor community.

Version 1 .O was published in October, 1990 and underwent extensive review within the IGES community. Version 1 .l was formally published in March, 1992 and incorporates changes designcd to resolve the comments against Version I .O. The March, 1992 version of the document is the one being referenced by MIL-D-28000, and the one that is being submitted to the I. P. 0. for approval and inclusion in the next version of the IGES Specification.

This extensive review process has insured that the 3D Piping IGES Application Protocol is not I shipbuilding or NIDDESC solution, but instead represents a consensus agreement among several industries of a viable way to transfer piping product model data in today's environment.

Version 1.1 of the Pining AP

The scope of the 3D Piping IGES AP is the exchange of 3D piping models at a Ievcl of detai' sufficient to support fabrication and assembly of piping systems. In this case, a 3D model consist, only of piping system data. Specifically excluded are other types of systems that arc similarly modelled, i.e. structural steel and concrete. I IVAC (heating, ventilation, and air conditioning), art' electrical cable tray and conduit systems.

This application protocol defines a core 01 required data which supports a corresponding set of piping-related activities. These activities include:

I) interference analyses
2) connectivity checks,
3) basic parts lists,
4) graphic presentations
5) basic piping isometrics.
6) pipe bending instructions, and
7) limited piping redesign.

VIVID® is a registered trademark of **Newport** News Shipbuilding.

The implication is that the model transferred will include enough information to support each of these applications on the receiving system, not that the end products are exchanged. For instance. "basic piping isometrics" means that the receiving system has enough information to generate an isometric drawing in its own format, not that the actual drawing is transferred.

The Attribute Table Entity in the IGES Specification was expanded to support the core attributes in the piping AP, as well as to include many other properties that are not required by the application protocol. This allows the functionality of the core data to be extended by agreements between the sender and receiver of the data.

The unique feature of this protocol is its attempt to use IGES to transfer data describing a complete product model, rather than just the graphical data associated with that model. It thus requires the sending and receiving systems to make specific interpretations of IGES entities. For instance, a pipe is not represented by a solid model of cylinders and toroids, but instead has its 'centerline represented by an IGES Composite Curve Entity. The pipe diameter (and other properties) are referenced in the IGES file by a pointer to an Attribute Table Instance Entity.

In a similar manner, the Piping AP identifies many piping occurrences by special interpretations of various IGES entities. For example, a piping joint is represented by a null composite curve consisting of only two Connect Point Entities. The Composite Curve Entity will, in turn, point to an Attribute Table Instance Entit! to specify the properties of that joint.

The fact that this AP requires specific interpretations of IGES entities means that a general purpose IGES translator may not support this protocol. A company may need to modify its translator or write a new one in order to comply with the AP. However, the use of the 3D Piping IGES Application Protocol will enable the transfer of a far richer set of piping product model data than merely using IGES as a graphical transfer mechanism.

Version 1.1 of the 3D Piping IGES AP was formally issued in March, 1992. It has been extensively reviewed within the IGES/PDES Organization, and has been approved by the I. P. O's ABC and AVM Committees.

Validation testing of the application protocol is currently underway at the David Taylor Research Center. Upon completion of this testing, the AP' will be submitted to the IGES Project Committee and then the I. P. 0. Genera! Assembly for approval and inclusion in the next version of the IGES Specification. This will be the first IGES application protocol to be submitted to the I. I'. 0. formal approval and is also the version referenced in MIL-D-28000.

Version 2 of the Piping AP

The one issue that was not resolved ver:l successfully during the development of Version 1.1 of the 3D Piping IGES AP was how to handle the passing of models for components, especial!y standard library representations or cataIogs.

In the SEAWOLF Piping Data Exchange efforts, both the participating shipyards agreed to exchange material catalogs on a regular (monthly) basis, and to cross-reference each other's part numbers. Thus, the IGES files exchanged for piping merely referenced a part number for each component, and provided a transformation matrix to orient it correctly in space. It was assumed that the receiving system would recognize the part number in its catalog, have the component's geometry already loaded, and be able to orient the fitting correctly by applying the transformation matrix to a standard set of rules agreed upon for the origin and orientation of all components.

This approach was not deemed practical by the: developers of the 3D Piping IGES AP because one could not rely on a transfer only being successful if entire catalogs were exchanged between competitive CAD systems. Furthermore, discussions among the participants about catalog exchanges, often bogged down with issues about proprietary internal representations, or using configurations that were much more easily implemented on one CAD system than on another.

The eventual solution agreed upon for Version 1 .I was to not pass catalogs, but instead to pass ;I CSG (Constructive Solid Geometry) representation for each component whenever it occurred in the piping model. Although this method was inefficient, it at Icast provided an interim solution that would enable developmcnt and implementation of the AP to continue.

A working group, headed by NIDDESC, is currently developing a second version of the 3D Piping IGES Application Protocol which will address the catalog issue. The decision was mad,: to Classify all fittings as eithcr "specialty" or "commodity" components. "Specialty" items will be transferred individually with CSG solid IGES representations, as in the Version 1.1 solution.

Most standard components will be classed as "commodity" items. The working group in determining a neutral representations as far as origin and orientation for these fittings. The geometry will be passed as a parameterized list of key dimensions which will enable the component to be modelled on the receiving system in whatever form that CAD system uses for the given type of fitting. This solution will greatly simplify the processing of component data, and should make Version 2 of the 3D Piping IGES AP a much more easily implemented and valuable specification.

Several other enhancements will also be included in this version of the Piping AP. The attribute lists will be expanded to permit transfer of further information, which will support additional downstream applications.

A new IGES entity, called Piping Flow Associativity, has been approved by the IGES/PDES Organization, and will be incorporated in Version 2 of the AP as a better way to indicate groupings and properties of piping collections such as: Pipe **Runs,** Pipelines, Piping Assemblies, or Piping Systems.

It is also hoped that during implementation of Version 1.1 problems or difficulties may be revealed so that the developers of Version 2 will be able to find improved solutions.

The proposed schedule is to complete a draft of Version 2 of the 3D Piping IGES AP by the end of 1992, and then submit it to the I. I'. 0. for approval and incorporation into the IGES Specification.[2]

Conclusions from Piping AP Efforts

The 3D Piping IGES Application Protocol is providing a workable method for transferring piping product model data in today's environment. Version 2 will be available shortly, and this will greatly simplify the problem of passing catalogucd components, and thus enhance the implementability of the document. Eventually. the 3D Piping IGES Al' will be supplanted by a STEP application protocol for the transfer of piping product models (which NIDDESC is also developing), but in the interim, the IGES AP is providing industry with a valuable **tool.**

THE ENGINEERING DRAWINGS IGES APPLICATION PROTOCOL

Background of the Drawing

To convey knowledge about a product's design or fabrication, engineering drawings arc the most commonly used tools. **One** of the principal uses ! most Computer Aided Design (CAD) systems is the creation and production of these drawing:. The use of a CAD system can significantly increase the quality of drawings produced while reducing the time spent on their generation Because of this double benefit, drawings produced on CAD are becoming a necessary part of today's business environment, including shipbuilding.

Since drawings are used at various stages in the life-cycle of a product, and specific stages of the life-cycle are usually handled by different organizations, it is likely that an electronic drawing will be represented on several diffcrcnt CAD systems throughout its existence. This is due to the multitude of systems available, and their unique uses during the design, fabrication and support of a product. Assuming one wants a particular drawing resident on each of the CAD systems involved, one must either load the drawing from scratch on each system or find some Way of electronically transferring the drawing data from one system to another.

Loading the drawing from scratch is a time consuming process, and it is prone to error since a considerable amount of manual work is involved Therefore, electronic transfer is a much preferrcd alternative. For drawing data, the transfer can either be in rastor or vector form. Rastor transfer is best likened ιο faxing a document, in that the image is broken up into a series of dots which produce a picture of the drawing. This method **is** purely a two dimensional transfer, and the receiver cannot easily modify the drawing. Rasto- transfer, however, may be useful where the receiving system need not modify the data, such a.: plan file or manufacturing activity.

When modification of the received drawing, or **the** transfer of an associated model. is required then a vector transfer is called for. A vccι

2 Development of the 3D Piping IGES Application Protocol is being led by Dr. Burton Gischncr of General Dynamics/Electric Boa: Division, and he can be contacted at: **(203) 433-3948.**

transfer preserves specific entity types as well as spataial releationship Thus a three dimensional ellipse in the sending system should result in a three dimensional ellipse in the receiving system. A perfect vector transfer would result in exactly identical copies of the drawing, and any associatcd model, on both the sending and receiving systems. This lofty goal is seldom reached, although. perfectly acceptable results are achieved using the methods outlined in this paper.

Assuming a vector transfer is required, the next consideration is whether to use a direct translator or a neutral file specification. The direct translator takes the constructs of the sending system and converts them to the constructs of the receiving system. Such an approach may be useful when the translation is to be a singular event involving two specific CAD systems with no changes to software revisions during the process. If these conditions are not met, then the number of direct translators required increases rapidly, thereby losing any potential savings. In this case. which is more common, then a neutral file transfer is called for.

In a neutral file transfer, the drawing data on the sending system is converted to a neutral representation which is then read into the receiving system. The file can be transferred between systems using magnetic tape or telecommunications lines. Both the sending and receiving systems must have converters capable of understanding both the neutral file and the native CAD database. Perhaps the most common neutral file transfer for engineering drawings is IGES. The remainder of this paper deals with how IGES is being successively refined to enable the successful transfer of engineering drawings.

Drawing Exchange Using Straight IGES

Under continual development for the past twelve years, IGES is a collection of neutral representations for geometric, annotation and organizational entities needed to make up drawings with some product model data. These entities are grouped together in a fixed-format text file which a sending processor creates from the native CAD database. The file is then transferred to the receiving processor which reads the file and converts the IGES entities to native database entities and constructs. Specific information about the actual IGES file may be found in "Reference 1."

All of the constructs necessary to build an electronic engineering drawing are present in IGES. This includes not only geometry and annotation, but also itcms such as views. coordinate systems, line styles and subfigures. The problem with IGES, in fact, is that many of the necessary constructs may be represented several ways. As an example, there are two distinct ways to represent splints in an IGES file. parametric or rational b-splinc. This leads to problems when the sending system outputs one type, and the receiving system is set to receive the other. Both systems are correct, yet the data will not be transferred.

After organizations spent several years attempting to transfer data with the mismatches described above, a consensus was reached among IGES users that some refinement of the process was necessary for successful data exchange to take place. Since all of the IGES constructs were necessary lo some users, condensing the actua, Specification was not practical. Thus, some projects placed limits on how IGES could be used for a given transfer. Three of these are described below, for these should be considered the forerunners of the application protocol.

Project Peculiar Uses Of IGES

One of the largest driving forces behind IGES has been the U.S. Department of Defense (DoD). As many weapons systems have been designed and fabricated with IGES transfers as part of the process, DoD has a vested interest in establishing successful IGES transfers. To promote this goal, DoD has issued a military specification, MIL-D-28000 (2), which requires the use of subsets of IGES for various applications. One of these is the transfer of engineering drawings, which is the Class II subset. A subset restricts the type of IGES entities that may be used for a particular application, with the entities coming from the entire specification. No guidance is given as to how the entities will be used, which leads to problems when them are multiple ways to use the same entity. Because of this, the subset is not used in production, and the goal of the project team developing the AP is lo replace Class II with the AP.

Since a combination of entity restrictions and usage guidelines is required to successfully implement an IGES transfer, it would be a great advantage if both the sending and receiving systems were known before the transfer capability is developed. Such was the case for the representatives of the Navy, the Electric Boat Division of General Dynamics and Newport News Shipbuilding who implemented the SEAWOLF

Digital Data Exchange. The SEAWOLF submarine is a joint design project between the three organizations, and, from the outset, an electronic drawing exchange capability was desired to support the project. IGES was chosen as the transfer mechanism, and Computervision and Cadam were the CAD systems involved.

Because the SEAWOLF exchange was bounded as described above, intensive testing was conducted to establish an acceptable transfer capability. This involved considerable rework to both IGES processors, identification of specific entities and constructs to be used, and the generation of a set of specific procedures to be used for the exchange. The exchange is based on functional equivalence between sending and receiving systems, so while transmitted drawings may not look exactly alike, they will still be completely usable. An example of this is that block letters may be filled on one system, and in outline form on the other. The letters arc still readable on both systems. This exchange is currently in production; the key to this was the establishment of a set of specific project information to use for the exchange. For more information on the SEAWOLF program, please see "Reference 5."

The U.S. Department of Energy (DOE) took the idea of project specific exchange documents one step further. For their sites involved in nuclear work, DoE developed a plan for the exchange of drawing data amongst the CAD systems involved. Again this plan was IGES based, and the exchange was bounded by the involved systems. This project, known as the DOEDEF (Department of Energy Data Exchange Format) was planned around an agreed to level of exchange capability, which was tested before actual production exchanges. Also, key to this program was the development of project specific instructions, including what entities and constructs could be used. This project involved more than two CAD systems, so the testing and documentation was even more involved than that required for SEAWOLF.

What the three projects described above all point to is that for IGES exchange to work both entity constructs and specific usage instructions are required. Although the problem is simplified if the sending and receiving systems are known, this is not always the cast. Therefore, a more comprehensive document is required to guarantee an acceptable level of IGES drawing exchange. The answer to this need is ant application protocol, AP, which defines how IGES can be used for a specific discipline exchange, in this case engineering drawings. By having CAD systems. and their users, agree to produce and receive IGES files in a certain way. an acceptable transfer can be assured. Thus, an AP is a project specific document applying to the entire class of IGES drawing exchange. The rest of this paper traces the development of an AP for engineering drawings.

Engineering Drawing IGES AP Development

As stated above, an AP for engineering drawings covers an IGES exchange between any combination of users and systems that state they produce AP compliant files. Therefore, the logical group to develop such a document is a combination of CAD vendors and users. The IGES/PDES Organization recognized such a need and directed the I.P.O. Drafting Committee to put together such a group and produce an AP.

Early efforts centered around an AP to govern the exchange of drawings that arc purely two dimensional, with no associated product model. As development proceeded on this protocol, it became evident that this class of exchange was really a subset of the broader category of exchange of drawings with an associated model. Therefore, this project was rolled into the comprehensive protocol which is under activ development.

To efficiently produce the protocol, the L.P.O. Drafting Committee formed a specific project devoted to this document. The project is chaired by Mr. G. Morea, who is sponsored by NIDDESC The Navy actively endorses the IGES protocol concept, and NIDDESC expects this protocol to replace the Class II subset in MIL-D-28000 (2). The I.P.O. project includes members of both the vendor and user communities. Representatives from Caterpillar and Sandia National Laboratories have been especially active from the user community. Likewise, representatives form Computervision and Autodesk have been active from the vendor community. Both the users and vendors realize that a successful protocol implementation will require input from both parties. Working under the Drafting Committee. the project group meets regularly to develop the document.[3]

[3] Development of the Engineerings Drawing IGES Application Protocol is being led by Mr. Gregory Morea of General Dynamics/Electric Boat Division, and he can be contacted at: **(203) 433-3403.**

Again. there are several different combinations of drawings and models that need to be exchanged. depending on specific project needs. To accommodate this, the protocol has established a taxonomy of engineering drawing creation and exchange parameters. As examples, there may or not be an associated model, and the dimensions may or may not be associated with features of the model. Depending on how these parameters arc set, certain levels of exchange functionality are defined. These range from the exchange of two dimensional sketches to the exchange of a model alone from which a drawing is automatically produced on the receiving system.

To support each of the defined levels of functionality, a set of application requirements is defined. 'These specify the constructs that both the users and vendors must use to produce compliant files. A reference model organizes this data from a logical standpoint, and an interpreted model provides the specific IGES entities and constructs to be used in file creation. This protocol uses the same reference model as STEP AP 202, Associative Draughting. **As** STEP is the logical progression from IGES, this protocol provides a bridge between the two. In addition, data generated from this protocol will be used to further validate AP 202 as it is developed.

Accompanying the protocol itself is a large body of test data. This data serves two specific purposes. The first is to validate the ideas and constructs specified in the protocol itself. The second is to provide a baseline for users and vendors to use when assessing compliance to the protocol. The test data is a combination of specially developed, protocol specific cases and actual user drawings.

To obtain the support that the protocol needs for effective implementation, it will go through a number of formal approval cycles before being published. The I.P.O. Drafting Committee, Application Validation Methodology Committee and IGES Project Committee all need to approve the document before the entire I.P.O. approves it. Once this is accomplished, the document will be published both as part of the IGES Specification (1) and as part of MIL-D-28000 (2). At this point. the protocol can be used to successfully transfer engineering drawing data within the IGES community.

Conclusions from Drawing AP Efforts

In summary, the protocol establishes a level of exchange capability that can be guaranteed independent of specific vendor user combinations by specifying a protocol compliant file.

This climates the need for rounds of testing now required each time a project seeks to use IGES for drawing transfer. In addition, this reduces the errors associated with attempts to use the entire specification. The document also provides an ideal transition to STEP.

SUMMARY

The eventual goal for data transfer is to use a neutral file solution incorporating STEP, the international standard for product model exchange, but the reality of this is several years away. Thus, NIDDESC has led the development of two IGES application protocols to provide an interim method for transfering piping product models and engineering drawings via IGES before the completion of STEP.

These application protocols provide valuable data exchange tools now, and will provide a baseline and guideline for the development of STEP application protocols. They will be the first application protocols submitted to the I. P. 0. for approval, and are setting a precedent for future developments.

The IGES/PDES Organization has agreed to include all approved application protocols as part of the IGES Specification, and MIL-D-28000 will reference these documents so they can be invoked on DoD contracts. Thus, by guiding development of the 3D Piping IGES Application Protocol and the Engineering Drawings IGES Application Protocol, NIDDESC has taken the lead in providing national standards to enable production exchange of this data in today's environment.

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Building on the Success in Standardization of the U.S. Navy

No. 6A-1

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ABSTRACT

Standardization of hull, mechanical and electrical (H,M & E) components in U.S. Naval ships can take the form of identical components on one ship, on one class of ships, or on the entire-Navy fleet. The Navy has shown through a variety of successes that it has the potential to do even more challenging tasks in this area. This paper describes the data base and tools used by the Navy and some of the Navy's success. A vision and course of action for the future arc discussed that might include commercial as well as naval ships.

LIST OF ABBREVIATIONS

ABV	Annual Buy Value
AIR	Average Introduction Rate
AMC	Acquisition Method Code
AMSC	Acquisition Method Suffix Code
APL	Allowance Parts List
ASF	Acquisition Savings Factor
ATC	Affordability Through Commonality
AUP	Average Unit Price
BOSS	Buy Our Spares Smart
BRF	Best Replacement Value
CD-ROM	Comapct Disk - Read Only Memory
DART	Detection Action Response Technique
DOA	Data Ownership Analysis
DoD	Department of Defense
EBV	Estimated Buy Value
EC	Equipment Category
ECP	Engineering Change Proposal
ESC	Engineering Support Code

H,M&E	Hull, Mechanical, and Electrical
HEDRS	Hull, Mechanical and Electrical Equipment Data Research System
IBS	Integrated Bridge System
ILS	Integrated Logistics Support
LAPL	Lead Allowance Parts List
NAVSEA	Naval Sea Systems Command
NAVSEALOGCEN	Naval Sea Logistics Center
NAVSUP	Naval Supply Systems Command
NDI	Non-Developmental Item
NSN	National Stock Number
NSTFP	Navy Standard Titanium Fire Pump
OEM	Original Equipment Manufacturer
PAS	Potential Acquisition Savings
PBV	Projected Buy Value
PESS	Potential Economic Savings from Standardization
PMS	Planned Maintanance
PPR	Planned Program Requirements
PTD	Provisional Technical Documentation
SBA	Standardization Benefits Analysis
SCSC	Standardization Candidate Selection Criteria
SDCL	Standard Design Components List
SEL	support Equipment List
SPCC	Ship Parts Control Center
TPIS	Total Potential ILS Savings

INTRODUCTION

The Department of Defense (DoD) defines standardization as:

"... the process by which the DoD achieves the closest cooperation among services and agencies for the most efficient use of research, development and production resources and agrees to adopt on the broadest possible basis the use of:

a. common or comparable operational administrative and logical procedures

b. common or compatible technical procedures and criteria

c. common, compatible or interchangeable supplies, components, weapons, or equipment, and
d. common or compatible tactical doctrine with corresponding organizational compatibility (1).

The Defense Standardization Manual states that the objectives of standardizations are as follows:

1. Improve the operational readiness of Military services.
2. Conserve manpower, money, time, facilities and natural resources.
3. Optimize the variety of items used in logistics support.
4. Enhance interchangeability, reliability and maintainability.
5. Ensure that products of requisite quality and minimum essential need are specified and obtained.
6. Ensure that specifications and standards are written so as to facilitate tailoring of prescribed requirements to the particular need.
7. Assure that specifications and standards imposed in acquisition programs arc tailored to reflect only particular needs consistent with mission requirements (2).

The U.S. Navy has made significant progress in the area of standardization. The authors feel a comprehensive, on-going program requires the following elements:

- Data Base -- to keep track of the components in the Navy fleet;
- Tools for Evaluating Standards to allow for the calculation of costs and benefits of alternative actions;
- Examples of Success -- to show a proven track record and build credibility; and
- Vision and Plan of Action -- to set out the goals and the course of action for reaching them. (The necessary resources must also be committed to this effort.)

In this paper the authors give their views on these four elements of a comprehensive program.

DATA BASE (3)

In order to maximize the benefits attributable to the standardization effort, standardization concepts must be involved as early as possible in an acquisition. This requires that standardization be a guiding principle in the design phase. For this to be possible, designers must have access to the widest variety of information regarding what equipment is already in the Navy supply system and how it can be adapted to new systems. Both performance and physical characteristics must be supplied in order to facilitate the implementation of designs utilizing multiple-application (standard) equipment.

This basic requirement, item identification and cataloging, is a process associated with standardization that is essential for its success. Past Navy practice neglected this. Previously, the Navy emphasized performance specifications and standards in the hope of obtaining standard items. This offers designers only limited information based on technical requirements, and many items with only small variations can satisfy such requirements. Specifications and standards do not identify existing equipment and as a result new and differing equipment are introduced at great logistics expense.

The cataloging function identifies the "universe of equipment" while the standardization function works to compress this universe. The cost-savings associated with controlling the entry of equipment is examined in more detail shortly.

On October 1, 199 1, the Naval Sea Logistics Center (NAVSEALOGCEN) released the third edition of the Hull, Mechanical and Electrical (HM & E) Equipment Data Research System (HEDRS). This is a personal computer Compact Disk-Read Only Memory (CD-ROM) based data base which is available at no cost to those involved with Navy acquisition, including designers. The system is intended to provide application, identification, physical and performance characteristics, availability of logistics documentation, points of contact with specialists, and reprocurability information on all HM & E equipment currently installed in the Active and Active Reserve fleet. A deficiency in this process is that manufacturer's data needed to fully describe each item has often been inadvertently omitted or withheld by the manufacturer.

The bulk of design activity equipment data comes from manufacturers' catalogs or in-house lists of equipment. Unless made a requirement, designers will be less likely to implement a system like HEDRS. Navy acquisition directorates have begun to contractually require HEDRS as the principal means of equipment selection.

With HEDRS the Navy must take the responsibility of cooperating with designers in equipment selection decisions. This requires direction and monitoring. This has been accomplished by the requirement for standardization deviation reviews and the use of a database management system.

TOOLS FOR EVALUATING STANDARDS

Since a great portion of the full life cycle costs of equipment are expended during the operational phase on board a ship, the Navy, through several services, such as the Naval Sea Systems Command (NAVSEA), Naval Supply Systems Command (NAVSUP), Ship Parts Control Center (SPCC), Naval Sea Logistics Center (NAVSEALOGCEN), tried to create some criteria for logistics, acquisition and standardization. The free enterprise system and the direct competitive strategies and regulations provided the fleet with a large number of dissimilar and uncommon parts and components. The decline in the number of vendors participating in the defense industrial base and budget constraints created the need for a higher degree of commonality of parts and components. The three models that were offered by NAVSEALOGCEN as a data base management system were:

1. Data Ownership Analysis (DOA) model,
2. The Integrated Logistics Support (ILS) Cost Analysis model, and
3. Standardization Candidate Selection Criteria (SCSC).

Data Ownership Analysis Model (4)

The Data Ownership Analysis model attempts to quantify how much the government should be willing to pay for manufacturing data rights and Level III drawings for reprocurement action. Since the beginning of the "Breakout" and the "Buy Our Spares Smart" (BOSS) programs in 1983, the Navy has steadily concerned itself with getting the data rights from the original equipment manufacturer (OEM). However, securing data rights may not always be desirable and the BOSS program has successfully imposed its own criteria frame work. Yet, putting oneself in the place of a typical contractor for a moment, there is a natural inclination to view data rights as "proprietary" or as a "partial fail-safe remedy" to long term corporate well being. To relinquish these data rights routinely will surely create some needless "data rights value added premium" costs to the Government in its quest to secure data rights. The proposed model needs time to confirm its viability and the calculation's volatilities. The decisionmaker will have to add his or her touch in order for a decision to be made. The model tries to develop an analytical approach for the economic analysis necessary to objectively evaluate the cost/value to the Navy for the procurement of manufacturing data and rights in data for parts, components and equipment. The model is constructed such that it evaluates the trade-off between the value of Data (DV) and the Potential Savings (PS) associated with acquiring data rights for parts. When evaluating equipment, the model is repeated for each part making up the equipment. PS will be a function of the following.

a. Population (POP) includes installed and replacement quantities and is a function of the replacement rate (R) and the lift (L).
b. Item price (Pp) is a function of the time value of money. All future prices will be developed based on current price and interest (discount) rates (IF).
c. The interest (Discount) rate is (IF).
d. The number of parts is (N) which expresses the complexity of the equipment.
e. The Savings Factor (SF) is a constant equal to 0.25.
f. The OF (Obsolesence Factor) is a variable value ranging from 1 .0 to 0.0. The values are developed from the following relation:

   OF= (Number of years of part obsolescence) % (Number of years for system life) (1)

   As the obsolescence value of the item approaches the anticipated design life of the system, the value of OF approaches 1.
g. The State of the Art Factor (SA) is a variable value ranging from 1 .0 to 0.0. This factor provides a measure of sensitivity to the stability of the industry. SA=O implies an increasing risk of the survival of the industry and conversely SA=l implies decreasing risk to the industry. It may be evaluated as

   SA = 1 -l/B, (2)

   where B = number of FSCM's (Manufacturers).
h. The Commercial Application factor (CA) is a variable value ranging from 0.0 to 1 .0. Subjective values are determined for CA. However, the value of CA will essentially be equal to 0.0 for items defined by Military Standards or National Association Standards.

   CA=O, implies that,
   1. The Navy already owns the data,
   2. The Navy is already competing the item, or
   3. It is a common item.

   CA=l, implies that them is measurable value to data ownership. One way of defining CA may be, CA = l/Z where 2 is the number of Allowance Parts List (APL) Numbers Associated with the equipment. If there are a number of APL's then CA approaches 0, implying limited value for acquiring Data Rights. This would be the case if a part is cited in many Allowance Parts Lists, indicating the part is used or manufactured over a range of equipment manufacturers.
i. The testing of Tools factor (T) is the variable dollar value representing the total investment in special test equipment, production machinery, tools and/or, inspection facilities required to manufacture the part and maintain the necessary quality.
j. The Life (L) is the expected system's life in years.
k. The Replacement Rate (R) is the ratio of the designed system life to the part life expectancy.

The analytical expression for the value of a piece of equipment is :

$$DV < \sum_{p=l}^{m} [\{ \sum_{y=l}^{n} xy + \sum_{y=0}^{n} xy \text{ (BRF)}$$

$$(SL) \}\{ Pp (1+If)Y\}] (SF) (OF) \quad (3)$$

$$(SA)(CA) - \sum_{p=1}^{m} (T)$$

Σxy = total number of parts added to the part's initial population after initial procurement

Σxy(BRF) (SL)= represents the replacement population quantity from the initial procurement

Pp(1 +If)Y = represents the effect of inflation on the price

P = Part number (identifies which particular part of the equipment is being evaluated during this iteration)

m = Total number of parts making up the equipment

Y = Year number

n = Total number of years

Xy = Number of parts entering the population in year y

BRF= Best replacement factor

SL = System life in years

Pp = Price of part at initial procurement

If = Average annual inflation rate

SF = 0.25 = Savings factor

OF = Obsolescence factor

SA = State of the art factor

CA = Commercial application factor

T = Cost of special test equipment, tools, etc., in U.S Dollars.

The DOA model can be demonstrated by performing the calculation for one of the parts of a particular piece of equipment. In this example, a dehydrator will be used. In this sample calculation, data for the sensor assembly hominifier (one of the dehydrators parts) is examined. The following data for the part is provided:

Price (P)= $657.80
SF= 0.25
Z= 5
SA= 0.97
BRF= 0.074
OF= 1.00
Added Population = 278
SL= 20 years
Then

CA = l/Z = l/5 = 0.20

From the added population the replacement population can be calculated as a product of the added population, BRF and the part's life (SL).

Replacement population= 41 2

If the cost of tools and special test equipment (T) is assumed to be $ 4,000 and the inflation rate (If) is 2.0 %, then the potential savings (PS) is $25,147. If all the potential savings are calculated for all the parts making up the dehydrator and summed, total potential savings is $3,443,809 for the dehydrator (details not shown here). If the necessary technical data are purchased, this savings must be greater than the cost of the technical data so that competition can be achieved.

The DOA model has not been used in recent years due to the lack of a major standardization effort, and although NAVSEALOGCEN officials rely on it, one needs to see it performed more often, to be sure of its success.

The ILS Cost Analysis Model (4)

The ILS Cost Analysis Model, associated with introduction of new equipment to the Navy, has as an objective the development of a logical, rational methodology to accurately evaluate the life cost. The increased pressure to minimize cost has forced the Navy to focus considerable attention on improved efficiency and economics. The analysis is intended to:

a. Provide a reproducible, logical, and conservative mathematical model for the assessment of costs associated with objective ILS variables,
b. Provide a consistent criteria to objectively evaluate the cost proposals submitted in competitive procurements where the basis for competition is a performance specification, and
c. Provide a rational basis to develop budget and fiscal requirements associated with ILS.

This model identifies the variables associated with life cycle support of equipment and quantifies those costs which should be considered in the economic analysis relevant to competitive procurement of functionally interchangeable pieces of equipment. The vast majority of equipment used by the Navy are procured through performance specifications. This procurement philosophy results in greater flexibility with respect to equipment design and competition, which is intended to produce better quality at the lowest possible price. The traditional method for measuring the economic advantage of competition is to compare the difference in procurement prices. This practice is both logical and meaningful for those situations where no follow on logistical support and life cycle costs are anticipated. When follow on logistics support is required, which is the case for almost all Navy equipment, additional economic considerations must be evaluated to realistically measure the net savings resulting from competition. The latter typically was not considered in the past since the bill of the life cycle cost would be passed on in the next fiscal years.

In accordance with the Federal Acquisition Regulation (part 14), the Government is authorized to incorporate economic evaluation criteria in procurement contracts. Savings resulting from competitive procurement of functionally interchangeable equipment is equal to the actual savings resulting from the least cost equipment procurement minus the costs associated with the increased needs for logistics and infrastructure support of more items. The actual savings resulting from equipment procurement is easily determined in the review of competitive price quotations. The costs related to increased needs for logistics support are a function of the following variables.

Cost of Provisional Technical Documentation (PTD) (in dollars). This cost necessary to develop adequate support is a real cost which is extremely difficult to determine. Normally this cost is buried in the initial contract price for HM&E equipment. Accordingly, very little data is available on which to base an objective estimate of the value of PTD. This variable, however, is considered virtually meaningless in the context of this analysis, if during the competitive procurement the requirement for PTD is exercised and included as part of the contract price. In this situation, all competitive quotes must include the cost of PTD. Therefore:

$$C_{PTD} = 0 \qquad (4)$$

in this analysis in order to avoid double-counting of this cost.

Cost of Provisioning (Cp) (in dollars). Support must be developed for each new piece of equipment introduced to the Navy. The process which accomplishes the development of support is known as provisioning. In this process PTD is analyzed, maintenance philosophies are developed, management data is developed, parts are cataloged, initial supply support quantities are projected and procured, and all relevant support data arc loaded to data files. The result of the data files loading is an Allowance Parts List (APL) which fully describes intended maintenance philosophies and requisite parts support. This evolution requires substantial resources which can be estimated by the following equation:

$$Cp = 450+300(NPN)+75(PN) \quad (5)$$

where:

NPN= Number of Parts Representing New Items of Supply

PN = Number of Parts Currently in the Supply System

Initially the most practical means for estimating the value of this variable, as well as all others, is to assume that the number of parts contained in the piece of equipment will be the same as that in the competed alternative. A further credible assumption is that 25% of the parts identified in any HM&E equipment PTD will represent new items of supply and that 75% will represent current items of supply. For Electronics, only 15% represent new items of supply and 85% J represent current items of supply so:

$$Cp = 450 + 0.25 (300) (P) + 0.75 (75) (P) \text{ for HM\&E} \quad (6)$$

$$Cp = 450 + 0.15 (300) (P) + 0.85 (75) (P) \text{ for Elect.} \quad (7)$$

where:

P = Number of different Parts in the equipment to be competed so we have

$$CP = 450+131.25P \text{ for HM\&E} \quad (8)$$

$$CP = 450+ 108.75P \text{ for Elect.} \quad (9)$$

Cost of NSN/APL Maintenance (CM) (in dollars). Part of the cost of new equipment to the Navy resulting from competition is an increase in the universe of parts which must be supported by the Supply System. Costs associated with the management of these additional (new) parts can be quantified and, in fact, represent a negative benefit to the desirability of competition. The initial costs associated with NSN maintenance arc those related to the provisioning evolution which is covered by the section of Cost of Provisioning. This section deals exclusively with costs associated with the annual maintenance of new items of supply. Two variables must be considered to effectively estimate the negative costs associated with maintenance of new items of supply resulting from competition. These variables are:

1. the number of new items of supply to be managed, and
2. the projected lift cycle for the new items.

Based on a 1981 Department of the Army report, the annual cost to maintain an item in the supply system is $ 448.

$$C_M = 448 (NP) (L) \quad (10)$$

where:

NP = Number of New Items of Supply

L = Projected Lift Cycle of Equipment

$$CM = 448(0.25)(P)(L) \text{ for HM\&E} \quad (11)$$

$$CM = 448(0.15)(P)(L) \text{ for Elect.} \quad (12)$$

therefore,

$$CM = 112(P)(L) \text{ for HM\&E} \quad (13)$$

$$CM = 67.2(P)(L) \text{ for Electronics} \quad (14)$$

Recalling that,

P = Number of different parts in the equipment to be competed

Cost of Training (CT)& dollars). Increased training costs resulting from the introduction of new equipment is a function of numerous variables. Depending on the complexity of the equipment, these costs are a function of:

a. length of training required,
b. training aids, tools and support equipment,
c. development of course material and text books,
d. maintenance parts support,
e. training site costs, and .
f. travel and labor costs for both students and instructors.

For this model a more conservative estimate is used based on the following assumptions

1. Since new equipment is being introduced as a competitive alternative rather than as a new application, all training requirements for the original equipment have been established. Therefore, there is no cost impact related to items a, c, e, and f above.
2. With respect to item b, it is assumed that the two pieces of equipment will be required to augment current training facilities.
3. With respect to item d, maintenance, repair and occasional replacements will cost an average of 50% of training hardware capital costs per year for the expected life cycle training requirements.
4. Need for training will be eliminated 4 years prior to the projected life of the equipment application.

Based on the above assumptions

$$C_T = 2(PR)+0.5(2)(PR)(L-4) \quad (15)$$

where:

PR = Unit Price of the Equipment

L = Life of the Equipment Application

$$CT= PR (L-2) \quad (16)$$

The Management Consulting Directorate of the office of the Auditor General of the Navy has made several recommendations regarding the ILS cost algorithm. One of these recommendations was a change to the cost of training. The cost of training associated with the introduction of any new piece of equipment will automatically require a minimum of one senior technician to review course material, liaison with manufacturing representatives to ensure training is pertinent and to visit manufacturer's plants. This cost was assessed as at least $2000 (the assessment was made in October 1989).

Therefore:

$$CT = 2000 + 2(PR) + .5(2)(PR)(L-4) \quad (17)$$

Cost of Technical Manuals(CTM) (in dollars). The estimate of the cost to develop and print technical manuals for HM&E equipment covers a wide range of values. The cost is approximated by the following equation:

$$C_{TM}= 62.5 (P) \quad (18)$$

where

62.5 (P)= $ 62.5 per Part Number

The Managment Consulting Report recommended a change to the cost of technical manuals. The cost of technical manuals for standard hull and mechanical systems which are basically commercial items and have commercial technical manuals may be zero. However, the ordinance and electronic systems are generally government specific and their manuals must conform closely to specifications. In such cases, reproduction and changes cost $200-$300 per page, with 20-30 pages average. A one time added cost of $5000 is recommended for electronic systems.

$$CTM = 5000 + 62.5(P). \qquad (19)$$

Cost of Installation Drawing Changes (C_D) (in dollars). Assuming that equipment introduced as a result of performance specification competitive procurements meet only those functional requirements of the application, it is reasonable to assume variations in form and fit will exist between the original equipment and the competed equipment. Differences in these variables will result in the need for installation drawings revisions at an estimated $1000 per drawing so:

$$C_D = 1000(CL) \qquad (20)$$

where:
CL= Number of Classes of Ships Receiving Equipment

Cost of Configuration Control (CCC) (in dollars). Identification of equipment is an important factor, and although this cost may not represent a great expense, it must be considered in the evaluation of competitive procurement quotations.

$$CCC=2O(POP) \qquad (21)$$

where:
POP= Number of Pieces of Equipment Competitively Procured

Cost of Testing (COT) (in dollars). One of the basic premises of this model is that procurement specification is a performance specification. The implication is that performance testing is necessary to assure product conformance. Costs associated with testing are integrated into the competition quotations. The option to waive testing requirements can be made by the Government. In view of the above, no performance testing costs need to be developed in the cost competition analysis. Therefore:

$$CQT=O \qquad (22)$$

Cost of Planned Maintenance (CPM) (in dollars). Although Planned Maintenance (PMS) is an integral part of ILS, consideration in the economic analysis related to competitive procurement is negligible. Therefore:

$$CPM= \$500 \qquad (23)$$

The model for HM&E components is summarized below.

$$C=950+ 193.75(P) + 112(P) (L) + (PR)(L) +lOOO(CL) + 2O(POP) - 2(PR) \qquad (24)$$

where:
C= Cost for competitive procurement to performance specifications (in dollars)

P = Number of parts in the original equipment
L = Lift cycle of the equipment in years
PR = Price of the original material (in dollars)
CL = Number of classes of ships receiving the equipment
POP= Number of equipment competitive procured

Consider a competitive procurement of the same dehydrators to support installations for 1986, 1987 and 1988. There are currently 199 installations of the dehydrators'in the fleet with a requirement for 88 additional installations during 1986 through 1988. In order to logically evaluate the potential savings to the government through a competitive procurement, it is necessary to develop the hidden costs associated with the introduction of an alternate design from the competitive procurement.

Given that:
P =58 (Number of Parts in the Original Equipment)
L = 20 (expected Life Cycle of the Equipment)
PR = $14,160 (Price of the Original Equipment)
CL = 5 (Number of Classes of Ships)
POP= 88 (Number of Equipment)

Substitution of the given values into the equation yields

C = $403,747.50

This value of C represents the hidden costs to the Navy if the dehydrator is awarded for an alternate design. Accordingly, it is recommended that, in review of quotations received relevant to this procurement, only those quotations for alternative designs where the quoted contract price is more than $400,000 less than the original equipment manufacturer's quotations be considered for award.

This model is followed by the Navy, in new construction and acquisition contracts, as in LHD- 1, AOE-10, and LX class programs. It is also used by contractors who evaluate the life cycle cost based on their data, so as to make a bid.

<u>The Standardization Candidate Selection Criteria Model </u>(4)

The Standardization Candidate Selection Criteria (SCSC) model offers big benefits. The purpose of this model is to provide for a conservative, objective method for ascertaining the economic benefits of HM&E standardization. The techniques used are intended to provide a framework for prioritizing functionally similar equipment types that show the greatest potential for standardization savings. This model will facilitate a logical and consistent criteria to be used to objectively evaluate nominees for standardization efforts. The model is divided into four phases.

Phase 1: Equipment nomination- Develops procedures to stratify nominated equipment types into functionally similar groupings with standardization potential.

Phase 2: Economic analysis- Nominated equipment groups arc analyzed according to potential economic savings from standardization efforts.

Phase 3: Design selection- After an equipment group has been identified as having substantial economic merit for standardization, an analysis is conducted to determine the optimum method for achieving design standardization.

Phase 4: An analysis to rank those groupings that have passed the evaluation criteria of phases 1, 2, 3.

This model was used for the Navy Standard Titanium fire pump (described later) and is currently not used due to the lack of a major equipment standard design program. It would be valuable in case the Navy decides to standardize other equipment, for example compressors.

The model evaluation criteria will be presented for each phase followed by an example, such as the centrifugal fire pump presented later, which will illustrate practical applications of the method discussed.

Phase I: Equipment Nominations. This phase is designed to focus the range of nominated equipment types into functionally similar groupings.

The first step in Equipment Nominations is to nominate the equipment type. Nominations for HM&E equipment standardization may be developed from a variety of sources; (e.g. NAVSEA, NAVSUP). Each nomination source will have had experience relating to the equipment nominee that indicates a need for equipment standardization. In addition to these sources, a quantitative method for nominations has been developed to identify equipment groups on an Equipment Category (EC) and Lead Allowance Parts List (LAPL) level, which ranks equipment types according to the commonality of primary equipment performance characteristics within a LAPL. The resultant groups provide for potential standardization candidates based upon the number of APLs that arc identical in the primary characteristics selected. This method is called the Standardization Benefits Analysis (SBA). The SBA also contains a model for conservatively estimating the ILS costs associated with APL proliferation.

For example, Equipment Category 01 pumps were examined by the model, using the previously discussed methodology. A report was developed that showed the number of APLs and the equipment population by LAPL that compared in the capacity performance characteristic, the pressure performance characteristic, and the capacity and pressure ratings combined. The results showed that there arc several LAPLs (or equipment types) that had sufficient commonality to warrant further investigation.

The second step in Equipment Nominations is to identify LAPLs associated with equipment type. Once an equipment grouping has been nominated the LAPLs that generically define the equipment group must also be identified so that only similar equipment are examined for standardization.

After the review of the SBA for EC 01 (pumps), LAPL 0l-011 was selected for standardization based upon the high number of APLs and the equipment populations for that LAPL. The LAPL 01-O11 is defined as Centrifugal Fire Pump.

The third step in Equipment Nominations is to stratify LAPL. The LAPL has to be stratified, by developing primary performance characteristic data that will further refine the nominated equipment into groups of like equipment with similar performance characteristics. AI this time, one must obtain application data for the sub-groupings. Relevant applications data for each sub-group arc defined as follows:

- APL Numbers for each group,
- Ships with APL installed,
- Ship Population,
- Manufacturer (CAGE),
- Service Application Code (SAC), and
- Ship Work Authorization Boundary (SWAB).

As an example, the primary characteristics chosen for LAPL 01-011 were capacity and pressure.

The fourth step in Equipment Nominations is to develop full parameters. After the LAPL has been stratified, the model develops full parameters that will further refine the sub-groups to homogeneous groupings. The intent is to segregate equipment groupings to a level that is functionally similar for comparison purposes.

For LAPL 0l-011, capacity and pressure ratings combined were used to identify functionally similar equipment.

The fifth step is to segregate sub-groups according to parameters. Here a further segregation of equipment is developed according to the parameter selection criteria developed. For each group, an APL introduction rate analysis is developed to show the historical population trends over the life of the APL group.

As an example using capacity and pressure characteristics, a report was developed to show the exact number of APLs where capacity and pressure combined to make exact matches. This report shows that there are 41 APLs in LAPL 01-011 with capacity rating 1000 GPM and a pressure of 150 PSI.

The sixth step is to develop the ratio of APLs to manufacturer and APL to population for trend analysis. For each homogeneous group, it is necessary to develop a ratio of the number of APLs in the group to determine if standardization will have a significant impact upon the industry. In addition, a comparison between the number of APLs introduced and population will indicate the current relative degree of standardization. In this case the CAGE ratio is approximately 5 to 1.

The final step in Equipment Nominations is candidate selection. Using intelligence gathered, one should select the grouping with the highest number of APLs with low APL to CAGE ratios that also exhibits a high level of fleet introductions in the recent past.

In the cast of pumps, the 1,000 GPM, 150 PSI fire pump has a high number of APLs, an APL to CAGE ratio of 5: 1 and has had 310 equipment installations in the last ten years. Therefore, it is considered a likely candidate for economic analysis.

<u>Phase 2 -Economic Analysis</u>. The objective of phase 2 is to provide a method that will enable an economic analysis to be performed on those equipment groups nominated during phase 1 and to provide a basis for economic comparison among candidate groups.

The first step in the Economic Analysis is to obtain NSN and related data. During this data collection stage it will be necessary to obtain the following data for each APL:

- National Stock Number (NSN),
- Unit Price,
- Planned Program Requirements (PPRs),
- Quarterly Demand,
- Average Number of Parts per APL,
- Acquisition Method Code (AMC), and

- Acquisition Method Suffix Code (AMSC).

For the case of the fire pump, NSNs were obtained for 25 of the possible 37 APLs with corresponding prices. PPRs and demand history were, on the whole, not available as the 1,000 GPM fire pump is not normally an item of supply. The average parts per APL were computed to be 23. The average price per unit was $ 44,627.

The second step in the Economic Analysis is to compute the total Projected Buy Value (PBV). In order to compute potential acquisition savings, the PBV must be determined. For this model the PBV will conservatively be estimated for a five year period. Two alternate methods will be used to determine PBV: (1) Use the Annual Buy Value formula developed by the Breakout Program for equipment that are normally items of supply, or (2) an approximation method for those equipment that are not items of supply and for which there is little recurring demand history. In either model choice, input from the Program/Life Cycle Manager will be solicited to obtain projected demand for the equipment.

The third step in the Economic Analysis is to compete the Annual Buy Value (ABV). This is computed as follows:

ABV= Annual Replacement Usage (ARU) * Replacement Price (25)

where

ARU = Planned Program Requirements (PPR) + [Quarterly Demand- (Carcass Return Average * Survival Rate) *4] (26)

After computation of the ABV, multiply by 5 years to determine PBV.

PBV= ABV * 5 (27)

PBV will be computed for each APL and summed to determine the total PBV for each group.

Total PBV = PBV for APLs 1 through N

The fourth step in the Economic Analysis is the Estimated Buy Value (EBV). This model is computed in a similar manner to ABV:

EBV= AUP * AIR (28)

where Average Unit Price (AUP) is equal to the sum of Unit Prices for those APLs with pricing information divided by the number of APLs with pricing information. Average Introduction Rate (AIR) is the total of equipment populations introduced in the past 10 years

Total PBV= EBV* 5 (29)

For the case of the 1,000 GPM fire pumps the EBV method is used :

AUP = $44,627
AIR =31
EBV = $ 1,383,437
Total PBV= $ 6,917,185

The fifth step in the Economic Analysis is to determine Potential Acquisition Savings (PAS). The potential acquisition savings to be obtained from a competed acquisition of standard design is equal to the Projected Buy Value (PBV) multiplied by the Acquisition Savings Factor (ASF) which is 0.25 to provide a conservative estimate.

PAS = Total PBV * ASF (30)
PAS = $ 1,729,296

The sixth step in the Economic Analysis is to determine Potential ILS savings. The ILS model is used to identify these costs. For the cast of the fire pump only two costs were used, the Cost of Provisioning (CP) and Cost of Maintenance (CM), with both expressed in dollars.

CP =450 + 131.25 P
P = Number of different parts

per APL = 23

CP = 6,487.50

CM = $448 (0.25) (P) (L)

L = 0.5 l/(1+1) is the arithmetic progression factor representing the annual incremental increase in NSNs over | year.

CM = $50,232

Total Potential ILS Savings, (TPIS)= Total CP + CM

Total CP = CP *Average number of parts per year(l.3) * number of years(5)

Total CP= 6,487.50 * 6.5 = $42,168.75

TPIS = $92,400.75

The seventh step in the Economic Analysis is to determine Repair Parts Acquisition Savings. It may be concluded that acquisitions of repair parts will realize essentially the same savings factor as the acquisition of the end item due to the increased quantities that will be obtained with a standard design.

TRP = Total Repair Parts Cost

RPS = Repair Costs Savings

RP = Annualized Repairs Part costs

ASF = Acquisition Savings Factor (0.25).

TRP =RP * 5

RPS = TRP * ASF

For the case of the fire pump and from the 3M (Navy's Maintenance and Material Management System) database,

RP= $1,954,084

TPR= $9,770,472

RPS= $2,442,618

The eighth and final step in the Economic Analysis is to determine the Total Economic Savings from Standardization. For the selected equipment group, the Potential Acquisition Savings (PAS), the Total Potential ILS Savings (TPIS) and the Repair Parts Savings will be added to determine the Total Potential Economic Savings from Standardization (PESS).

PESS= PAS+TRIS+RPS (31)

PAS = $ 1,792,296

TRIS =$92,400

RPS = $ 2,442,618

For the case of the pump the total economic benefits arc $4,327,314.

<u>Phase 3: Design Selection</u>. After it has been determined that pursuing a standard design is economically feasible, an evaluation criteria must be established to provide for the optimum method in obtaining the design.

The first step in Design Selection is to determine availability of technically acceptable drawings. The "ideal" situation will be when the Navy has in its possession the drawings in a competitive procurement. The Acquisition Method Code (AMC), and Acquisition Method Suffix Code (AMSC) provide the necessary methods to make this determination.

The second step in Design Selection is to obtain Engineering Support Codes. Through manufacturer surveys, information is obtained concerning the supportability of equipment or components. This information is translated to an Engineering Support Code (ESC) with the following definitions:

ESC A - Fully supported by the manufacturer, both end item and repair parts;

ESC B - Obsolecent: Repair parts support only; and

ESCC - Obsolete: No support for end item or repair parts.

The ESC will provide intelligence in determining the manufacturer's ability and willingness to sell a "standard" design.

The third step in Design Selection is to determine acceptability of the design. When the intelligence has been obtained concerning the availability of data rights and the Engineering Support Codes, each design must be examined to determine if, through past fleet use, that design has proven acceptable from the performance and maintenance standpoint.

The fourth step in Design Selections is to develop a standard design method. If data and rights are currently owned by the government, this standard design should be pursued. For those APLs that have been determined to be an acceptable design but data rights are not available, there are five options for using this design:

1. purchase of data and rights,
2. abort the project,
3. reverse engineering,
4. sole source procurement, or
5. develop new design.

The above five options must be examined from an economic standpoint and compared to the economic savings threshold developed in phase 2 to determine the feasibility of the approach. This will require negotiations with the manufacturer to obtain cost estimates for purchase of data rights and bailment.

Phase 4: Group rankings. The SCSC model is used across a wide selection of equipment to be able to prioritize standardization efforts. The economics and design selection methods are used as the basis to rank those equipment types that present the highest return on investment. Subjective factors that were not considered in the SCSC, such as improved maintenance factors and improved reliability, may also be considered in prioritizing equipment for standardization.

EXAMPLES OF SUCCESS

Several of the Navy's successes with standardization are described below, showing examples that deal with the LHD-1 class, the Navy standard titanium fire pump, and some non-developmental item products manufactured by Sperry

LHD-1 CASE

The standardization plan for the LHD-1 class was prepared to identify and describe methods and procedures to be followed by the shipbuilder to ensure achievement of effective, traceable standardization during the design and construction phase of the ship. As part of the design function, the contractor maximizes selection of equipment and components from approved lists of standard items. The plan ensured that intraship standardization requirements are included in equipment and component selection during the design phase, and that standardization considerations arc included in the selection of potential suppliers.

Obiectives. The purpose of this plan is to reduce acquisition and life cycle cost through selection of equipment and components of proven performance which are currently in Navy service with support products and documentation in place. To this end the contractor's first requirement is to achieve the maximum practical level of commonality. The contractor selects from systems, equipment and components contained in the Navy Standard Design List, the LHD class HM&E Supportable Equipment List and the Navy HM&E Supportable Equipment List. However, selection of an item on these lists does not relieve the contractor of the requirement to ensure that the item meets all requirements of the Ship Specification. The contractor's second requirement is to achieve the maximum level of interchangeability of equipment and components by reducing the number of unique items of like function installed in the ship (intraship standardization).

Requirements. Contractor-furnished equipment and components are to conform to the following.

a. Maintain commonality with equipment/components used in the LHD- 1 program.

b. Limit the range of equipment and components used on the LHD-1 class.

Provision the LHD-1 class for the maximum use of common support and training material.

d. Maximize intra-Navy standardization.

e. Require all suppliers to comply with these standardization requirements and communicate these objectives to their sub-tier suppliers when procuring equipment and components.

Procurements. Source selection evaluation criteria for vendor equipment selection includes a separate evaluation factor for standardization. This factor is weighted to assure a positive effect on vendor selection and award. Additionally, the contractor develops a standardization oriented strategy with equipment from the same vendor for follow-up ships. Efforts directed toward consolidating procurement of identical equipment/components in order to minimize the number of different equipment/components used in any one system or subsystem. The contractor makes every effort to keep the number of different manufacturers for like performance items to a minimum.

Order of selection. The order of precedence for selection of HM&E equipment and components for the LHD-1 class is as follows:

Navy Standard Design Components List (SDCL)

b. LHD class HM&E Supportable Equipment List (SEL), then

Navy HM&E Supportable Equipment List.

Non-standard equipment. The use of non-standard equipment is authorized when one of the following conditions existed.

a. There is no standard equipment and component available which meets the specified performance or design requirements, and the specified performance requirements cannot be modified to permit use of standard components.

b. The suitable standard equipment and component cannot be supplied in time to satisfy the construction schedule.

c. The selection of nonstandard equipment and component would offer a significant performance or design or cost advantage over all available standard equipment.

After the selection of a supplier, the supplier's performance must be monitored during the production phase to identify any changes affecting standardization. This control was exercised through the review and analysis of supplier data and supplier-issued drawings. Additionally, standardization personnel participated in the review and approval of supplier changes and request for deviation.

The Navy Standard Titanium Fire Pump (NSTFP).

Pumps are one of the-most common components, and one that appears multiple times at different places on board a ship. The U.S Navy population of pumps is approximately 120,000 in 8,000 different designs, with 9,000 different mechanical seals (5). The Navy fire pumps have historically been plagued with high failure rates and poor supportability. Fire pumps were procured competitively to performance requirements specified by the system designer. This resulted in a total of 190 different configurations in the fleet which created serious problems in support, technical documentation, training and maintenance. Little configuration control existed. Continuing problems of the fire pumps until 1971 were:

1. deteriorated casings,
2. high repair costs,
3. high incidence of premature failures, and
4. excessive fleet maintenance requirements.

These problems caused the Navy to create the Detection Action Response Technique (DART) program which was aimed at curing the failure. Corrective actions taken through the DART program were as follows.

1. New material was selected- Highly alloyed stainless steel (alloy 20).
2. Maintenance improvement was made by ship alteration or replacement of mechanical seals.

During the 1976-1983 period the alterations created new problems which were as follows.

1. The stainless steel alloy casing and the impeller material were failing. (Degradation of pump materials due to erosion, corrosion, galling.)
2. The stainless steel alloy presented a major repair problem in the restoration of its corrosion resistant quality.
3. The bad quality of the repair parts (supply from unqualified sources) was creating new failure related problems, e.g. off design impeller, overloads to the motor.
4. Repair quality was also poor due to the lack of adequate definition for the repairs and the proliferation of large quantities of makes and models.
5. Degradation of motor insulation resulted in shortings of the windings.

The Navy Standard Titanium Fire Pump (NSTFP) was an outgrowth of an older Navy program. Both programs were aimed mainly at improving reliability. The NSTFP program followed basic steps to:

1. improve the basic pump design,
2. standardize system design pressure and capacities,
3. procure a large production run
4. obtain rights in data,

5. develop adequate logistics support for the standard pump,
6. backfit the standard pump in the fleet on an economically justifiable basis, and
7. specify the standard pump for all new ship designs.

Many changes were developed in order to improve reliability and maintainability. Titanium, a more corrosion and erosion resistant material, was specified in lieu of bronze, nickel-copper and stainless steel. Titanium was chosen based on proven fleet performance as the U.S.S CONSTELLATION (CV 64) had a titanium pump with 10 years service (over 75,000 hrs with no failures other than bearings) and USS SEA DEVIL (SSN 664) had an ASW pump with over 30,000 hrs and no wear or deterioration. Mechanical seals replaced packing in order to minimize leakage into machinery spaces. High efficiency, sealed insulation motors provided more reliable service than the old motors. A more compact pump design was adopted which eliminated the need for component alignment and required 50% fewer parts, 30% less space, and 34% less weight. Installation flexibility was greatly enhanced due to the reduced size of the new pump. The new pump, a close-coupled centrifugal, has no bearings, uses a mechanical seal, and has provision for emergency packing. Close-coupling eliminates the need for pump-motor alignment. The NSTFP pump has a low-noise motor with thermal protection. Since these motors require sealed insulation systems, if flooded they may be operated immediately after dewatering. The pump has passed shock, vibration, and sealed insulation quality tests. Table I presents a comparison of technical data between the old and the new pump.

	NEW	EXISTING
MATERIAL	TITANIUM	BRONZE or ALLOY 20 or CU-NI
DESIGN	CLOSE COUPLED HORIZONTAL or VERTICAL	SPLIT CASE HORIZONTAL
WEIGHT AVG	1,225 Kg (2,700 lbs)	1,724 Kg (3,800 lbs)
SIZE	134.6cm X 52cm X 63.5cm 53in X 20.5in X 25in (NO BASE)	190.5cm X 5.7cm X 91.4cm 75in X 22.5in X 36in (WITH BASE)
MOVING PARTS	5	11
COUPLINGS	NO	YES
SEALS	1	2
BEARINGS	NO	2
Source: Navy Standard Titanium Fire Pump (NSTFP) 750-1000 GPM, Technical Documentation and Program Description		

TABLE I: NEW PUMP DESIGN ADVANTAGES VERSUS EXISTING PUMP DESIGNS

Review of the existing fire pump population and discussions with the fire main system designers revealed 6 different pressure/capacity combinations that would meet the majority of the Navy's 190 different configurations and the 1200 units in the fleet. Further study indicated that one pump design could meet each combination by slightly modifying the pump's impeller. This single Navy-owned design in six capacities (2839-3785 liters/min) or (750- 1000 GPM) and three pressures (6464,7757, 19030 mm hg) or (125, 150, 175 PSI), has already been installed (since 1985) in most ships of the fleet, including carriers, cruisers, amphibious ships, and auxiliaries. Except for a few minor mechanical seal problems, which are easily corrected, there has only been one casualty.

The intent of the program is to replace existing units with NSTFP's during scheduled overhauls when an existing pump is beyond economical repair. The NSTFP is available for new construction ships and has already been specified for use in applicable designs. With this gradual introduction approach, eventually all 1200 pumps in this family will be standardized and uniformly supported.

A competitive procurement for 179 pumps was initiated based on the new design and performance requirements. The procurement required full rights in data so that the Navy could competitively procure additional units and spare parts without losing configuration control. Technical manuals, technical repair standards, planned maintenance system cards and provisioning technical documentation were also provided under this contract. A follow-on contract was then competitively awarded to a second vendor for 675 units. At least two other suppliers have also provided spare parts or complete units. Table II presents the cost advantages of the new design especially when ordered in large quantities.

	NEW	EXISTING
MATERIAL	TITANIUM	BRONZE or ALLOY 20 or CU-NI
ANNUAL AVERAGE COST REPAIR-MAINTANANCE	$800 MAX	$4,500 - $12,000
PROCUREMENT COST/UNIT LOTS OF 10-20	$55-65 K	$85-97 K
PROCUREMENT COST/UNIT 179 UNITS	$26 K	
PROCUREMENT COSTS/UNIT 675 UNITS	$21 K	

TABLE II: COMPARATIVE COST ANALYSIS

Feedback from the fleet, shipyards, and repair facilities further indicates that the pump fully meets the goals it was set to meet. This program provided the Navy with a most reliable pump which due to the standardization and the large orders has a low procurement cost, and reduces the life cycle cost.

The NDI As An Acquisition Method Of Equipment

The use of nondevelopmenta1 items (NDI) to satisfy defined requirements is a preferred (especially in the Army) acquisition alternative and is one of the better methods to acquire equipment in an orderly expeditious manner.

In February 1989 President Bush directed the Secretary of Defense to improve the procurement process and its management practices to get better defense value for the taxpayer's dollar. Secretary Cheney proposed the Defense Management Report. Two of the key elements of the report are relevant. The first is to achieve the highest degree of standardization possible. The second is to maximize procurement of non-developmental item (NDI) products.

The NDI program is a program applied to all Navy programs that result in the procurement of hardware or software and is a principal means to satisfy the material needs of the Navy. NDI material is defined to be already developed and available hardware or software that is capable of fulfilling Navy requirements, thereby minimizing or eliminating the need for costly, time consuming Government-sponsored research and development (R&D) programs. NDI is usually off-the-shelf or commercial-type products, but may also include equipment already developed by the Navy, other military services or foreign military forces. Changing economic and political conditions, coupled with rapid technological advances in the commercial sector, dictate that the Navy explore NDI solutions and implement those solutions when it is in its best interest. Earlier NDI definitions have resulted in two general categories and a third level of effort, as described below.

a. Category A. This category applies to off-the-shelf items (commercial, foreign, other services) to be used in the same environment for which items were designed. No modification of hardware or software is required.

b. Category B. This applies to off-the-shelf items to be used in an environment different than that for which the items were designed. Modifications to hardware or software are required to militarize and/or make the item more rugged.

c. Third Level of Effort. This approach emphasizes the integration of existing/proven components and the essential engineering effort to accomplish system integration.

This strategy requires a dedicated research and development effort to allow for system engineering of existing components, for software modification and development and to ensure the total system meets the requirements.

The NDI program is intended to be an institutionalized consideration during the acquisition process to such an extent that its use would be a rule and not an exception, but full compliance with performance objectives is required. In the cases where less than full compliance with performance objectives is justified, then data should be provided to permit an informed trade-off analysis of performance versus cost and schedule.

Advantages - Disadvantages. The whole idea of the NDI program requires an in depth market investigation to determine if there is a product in the market that satisfies the requirements and to gain enough data in preparation of the request proposal. If the NDI approach cannot be used, the investigation serves to identify components that could be used in a development solution either by the Navy or by the producer, or even in a combined effort. The advantages of such an acquisition strategy are:

low technical risk,

a. reduction of program cost,

c. probable shared R&D costs,

d. reduction of time-to-field, and

e. increased Navy strength as a customer in the commercial market.

An important advantage of NDI is the reduced acquisition time, which is accomplished, in part, by minimizing Navy testing. When there are existing data by the contractor or the producer and these data provide reasonable and acceptable answers to the test issues and requirements, there is no need to extend the time of test and the Navy can experimentally install an item on board a ship to further evaluate its performance.

Even though the NDI program provides many advantages, it also presents some unique problems to the logistics and support communities.

a. Reduced lead time means less time to prepare organic support

b. Supportability issues must influence source selection since design is already established.

c. Standardization goals may be adversely affected.
d. Suitability and adaptability of existing support elements must be determined.
e. Suitability of interim contractor support should be determined as part of the requirements formulation.

Logistics and Support is surely the most difficult aspect of NDI program acquisitions as it needs day to day top management attention, both by the developer and the design managers. Federal regulations require that competition be maximized on everything that is procured but provides specific circumstances which allow the purchase under other than "full and open" competition. In addition, there is some flexibility that allows up front decisions permitting non-competitive, smart buys when a complete and effective analysis has been done. Naturally these exceptions should be clearly justified. First, it must be shown that everything feasible to maximize competition for the life cycle cost of the system in question has been done, and secondly that the resulting decision is in the best interest of the Navy given the data and facts available.

The NDI program created, at least in the beginning, unique challenges for the acquisition as well as for the supply community. The basic equipment requirements placed by the Navy tend to idealize the equipment. This is one reason why the NDI solution took so much time to be implemented, as both threat assessments and resource practices tend to select the most advanced technology in the equipment solution. Cost constraints over the last several years and the recognized need to speed up the processes have changed the trend. The design managers have begun to negotiate and relax specifications whenever possible. Suppliers and developers have many opportunities to review, evaluate and challenge the requirements, and assist the design manager in establishing a more realistic requirement.

The design manager is also striving to involve industry early by inviting their participation and review during requirements formulation. This means staffing the drafting requirements documents with industry and letting them know early what is needed.

The end result is that the Navy is becoming a smarter buyer. The Navy knows better what is practical and can intelligently trade-off specifications for what is available in the market place. The design manager is becoming an honest broker, bringing the Navy and the industry together to arrive at the best match and fit, with the Navy having the final word. A challenge for the Navy and the supplier is supportability. It does the Navy no good to deliver an item that cannot be repaired due to lack of spare parts. Another concern is availability. The NDI must represent current technology and be available to the Navy, without future configuration changes, for the intended life cycle. The Navy does not want to select an item only later to find that the vendor intends to discontinue or significantly upgrade that item with enhancements that are not needed.

The decisions to acquire a NDI or a commercial component is the end product of a process, which includes risk assessment and cost benefit analysis. The NDI program can be viewed as one more strategy for tailoring life cycle processes so the Navy can extract the maximum from what is already in the market place.

The Perspective of the Suppliers

The commercial market was reached through the NDI program and the desire of the Navy for cost reduction. The commercial market started exploiting the chance it was given to increase sales by having a big customer such as the Navy. There were numerous cases where products followed the process which is described below:

a. they were made for commercial use;
b. they were introduced and tested in the commercial market; and
c. they were either used with no changes in the military or their use was extended, through several changes, in the military.

A typical example of a commercial project that was used on board a Navy ship was the Integrated Bridge. A firm has developed a modem and comprehensive approach to commercial bridge operation, which essentially improves the way in which essential data is communicated, manipulated and displayed. The new approach is a significantly faster operation that is more efficient than a conventional system. At the same time it is based on standards which have been proven in the maritime industry, as well as in aerospace and information systems fields. The bridge model offers a complete turnkey service including design, installation, commissioning and support.

In developing the bridge system, the designer has researched and carefully considered the requirements of the commercial marine customers. Many of the potential customers visited the contractor's facilities to view developments and offer comments and advice. The most important requirements which were identified by company and customers were:

a. improved operating efficiency, consistent with safety and reliability;
b. better information processing on the bridge, both to enhance operator judgement, and to improve the overall control of business performance;
c. better control in the shore office; and
d. optimum lifetime cost of installation.

Modem techniques allow equipment to be networked together to derive maximum benefit from the fusion of data from many sources. This focused data can be accessed through integrated display and control consoles which are parts of the new integrated bridge. The objectives for the integration of the bridge model were:

a. system solutions to increase mission reliability,
b. enhanced decision making capabilities,
c. centralization of information,
d. reduction in manning requirements, and
e. provision for future enhancement

The bridge not only has the advantage of physical and electrical integration but also is connected through fiber optic media, has flexible interconnectivity, and most of all, modular installation. Each of these characteristics creates a number of advantages for the system.

Physical integration combines controls and indicators by operational function and:

a. enhances decision making,
b. reduces manning and watch complexity, and
c. eliminates individual remote displays repeaters and similar redundant equipment.

Electrical integration is the use of local area networks to connect shipboard equipment and enables:

a. broad data exchange,
b. minimum equipment interconnections,
c. automatic error detection and correction.

Fiber optic media is a cable system of high information content which allows high data rates, saves space and weight.

Flexible interconnectivity, is the connection of digital systems built to multiple input/output (I/O) standards and:

a. interconnects networks, and
b. interfaces networks with variable I/O converter modules.

Modular installation makes maximum use of prepackaged, prehamessed, rack-mounted equipment prior to installation and:

reduces installation costs,
a. reduces damage and testing, and
b. locates for best equipment life and maintainability.

The firm has developed and introduced specific operating parameters to accomplish a better bridge such as:

a. touchscreen operation,
b. minimum operation workload,
c. enhanced data presentation,
d. display resolution,
e. bridge data communications, and
f. ship-to-shore data link.

<u>The main elements of the system.</u> The bridge is configured from six system elements, each of which performs defined functions relative to the operations of the vessel or the communication with the shore. These six elements are:

1. Shipboard Token Ring Data Network, the Seanet,
2. System Sensors,
3. Navigation System,
4. Steering Control System,
5. Vessel Management System, and
6. Suterlight Communications System.

The modem and comprehensive approach has been related-directly to customer requirements and is providing operational benefits, including:

a. improved efficiency and productivity,
b. quicker assimilation and judgment of data,
c. reduced operator fatigue,
d. more timely, accurate information on the vessel and in the office,
lower support cost,
f. enhanced spatial arrangement, and elegance.

The Integrated Bridge System (IBS) is installed or is being installed on more than two dozen vessels throughout the world. The commercial success, the advantages of the system, as well as the persistence of the developer (the company paid all costs of placing the IBS aboard the ship) persuaded the Navy to try the new bridge on the newly constructed carrier, U.S.S Abraham Lincoln (CVN-72). The decision of the Navy to keep the IBS on board the carrier in addition to the old bridge configuration and the ease of acceptance of this new system by the ship's crew demonstrate that the use of commercial grade equipment on Navy ships is possible and probable in the future. Shipyards, will also benefit with access to a turnkey supply of an integrated, tested bridge unit, reducing installation and commissioning costs, and saving time in the new build process.

Other Examples. The same company was asked to bid for some electronic equipment on the TAGOS-19 which was then under construction. The TAGOS was to have a doppler speed-log for which the specifications were similar to a unit from another company, which was supposed to supply the TAGOS-16, 17, 18 with the same unit. The firm's engineers noted that the Sperry SRD-421 two access speed-log could be used instead of the other having the same characteristics at half the price. The company made the bid and won the contract. Their speed-log had to have a binary output and their engineers had to design and add a new card to fit in the same rack with other electronic equipment. The success of this design which was an off-the-shelf commercial equipment with a slight change made in conjunction with an Engineering Change Proposal (ECP) for future ships; the firm installed the SRD-421 speed-log in other TAGOS ships as well as in other auxiliary ships. The Navy saved money by using a commercial design with a small alteration.

This developer also made an effort with the Navy to create more uniform Gyrocompasses. The MK-19, MK-23 and MK-27 electronic gyrocompasses have been used on U.S Navy and other countries' naval ships since the early 1950s. The MK-19 supplies combat ships with ship's roll, pitch, and direction information for navigation and combat systems alignment. The MK-23 supplies auxiliary ships and MK-27 supplies small boats with ship direction information for navigation. In response to changing fleet requirements, those gyrocompasses have been altered into many different configurations. There are more than 50 configurations of the MK- 19,4 of the MK-23 and 20 of the MK-27. Although similar, these 74 configurations are not interchangeable.

Problems started surfacing with these multiple configurations when foreign home ports and extended overhaul cycles became economic necessities. With foreign home porting, worn gyrocompasses have to be exchanged with ones that have been overhauled in the United States because foreign shipyards do not have gyrocompass overhaul facilities. It is very difficult, if not impossible, to obtain matching configurations in these instances. Extending ship's overhaul cycles beyond 60 months has thrown them out of synchronization with gyrocompass overhaul cycles. Worn gyrocompasses must be exchanged and matching is nearly impossible.

One of the solutions would be to stock at least one of each of the 74 configurations in the Navy system.

The cost would be prohibitive for this impractical solution. The best solution is to reduce the number of configurations by consolidating their differences.

NAVSEA approved design changes consolidating all existing MK-19 models into four configurations, which have been installed on ships since 1990. The master compass and control cabinet of each upgraded system is calibrated together, assigned identical serial numbers, packaged in one container and given one NSN. This consolidation eliminates many system casualties caused by substantial performance of mismatched units. The MK-23 and MK-27 will be overhauled beginning in 1990 and updated to one of two configurations depending on the equipment carried aboard their ships.

Consolidation costs will be modest because the work will be accomplished during regular overhauls, cutting installation costs. Also the volume involved allows for an assembly line-type of operation. In addition spare gyrocompasses from decommissioned ships will be overhauled and placed in the supply system to be available for turn-ins. Going from 75 to 9 gyrocompasses configurations is simplifying logistical support and is resulting in more reliable operational performances of all systems.

VISION AND COURSE OF ACTION

Externally the Navy is involved in many efforts related to standardization including

a) Ship Production Committee - Panel SP-6, Marine Industry Standards
b) ASTM Committee F-25 *on* Shipbuilding Standards
c) Technical Committee 8 on Ships and Marine Technology of IS0 (through the Technical Advisory Group within ANSI).

Internally the Working Group for Navy Standardization (and related Steering Committee) has existed since 1987.

In addition, there is significant effort related to standardization from the NAVSEA Affordability Through Commonality (ATC) team. The team was initiated in January 1992 by RADM Millard Firebaugh (NAVSEA 05, Ship Design and Engineering Directorate). The original charter of the team was to identify specific commonality approaches with high potential for improved affordability, and to quantify the potential cost benefits on a “total cost of ownership” basis (acquistion, life cycle support, and infrastructure). This effort is intended to serve as a foundation suitable to precipitate a fundamental change in the way U.S. Navy ships are designed, built, and supported: the use of common modules across ship classes, enabling a build strategy of rapid assembly of large subassemblies. These common modules are seen as the enabling action for improved standardization, as well as improved producibility. The team should complete its study phase in FY 92. In FY 93 the team will transition to a fully funded program responsible for identifying modules based on fleetwide systems engineering, designing and building prototype modules, and overseeing introduction of the common modules into new ship design and construction.

The Navy needs a comprehensive on-going approach to standardization utilizing an interdisciplinary organization with the necessary resources to carry out its work. In terms of a data base, HEDRS will serve an excellent foundation for future efforts. Tools will be needed to set priorities and to evaluate alternatives. The models described in this paper are a good start. Further calibration and refinement would be useful. The past Navy successes should be systematically reviewed for lessons learned. The ATC team may be the catalyst to start and coordinate future Navy activities related to standardization/commonality.

The future Navy vision should consider the future of the industrial supplier base. In recent years contracts for components have been recompeted on a regular basis with dual sourcing often being the objective. With the steady decline of the supplier base, the authors recommend a shift to long term contracts with high volume production runs. As much competition as desired would occur before the selection of the contractor. The choice of a technically-qualified vendor for a long term contract (either with high volumes stated or with future options) would be along the lines of a quality partnership as described in the Deming principles. With such a contract in hand a vendor could focus on improving the efficiency of manufacturing a particular component.

There is nothing particularly new or radical about this suggestion. In the construction of the FFG's in the early 1970's, the lead yard essentially established a subsidiary to choose and order about 45 different components with options for the entire class of over 30 ships to be built by three different shipyards. The follow yards were not forced to purchase from the lead yard. However, sharing of the financial incentives derived from using the options negotiated by the lead yard made such a course of action in the best interests of all concerned. All components ordered in this way had all necessary testing requirements fulfilled by the lead yard.

Another aspect to be considered is the size and scope of the items to be standardized. The methodology used to standardize a valve can be adapted to look at a section of a ship or module, such as the superstructure, galley area, etc.

Another basic part of the overall vision is whether components can be standardized that would be on both naval and commercial ships. The Mobilization/Sealift ships and Jones Act tankers might be two types of ships that could have some common components.

If the U.S. private shipyards plan to compete in the world market, they might consider elements of the European E3 Tanker Project (6). Five major shipbuilders from four countries (i.e., Astilleros Espanoles of Spain, Bremer Vulkan AG of Germany, Chantiers de l'Atlantique of France, Fincantieri of Italy, and Howaldstwerke Deutsche Werft of Germany) have joined together to design and build tankers that are Ecological, Economical and European (i.e., the 3E's). Each of the yards will specialize in one of the following areas in developing their standardized ship designs: naval architecture, structure, machinery, ecology and procurement. With a series production order the workload can be distributed among the partner yards.

The U.S. maritime industry can benefit greatly from further emphasis on standardization. The U.S. Navy has the opportunity to build on its successes to date to help lead the way in this area.

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The Shift to Formalized Shipbuilding Standards

No. 6A-2

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ABSTRACT

In today's shipbuilding environment it is important for United States (U.S.) yards to adopt a philosophy of constantly improving systems of both production and service. For years our industry has depended upon a "captive market", that of the U.S. Government. With present cut-backs in military spending the U.S. shipbuilding industry must become a competitive force in the world marketplace. To achieve this goal there are many areas our industry must address; one of these are implementing improved shipyard standards. Time and again U.S. yards "reinventing the wheel" as they face a new contract, while our foreign counterparts have well known, commercially viable National Standards. The lack of such standards in the United States, be they internally generated by an organization such as The Society of Naval Architects and Marine Engineers (SNAME) or adopted from an internationally recognized body, such as the International Organization for Standardization (ISO), is an area that must be addressed by our industry if we are to remain competitive in today's marketplace.

INTRODUCTION

Every shipyard has a standards program. It may not be definitive or conventional, and may exist at the lowest levels of the shipyard organization, but every shipyard does have a standards program. It can be something as simple as two laborers over a brown bag lunch deciding how they will work together on a fitting problem. They may have ignored, or not understand how their actions affect the company, they have developed a new standard. It may not be a definitive program, it may not be conventional, but every shipyard has a standards program.

HISTORY

Trinity Marine Group's (TMG) formal Standards Program began in February of 1991; so this group of yards are very close to the theme of the SNAME 1992 Symposium "Imnlementing Innovation: The Challenge of Change." Before the process of how this group of yards develops its standards some understanding of how this group grew into ten shipyards is important. The history will help in understanding why the methods used to implement a standards program were chosen.

Fig. 1 Shipyard Locations

Most of these yards are located along the Gulf Coast. The early growth of each individual yard can be directly attributable to the growth of offshore oil needs, the "Oil Patch." As the Oil Patch prospered, so did local shipyards.

In the early 1980's when the oil boom went bust, so did many shipyards along the Gulf Coast. Long term investors with the patience, foresight and money, seized an opportunity and saved many struggling shipyards from financial ruin. While this consolidation of the industry is good it was not without problems. Suddenly, yards that were once fierce competitors, were now suppose to act as partners under a common banner. One of management's earliest goals was to make this substantial group of facilities function as a team. This was not always an easy process; one does not go from competitor to team member overnight.

The experiences of the early 80's taught a valuable lesson to Oil Patch yards; never depend on any one sector of the marine industry for survival. Off-shore support vessels were the bread and butter of these Gulf Coast yards. Each depended on the Oil Patch to supply them with the orders needed to survive. Today that is no longer the case. Since the early '80 these shipyards have diversified their product base and today build in composites, aluminum or steel for clients as diverse as individuals wanting mega-yachts to the U.S. government to commercial interests. This diversity can been seen in Fig. 2.

THE CHALLENGE OF CHANGE

Such diversification of product base brings enormous challenges to a standards program. This means standards must constantly evolve to survive. This is true for small yards as well as large shipyard groups. Programs that have become static, by their very definition, are going nowhere. A standards program must be dynamic to take advantage of advances in new materials, new methods, new technologies, even new regulations. The world is full of change and shipyards must change with it or be left behind. Change is inevitable, if not embraced and managed the changes that take place will simply leave behind, those individuals, those companies, and those industries which resist change. The challenge of change is to both embrace it and manage it, and yet not change simply to be changing. Change without an overall purpose becomes chaos.

PURPOSE OF STANDARDS

All shipyards are striving to achieve certain goals they consider important. At the same time they need to preserve aspects of their particular

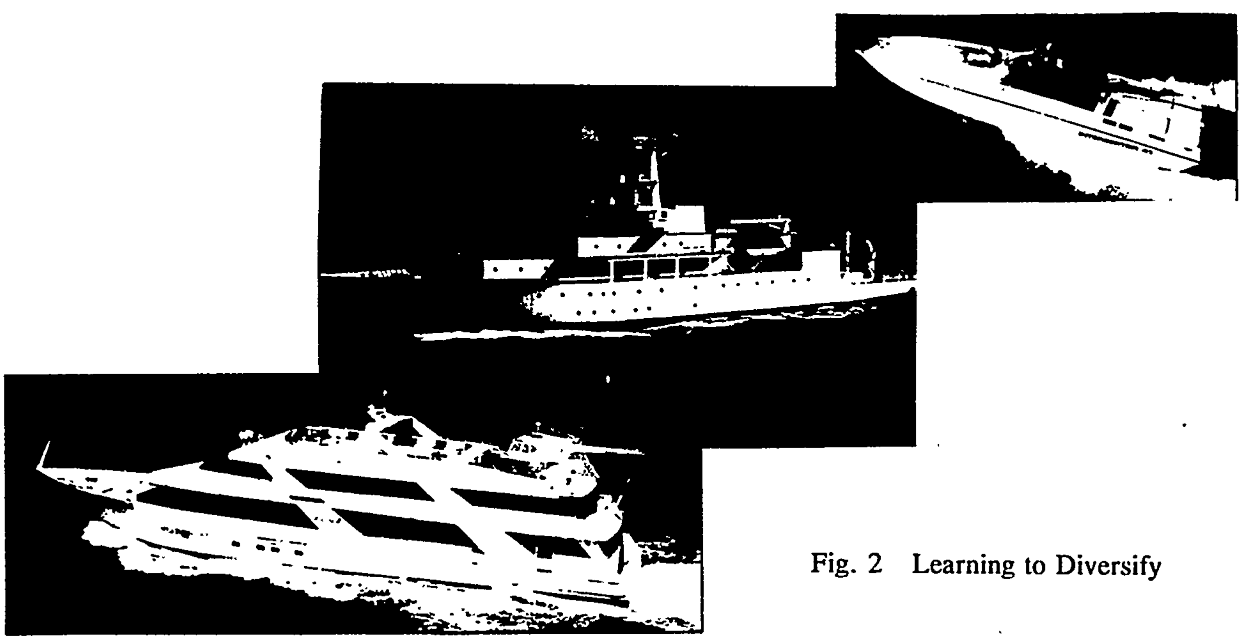

Fig. 2 Learning to Diversify

business which give them a competitive advantage, in the marketplace and of course, avoid problems where possible. The main purpose, and anticipated primary benefit to be derived from a formal standards program, is improved communication between the various shipyard disciplines. This improved communication will be an important factor in the accomplishment of these goals and desires.

GOALS TO ACHIEVE

By improving inter-departmental communication, overall effectiveness improves. People must do the right things, at the right time, in the right way to reach and maintain peek effectiveness. Effectiveness translates into productivity.

All shipyards have a rich pool of "corporate knowledge" that should be tapped. Most Gulf Coast shipyards have a heritage of father teaching son the boat building business. That is a legacy shipyards should strive to utilize, and foster as this is an important resource for the future of the shipyards, their employees, and greatly benefits the shipyards customers.

Shipyards of course, want to preserve certain things. Most yards have a long tradition of building quality vessels and in our day of increased competition quality is not an area anyone can afford to slight. Shipyards also want to preserve the lessons learned. Yards in the Gulf Coast area have built tens of thousands of vessels of various types; and during this process these yards have learned a good deal both from their successes and failures. Intelligent management definitely want to preserve those lessons learned so they are either repeated or avoid as prudence dictates, and a standards program is one way to preserve this knowledge.

There is also one thing that must be avoided in the development and implementation of a standards program, "Turf Wars." Many times yard personnel are all for standards, as long as they do not have to change the way **THEY** build or do something. This is the way standards are approach so many times, we are willing to comprise if "...we can do it our way." To avoid "Turf Wars," it is important for all involved in the process to approach standards with an open mind, and that open mindedness is maintained.

ORGANIZATIONAL APPROACH

Many shipyards have set up independent standards groups. There is absolutely nothing wrong with this approach, however, since a prime objective was to avoid "Turf Wars", it was decided not to establish an independent group that might add to the problem. Instead a Standards. Committee was set up.

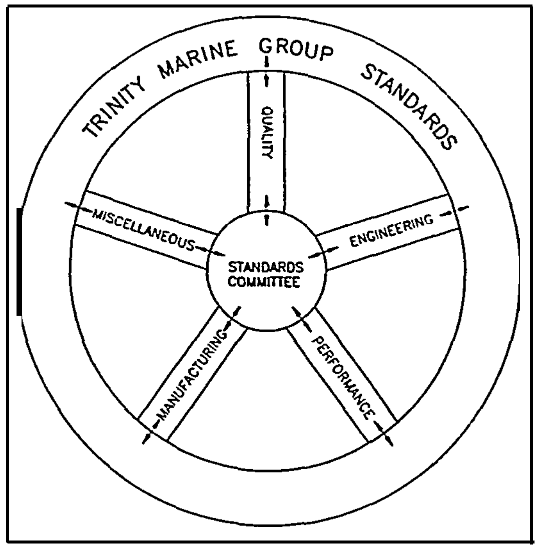

Fig. 3 Standards Organization Model

The idea behind this organizational structure, is to set the Standards Committee as a focal point, not a hierarchical organization with other people reporting to the standards group. The Standards Committee is to act as a forum for people to exchange ideas.

As figure 3 shows, information flows both ways, both into and out of the Standards Committee. By working as a team; objectives will be accomplish allowing development of a total body of standards useful to the shipyards and its customers,

The membership of a Standards Committee can be fluid. The advantage of this approach is to allow those with the appropriate experience to maximize their contribution to the organization. The group's basic structure consists of five people the Chairman, Engineering Manager, Operational Manager, Yard Manager and Warranty Engineer. Each of these people were chosen for a particular purpose.

The Chairman acts as interdepartmental facilitator. The important objective for the chair is to see that the process stays on course and that input is received from all those affected by the proposed standard.

The Engineering Manager acts as regulatory expert to make sure no design or production standard under development violates the many regulations shipbuilders face. The engineering department is responsible for writing/producing the standards along with maintaining the standards library and acting as publisher and distributer for standards within the company.

The Operational Manager's purpose is to make sure any standard developed are reasonable and buildable. This person, because of the position, has a global view of what each yard's capabilities are and must be assured that what has been designed is not the perfect solution that can not be built. This process of feedback is important to avoid wasted effort.

The Yard Manager was initially a planning sore spot. To pick one manager from a group of ten could have easily lead to the "Turf Wars" that are so counterproductive. Yet the viewpoint of a Yard Manager was critical to insure acceptance by the production group. Initial concerns proved to be unfounded, the Yard Manager has turned out to be one of the most valuable contributors to the standards process and there is a definite advantage to having the Yard Managers involved. Rotation of Yard Managers so each can serve on the Standards Committee is a definite possibility.

The Warranty Engineer is a hands on individual who actually fixes problems. What can happen with a standards group is they develop a standard that looks good on paper but simply does not work, for one reason or another, in the "real world. " Without some mechanism in place the standards group gets no feed back and it is difficult to expect a problem to be corrected if the problem is not known to exist. The Warranty Engineer is able to provide the needed feedback to correct, or even improve, existing standards.

WHY A COMMITTEE?

There are certain advantages to having a committee. There is a diversity of knowledge, the committee is looked upon as an impartial body, since each member will naturally see things from a slightly different viewpoint there is the advantage of collective judgement, and as the team begins to function together an open mindedness to different methods arises.

The goal of this team building effort is to achieve synergy. Synergy is simply one plus one equals three. Doing more with less. The results are greater than the sum of the parts.

Another added advantage of having a committee, instead of an independent standards group, or a group attached to engineering, which is the more traditional approach, is that a standards committee does not need to justify its existence economically, the activities of the Standards Committee become an overhead function. Original estimates indicated about 1.5 million dollars, would be required to set up a special group to do standards; most of that as one time charges, to hire the necessary people, set aside office space, install computers and add support staff. The decision against this approach saved $1.5 million for use elsewhere.

THE PROCESS:

At present the committee identifies needs for standards and then proceeds to develop them. This is viewed as a temporary phase, since it is desirable for most requests for standards to come from yard personnel. To date about fifty (50) requests have been received from the yards for standards. This is more than enough to keep the Standards Committee busy for the near future however; it is only a very small portion of the overall picture of needed standards within the group.

To achieve effectiveness every request for a standard received by the committee, is given a classification code. This is done by using the classic Pareto Principle. Vilfredo Pareto was an Italian economist, who was first to recognize that 80% of the wealth in Italy was controlled by 20% of the people. The Pareto principle has become known over the years as the 80/20 rule. This 80/20 rule is used to concentrate on, and receive maximum results with minimal effort.

When a proposed standard is received the Standards Committee group it into one of three classes, as shown in Fig 4.

Pareto Principle
(80/20% Rule)

Concentrate on maximum results with minimum effort.

Proposed standards grouped into three (3) classes.

A. Big Results - Little Effort
B. Avg. Results - Avg. Effort
C. Little Results - Big Effort

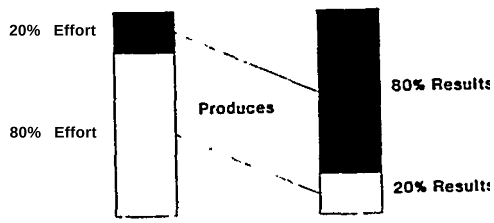

Fig. 4
Pareto Principle Applied to Proposed Standards

A proposed standard which is classified as being an "A" standard, is one from which big results are expected with very little effort; a "B" classification means average results are expected with average effort needed and a "C" classification standard is expected to give little *results* in view of the effort needed to accomplish the standard. There is no reasonable way of actually gauging in advance, the result, or the effort, that a particular standard will require so classifying proposed standards is a judgement call on the part of the Standards Committee.

After assigning a priority, based on the preceding classification method, the formalized process needed to both develop and reach final approval begins as shown in Fig. 5. This development and approval processes is a complex cycle of interconnected contacts and communications designed to insure that all those that the standard will affect can participate in its development and that maximum feedback is obtained by the Standards Committee.

This process is designed to enhance communications within the group - not get standards done quickly. The participation process is very important since standards not agreed to will quickly die without constant policing.

Fig. 5 shows this flow which starts with the need for the standard being identified. From there it goes to the Standards Committee where it is logged in, and prioritized. The standard is then assigned to the necessary people for review and comments. The Standards Committee then receives the reviewed standard and makes changes as needed; a draft standard is issued and, as shown in Fig. 5, goes round and round until the draft standard is finally "approved" by the Committee. This "approved" standard is then distributed to yard personnel for further review and comments. The comments received from the individual yards are incorporated into the proposed standard and the process begins again. This cycle continues until the concerns of those involved are addressed.

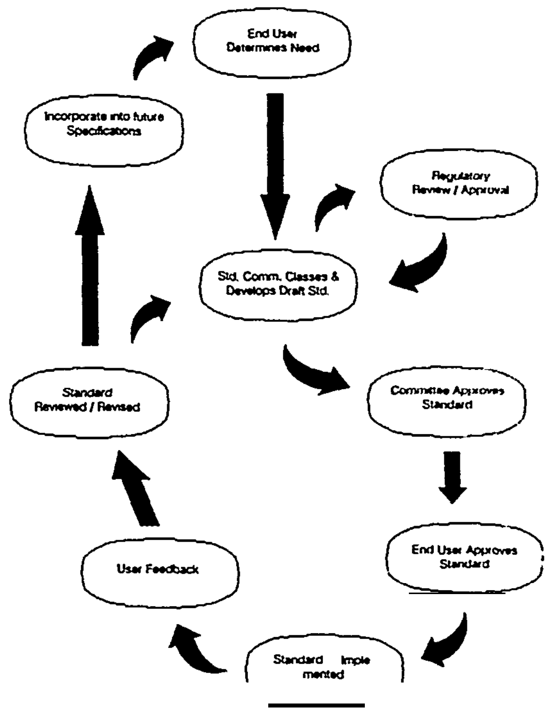

Fig. 5
Standards Development and Approval Process

This process is designed for maximum input from affected users and is critical for acceptance. Such an elaborate system helps in avoiding the "Turf Wars" which can so easily spring up.

With ten shipyards even the simplest things can cause problems. One of the first standards needed was the method used for determining Molded Lines.

Molded lines, on the surface, are not highly technical; they are however; an important communication tool. SNAME has produced a standard for molded line configuration that is excellent but as mentioned before, with many yards coming from different backgrounds and having different methods of doing things, over the years each developed unique standards for molded lines.

With the advent of Computer Aided Design and Drafting (CADD), and with the primary purpose of the standards program being communications between yards, molded lines were a priority. The process was given its first real test and after a few iterations the Molded Line standard was approved. Not advanced technology but an important communication tool that did not previously exist.

APPROVALS

An important part of this standards group is the final approval process. This is where every Yard Manager, not just those on the Standards Committee, must sign the final version of the standard to show their approval. Their signature shows they agree with the standard and that they will use the standard. This is a critical part of the process as maximum participation is important.

The forgoing process would all be for naught if not for what is the most important part of any Standards Program - Executive Managements Support. This support is the only thing that will give a Standard's Program a chance of reaching its potentials. Management must see the benefits for both the yard and for their customers. Standards can help yards build vessels at a lower cost (no reinventing the wheel) and to a higher level of quality (repetitive process limits learning curve problems). Both these result in a more competitive shipyard which benefits shipyard and customer alike.

CONCLUSION

Standards are only one weapon in the arsenal needed to be competitive in today's market place. It is a discipline that can run throughout the organization and have either a positive or negative impact on overall competitiveness. A standards program is necessary to take advantage of a changing environment. The cliche that standards will limit creativity is valid only if a limited view of what can be accomplished through a standards group is taken.

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Design/Production Integration and the Industrial Structure

No. 6B-1

Dr. Franz A.P. Frisch, Visitor, Defense Systems Management College

ABSTRACT

The naval architect or the designer is considered as the integrator of countless subsystems into the system, called the ship. In order to integrate, he must have in the design phase the freedom to communicate with all levels of production. This communication is the prerequisite to a successful design/production integration. The freedom to communicate can be fostered or impeded by the industrial structure.

The structure itself is driven by the economy of scope and scale and by legal requirements expressing views on competition and/or cooperation. The impact of structure and law on communication is sketched in comparative form for the American on foreign ship building industry.

The scope of the paper is restricted to fundamentals.

FOREWORD

Desiring to integrate the design/production process in ship building is not necessarily new. Advantages of such integration for time and cost-scheduling are well recognized. Less recognized is that integration is not only a management function but, rather, a response to existing facts of engineering, economy and law. Engineering concerns the process of the manufacturing operation. The process, in turn, is driven by the existing industrial structure which is a consequence of economic decisions, to be made within the framework of existing laws.

The objective of this paper is to sketch an outline of interaction between the design/production operation within the framework of technical, economic and legal facts.

The scope of the paper is restricted to "concepts only," explained in a rudimentary form, enough to get me point across. The paper deals with the essence of the design/integration problem.

OBSERVATIONS

It was evident from factory (1936) and ship yard (1948) experiences that design engineers and production engineers were a team. Prime contractors and subcontractors worked as another team. The goal of those teams was to deliver the best possible product at a cost acceptable to the customer. The term "price" had a strange connotation for the European engineer and the question about design and production integration would have been meaningless, because design and production has been an inseparable entity. The engineer with a master's degree had to know design AND production and to "design for production" was so self-evident that to mention it would raise astonishment.

The first time separation of design and production was encountered in 1957 when invited to the United States to testify about European ship building before panels of the Maritime Administration (MARAD). It was surprising that one could design and specify a ship in great detail without knowing the yard and its facility where the ship was to be built. In Europe at that time, bidding documents comprised a general arrangement plan plus two-to-five pages of "specifications."

In the early '7Os, in a major claims case for the U.S. Navy, this same separation was the culprit. The problems were complex but the conclusion was simple: Claims and disputes are the consequence of breakdowns in communication between parties involved. The different interpretations of rules, regulations and events are a failure in communication. Complexity is created by uncoordinated and often contrary goals of parties involved in the game, fostered by an insufficient market and empty order books.

Slowly and after many pleasant and unpleasant experiences, it became clear, first that NO ORGANIZATION CAN BE BETTER THAN ITS INTERNAL AND EXTERNAL COMMUNICATION. This holds true for an organization as small as a family, for a factory, apolitical organization or whatever. Second, THE FORMAL STRUCTURE OF AN ORGANIZATION CAN BE AN IMPEDIMENT OR A HELP FOR THE NEEDED COMMUNICATION. Of course, the formal structure and the purpose of an organization should be harmonized and driven by the specific need for communication in a particular organization.

Military combat units are a perfect example of a perfect blend between formal structure and communication need. In most other organizations, communication is the undernourished stepchild and rather a hang-on to the formal structures designed to satisfy other criteria; i.e., value-added subdivision, ownership preferences, financial aspects and other determinants. And, here the problem starts.

VALUE-ADDED HISTORY

Every product, be it an end product or an intermediate product in a production chain, has two major cost components. First is the material (M) a particular enterprise buys from the outside and, second, is the value-added (V) representing the enterprises contribution in capital (C) and labor (L). The M/V-ratio is the first and highest indicator for the organizational structure of an enterprise, and the sum of M plus V represents the cost of the product. (Price, a different matter, is not addressed.)

Shipyard specific: In the time of the reciprocating steam engine and the scotch boiler, most shipyards were almost self-sufficient or, in modem terminology, fully integrated. They bought only plates, profiles, bars and wires from the outside and everything else, from hull to engine and boiler, were made at the yards. Hence, the M/V-ratio was often 10 percent for M and 90 percent for V.

Beginning about World War II, the picture changed as a consequence of what may be called a technological revolution: Electronic devices arrived, new propulsion systems were developed, new weapon systems invented, and so forth. The (economy of) scope of all new subsystems needed specialists in design and production far beyond a shipyard capability, far beyond the economy of scale to be built by each individual shipyard, and new subcontractor industries developed delivering new specialties to many shipyards. The yards lost self-sufficiencies and became more or less assemblers, buyers and coordinators of products of the "supply industry." As a result, modem shipyards (building U.S. Navy ships) may produce only IO percent value-added, and, 90 percent of the ship cost is material, either in subcontracted material or government furnished material. Briefly, technology reversed the make-or-buy decision from 90/10 percent to 10/90 percent.

Table I illustrates this development.

PRODUCT LEVELS

A work breakdown structure (WBS) can be developed for anything and everything, what is called a system. In turn, every WBS can be defined with six levels, (used in many DOD studies). Each of the six levels is associated with a key activity, shown in Table II.

By inspecting examples in the table, note a non-homogeneity at Level I. Obviously, a ship and an aircraft or a tank are, if considered "systems," completely different entities. Now, go to Level II. The generic term of engine or air condition could apply to ships, aircraft and tanks. This points toward the need to split the WBS, beginning with Level II into types of subsystems like:

(1) structural

(2) mechanical

(3) electrical

(4) electronic

(5) chemical.

Within each subsystem level the first indication of homogeneity may appear and exactly this is it, what leads to the existence of, for example, mechanical industries, electronic industries, and so forth. Continuing through the next levels, components and elements are again "dedicated" to types of subsystems and only at the material and raw-material levels

Table I. VALUE ADDED HISTORY

		Ship Type								
		①	②	③	④	⑤	⑥	⑦	⑧	⑨
		Lead	Follow	Lead	Follow	—	—	—	Follow	—
		TAO		TAK X		CVN	CV	SSN	FFG	CG
TABLE A:										
Line #	Item									
①	Value Added	26	22	41	39	22	37	23	10	25
②	Money Flow	67	72	49	51	21	20	21	13	13
③	Business Volume	93	94	90	90	43	57	44	23	38
④	GFM	7	6	10	10	57	43	56	77	62
⑤	End Cost	100	100	100	100	100	100	100	100	100
TABLE B:										
Line #	Item									
①	Business Volume by Definition 100%	100	100	100	100	100	100	100	100	100
②	Value Added as Percentage of ①	28	23	46	43	51	65	52	43	66
③	Money Flow as Percentage of ①	72	77	54	57	49	35	48	57	34

Notes: Line 3 of Table A is normalized to 100% in Table B.

Source: ***NavSea Shipbuilding Statistic,*** **1980**

a confluence may occur, independent of the subsystem type.

Now to the naval architect: According to the classical definition, an architect is planner of the total. The architect must understand requirements and interactions of all subsystems. To what level of detail can the architect go before being overwhelmed? This point will be addressed later.

LINKAGE MECHANISMS

The six product levels are interacting and, by necessity, interconnected. The structure of the interconnectedness is called linkage mechanisms (plural). Three distinct forms of such mechanisms exist:

- first, ONE functional (or value-added) linkage mechanism
- second, EIGHT organizational linkage mechanisms can be identified and
- third, 32 ownership linkage mechanisms.

The Functional Linkage Mechanism

The "concept" of the functional linkage mechanism is ubiquitous: It is valid for any system and any type of subsystem and, furthermore, is identical to the value-added flow of the processes through the product.

The rudimentary form of the linkage mechanism is shown in Figure 1.

Figure 1 shows the functional linkage system from top-down, similar to a WBS. On the left side,

Table II. LEVELS OF PRODUCTS

PRODUCT LEVEL	NAME OF PRODUCT AND PRODUCT DEFINITION	PRODUCT EXAMPLES	KEY ACTIVITY AT EACH LEVEL
I	SYSTEM The end product	ship, aircraft, tank, missile	Assembling system
II	SUBSYSTEM A subassembly of the end product: a major subdivision of the end product	engine, bilge, air conditioning unit, gun, avionics	Assembling subsystem
III	COMPONENT A fundamental constituent of a subsystem or an end product ; a number of elements joined together to perform a specific function and capable of disassembly	carburetor, pump, heat exchanger, audio- frequency amplifier	Assembling component
IV	ELEMENTAL A fundamental constituent of a component or a subsystem: one piece, or a number of pieces joined together which are not normally subject to disassembly without destruction	screw, gear rotor, frontwheel bearing, frame	Making element
V	MATERIAL The basic ingredient (material) from which an element is produced	fuel oil, plate, wire, casting	Refining material
VI	RAW MATERIAL The mined (or untransformed) material	ore mineral, oil extracted	Extracting raw material

Source: "Financing Defense Systems Programs", Dr. Franz A.P. Frisch and David D. Acker, *Concepts*, Autumn 1981

there is **the product** (P). This might be the ship, delivered by the shipyard at the systems Level I. The shipyard bought material M1, originated at the subsystem Level II and applied labor (L_1) and capital (Cl), or its value added to the material. Thereafter, dissolution is continued of M_1 into Level II, and so forth, until arrival at raw-material Level VI.

Turning the flow from Figure 1 around, starting with raw material (RM) as first input, and adding value-added at the mine, the mined ore as product P6 is received. Thereafter, P_6 enters Level V as material (Ms), and so forth, through the system until arrival of/at the end product (EP), the ship. This flow is shown in Figure 2.

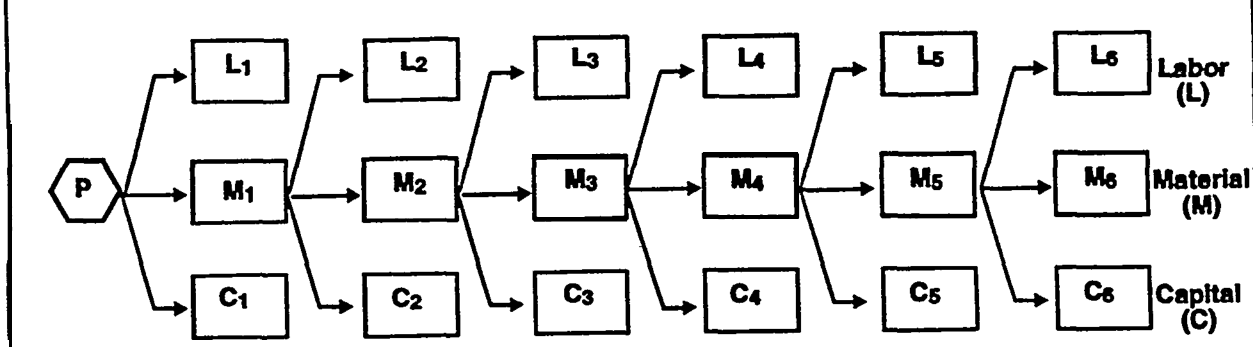
The most important point in Figure 2 indicates multiple suppliers at Levels VI through Level II. This indicates the possibility of competition at each level but does not mean competition must exist.

Functional linkage is the skeleton of the industrial anatomy, independent of selected organization or ownership of and at various levels, and is discussed below.

The Organizational Linkage Mechanism

While the functional linkage has been a MUST-concept, the organizational linkage is an OPTIONAL concept, to choose from eight possible forms as shown in Figure 3.

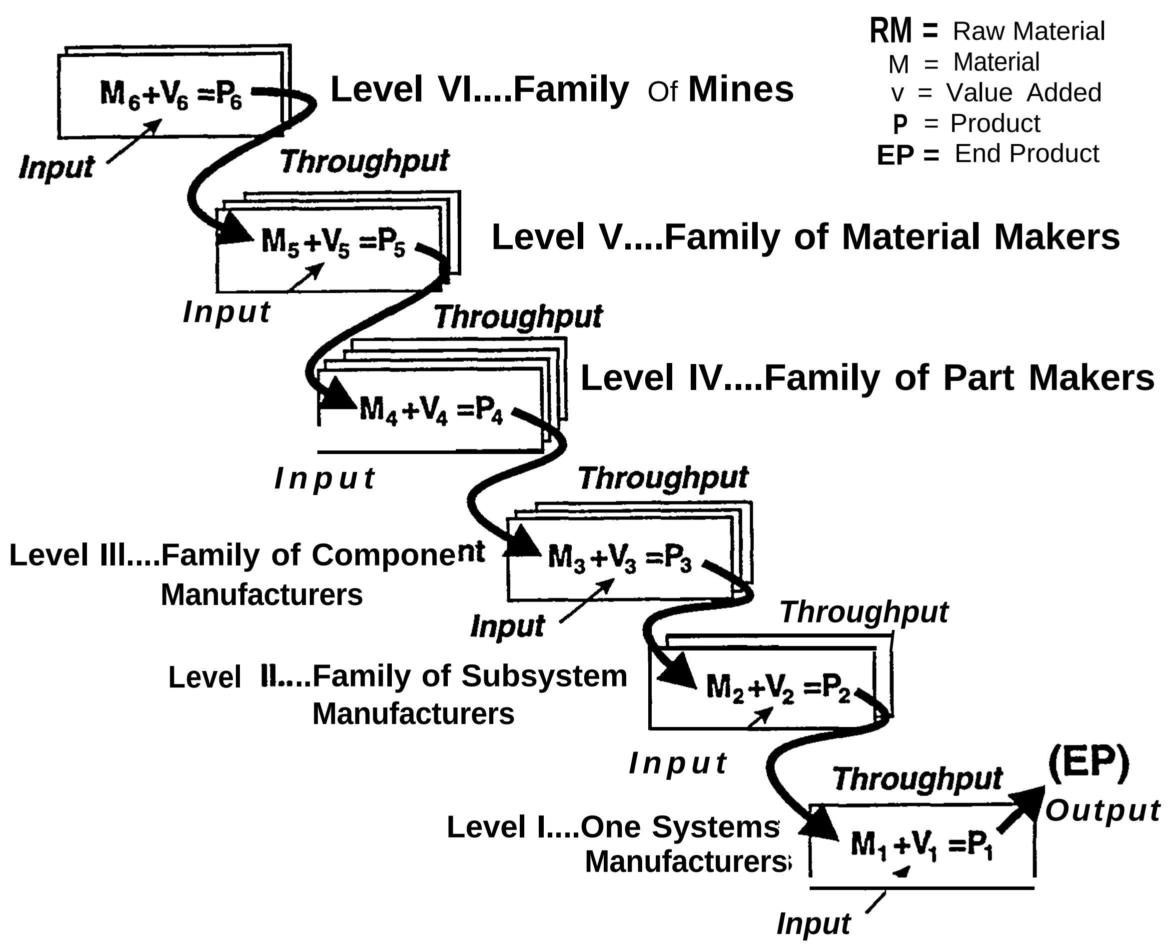
In Figure 3, only linkage between Level VI, the raw material, forward to Level V, the steel mill, may be called a natural linkage, but other linkages are free



Notes:
1. P represents the end product
2. Subcripts 1 through 6 represent labor, material, and capital at the six product levels within the supply breakdown structure.

Source: "Financing Defense Systems Programs Dr. Franz A.P. Frisch and David D. Acker, Concepts, Autumn 1981

Figure 1. Supply Breakdown Structure



Source: Dr. Franz A. P. Frisch, DSMC Paper

Figure 2. Value Added Flow

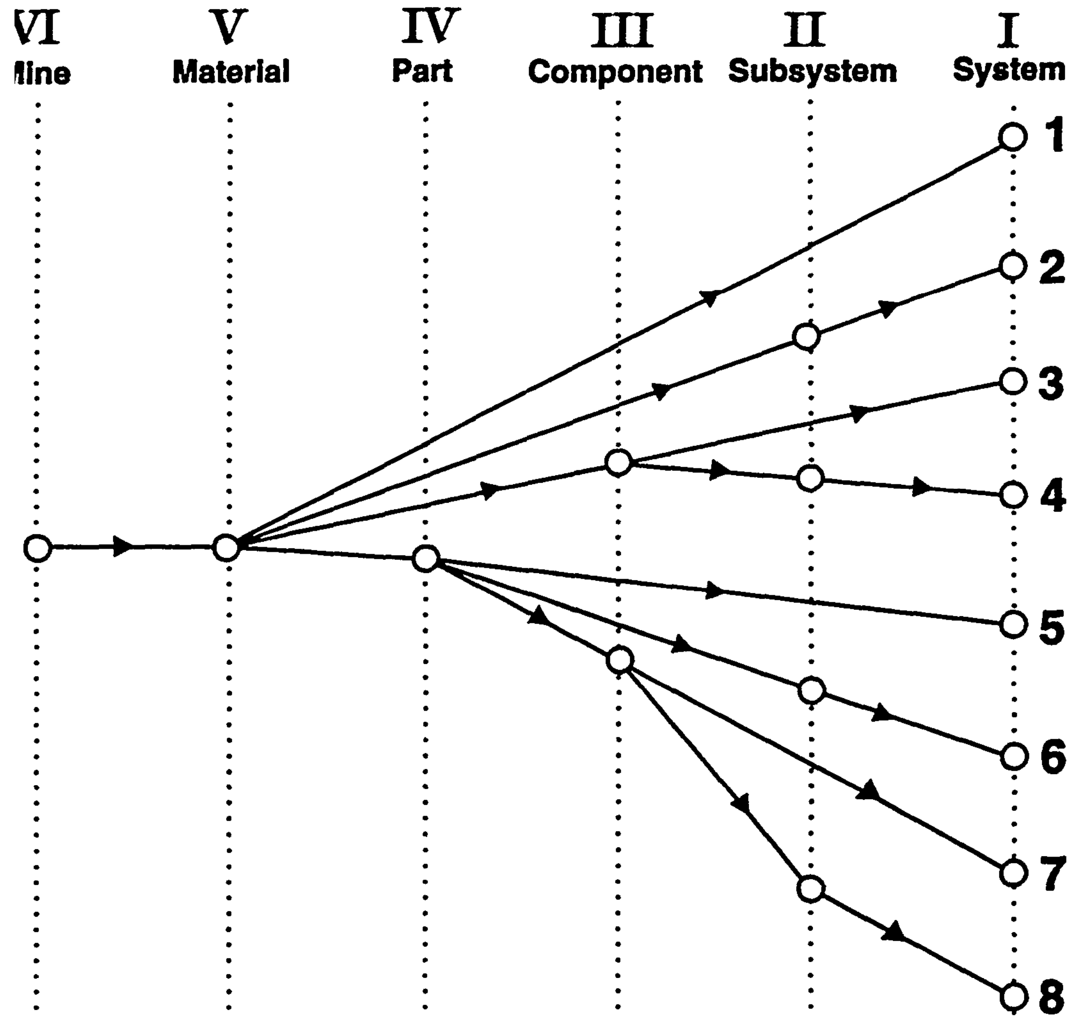


Figure 3. Organizational linkage

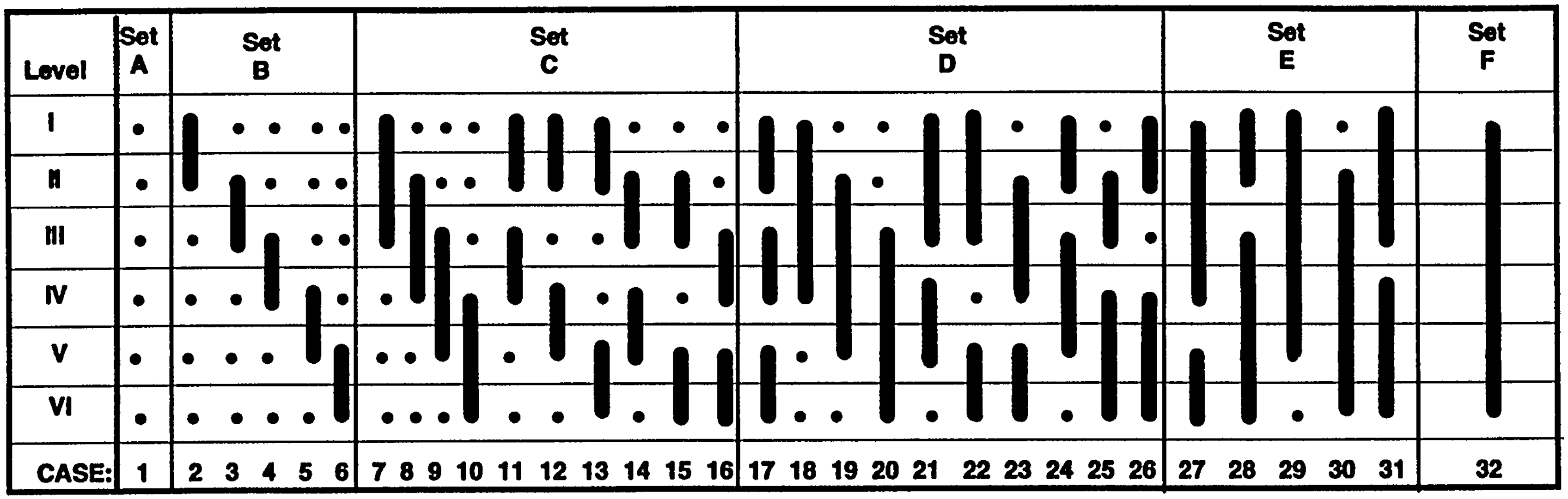
to choose. For example, in Path 1, the steel mill can deliver material directly to Level I (ship yard), or in Path 2 to Level II, manufacturer of the subsystem...and so forth.

Each of the selected eight branches will he driven by the economy of scale as expressed by uncountable make-or-buy decisions along each path. Each buy-decision can be “economically” superior to any make-decision. Even economic superiority has its trade-off. With every buy-decision, there is a shift from internal communication (within the family of one manufacturer) to external communication (across families of manufacturers). This point will be addressed later.

The Ownership Linkage Mechanism

The Dominant Ownership Structures shown in Figure 4 represent a part of the linkage mechanism. Dominant shall mean that only collocated levels may be under co-ownership. Non-dominant would mean lack of co-location like, for example, a common ownership for the shipyard (Level I) and the steel mill (Level V). The uncountable non-dominant ownership is not considered.

Cases #1 and #32 in Figure 4 represent the extremes. In Case #1, all levels have independent ownerships. In Case #32, all functional activities of the six levels have a common ownership. Forms of ownership are not only an economical problem, but are subjugated to legal constraints; i.e., embedded in cartel laws, rules for competition and others.



SET A....six ownerships
SET B....five ownerships
SET C....four ownerships
SET D....three ownerships
SET E....two ownerships
SET F....one ownership

Source: Dr. Franz A. P. Frisch, DSMC Paper

Figure 4. Dominant Ownership Structures

From a communication point of view, in Case #1 there may be almost perfect internal communication at the six functional levels, but tremendous difficulties with external communication across the levels. In Case #32, there may be imperfect internal communication because of organization size, but there are no problems with external communication because nodes for such do not exist. This points toward a trade-off between quality of internal communication as a function of organizational size and difficulties in external communication because of separation. More follows.

INTERLUDE AND CRITIQUE

So far, so good; the industrial structure was addressed in rough sketches and the naval architect was mentioned once. Let's call him the designer and his product the design. Nowhere, in any chart, did the designer or product appear. Is the design we are to "integrate" hiding? Has this paper, so far, missed the point? Is somebody forgotten? Where is the customer in the industrial picture?

Two answers are possible. First, the customer AND the designer are completely separated from the industrial sphere if the design is used as the basis for competitive bidding and the estimator at the shipyard is floating in uncertainties, as long as the ship yard has not received the competitive bids from all their subcontractors. Integration can start only after the lengthy bidding process is finished. Second, the customer works WITH the designer at or for a preselected ship yard, and the designer selects during the design and estimating process (in continuous communication with the customers) all subcontractors. In this way, integration of design and production starts at the beginning. No time is lost but advantages of competitive bidding have evaporated.

The two answers describe extremes; but, the first can be called the American way, the second the European way. In the first case, the designer is the "owners representative" but he and his design are NOT A PART of the industrial process. In the second case, the customer and the designer and his design ARE A PART of the industrial process.

Both concepts, competitive and the cooperative, have specific advantages and disadvantages and neither is optimal, but both are carrying illusions. The first is the illusion of integration and the second is the illusion of competition. The preferred illusions are embedded in value judgment, reflecting culture and philosophy.

COMMUNICATION CONTROL

Communication control shall be defined as anything and everything that fosters or impedes communication between design and production, at all levels and across all levels.

Looking at any industrial product and process but, in particular at ships and ship yards, there is differentiation among three control types. First is functional control, second is organization and ownership control, and third is the external control mechanism.

Structural Control

The need for structural control is dictated by the complexity of the product and of the processes. The designer and the ship yard, jointly as the "systems integrator," must conduct two activities. First, the subsystems (Level II) MUST be coordinated. Second, the production of the subsystems SHOULD be supervised to guarantee performance and quality. The counter-force to "must" and "should" is CAN. How much can we do? What is possible? To illustrate, look at Table III.

Table III is simple and a masterpiece of naivety (often called a sample for demonstrative purposes only); nevertheless, results are frightening. We assume 10 subsystems (Level II) only; we assume each subsystem is constituted only of 10 components (Level III); hence, the existence of 100 components only and, in turn, we assume existence of 1,000 parts. It must be a primitive system. Here is the result. If we can hire 1,110 independent supervisors, we can SUPERVISE 10 subsystems, 100 components and 1,000 parts. But what shall be done with the COORDINATION of (in round figures) 505,050 interactions? If most 1.110 supervised nodes interact, as assumed, there is a need for ONE coordinator able to understand more than a half-million interactions. Such genius does not exist on earth. So, what is to be done?

We invent the appropriate management system where the lower-level informs the higher-level only about some parameters of each product. For example, producers of subsystems will inform the systems integrator only about requirements for space, weight and power for each subsystem. This means that each

Table III LEVELS, ELEMENTS AND INTERACTIONS

LEVEL	ELEMENTS PER ???	POSSIBLE INTERACTIONS
I - System	10	
II - Subsystem	100	50
III - Components	1,000	5,000
IV - Parts	1,110	500,000
Total		505,050

Source: Dr. Franz A. P. Frisch, DSMC Paper

subsystem proper is for the systems integrator only, a black box with form and function, with input and output. Ultimately, subsystems are cargo colocated in the hull.

There is only one way to handle the problem. Product complexity and constant human limitations killed design/production integration on the drawing board as previously possible in primitive times. Today, the integration process is unpredictable if new subsystems, non-existent before, are involved. Today, the integration process reaches deep into the production phase as documented (for NAVY ships) in thousands of change orders. But change orders are nothing more than elements of a learning process about unpredictable coordination aspects. The solution: Learn to accept the management system of "muddling through" and do not ask for the impossible.

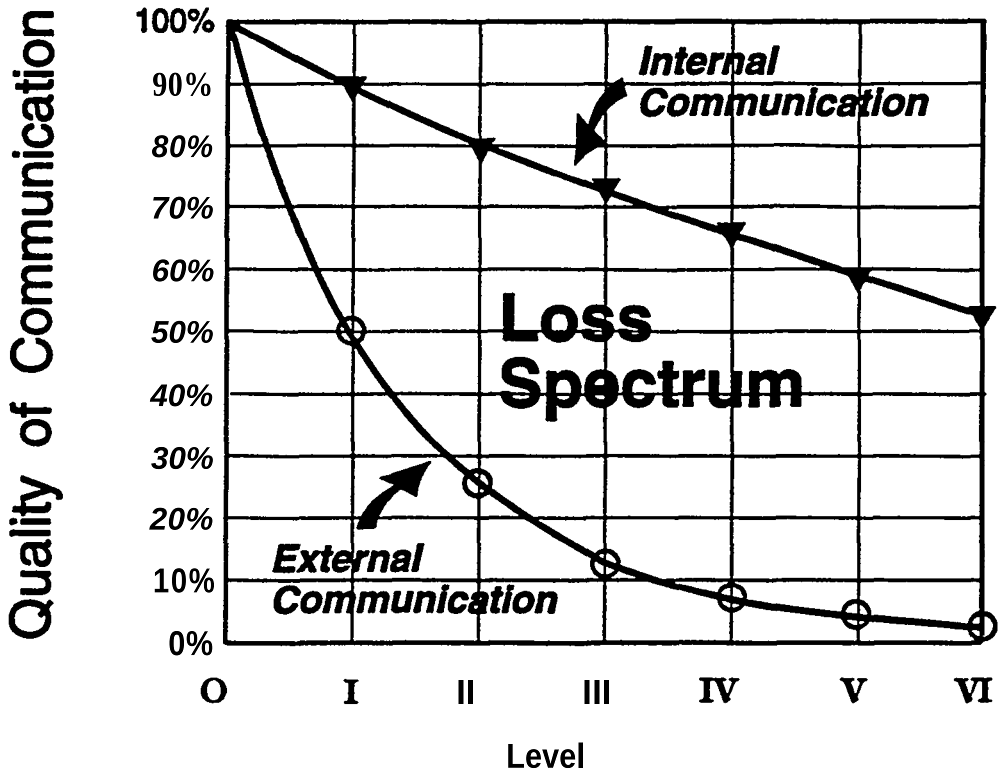
Organizational and Ownership Control

The structural control could be considered a product-driven engineering problem. Organizational and ownership control overrides the first and, driven by economy of scale and scope where communication control is exerted by nodes of organization (Figure 3) and nodes of ownership (Figure 4). Within each node, there is internal communication and, between nodes, there is external communication. Those communications can have different quality.

To illustrate, assume ranking the quality of communication from zero to 100. Zero would imply a complete collapse of communication and 100 of perfect communication, where communicating parties understand each other, unrestricted. Real communication quality will be (or must be) above zero and below 100, but how to "measure" quality of communication is an unsolved problem. Here, it can be assumed, that internal communication is always better (whatever this means) than external communication.

Rank internal communication at each level (I through VI) with 90 percent and the external communication with 50 percent (both optimistic assumptions). Next, select two extremes. First, combine the organizational Path #1 (from Figure 3) with Ownership Structure #32 (from Figure 4). Here, there is an overall communication efficiency of 0.9 to the sixth power or of a total of 36 percent. Second, combine the organizational Path #8 (from Figure 3) with Ownership Path #1 (from Figure 4). Here, there is an overall communication efficiency of 0.5 to the sixth power or of a total of less than 2 percent. The two extremes are shown in Figure 5.

The two curves in Figure 5 encompass the loss-spectrum of communication because of organization and ownership structure. The loss-spectrum indicates the range of trade-off. In the first case with 36 percent communication efficiency, there is the best possible design/production integration, but there are tremendous losses in the economy of scope and the economy of scale. In the second case, there may be the best possible economy of scope and scale, but there is a horrendous price with a 2 percent communication efficiency or, practically, impossibility for a foresight about design/production integration.



Source: Dr. Franz A. P. Frisch, DSMC Paper

Figure 5. Loss spectrum

To find an optimum between the two extremes could be an existing academic research task, based upon a menu of assumptions. As pragmatist however, trust the market forces.

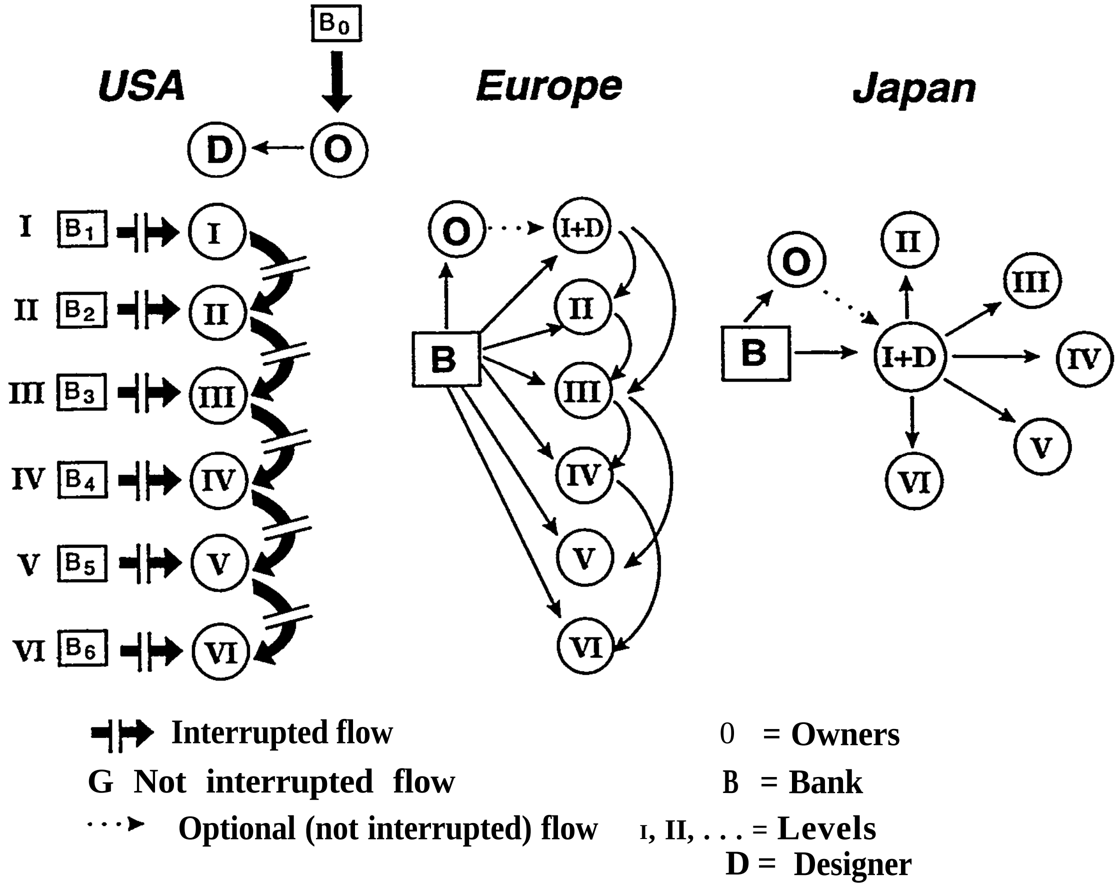
External Control Mechanism

The structural control dealt with engineering aspects, and the organizational and ownership control with economic aspects. The present external control mechanism finely deals with legal aspects of integration. Also, the three aspects are inseparable. This paper deals with the third aspect in isolation and compares American, European and Japanese concepts of the external control mechanism in the simplest form. In Figure 6, concepts are sketched.

The American is shown at the left side of Figure 6. The only firm communication link before bidding and source selection is the link between the ship owner (0), or the customer with the designer (D) as the owner's representative. Otherwise, no firm communication link exists. Communication between the ship yard, Level-I, and the subcontractors, Levels-II through VI, cannot be established before contract award; even then, companies might have to deal at arms length to avoid conflict with selected antitrust laws. Financing the owner and level activities is performed by different banks (B_i) and each bank, as lender, must work at arms length with the individual borrower according to the Glass-Stiegel Act of 1933. Hence, there **is** neither solid communication possible between the banks and the borrower, nor among the banks.

The European is shown in the middle of Figure 6. Note the designer (D) is an integral part of the prime contractor, or the ship yard at Level I. The Level I can freely associate with any level according to choice, but the owner (0) and all six levels of the supply hierarchy are linked to one bank (B), and the bank will have its employees on the board of directors at all six levels and at the shipping company or the owner's company. In this way, the bank (B), or a group of coordinated banks, takes the roles of communicator and coordinator during the entire process, from design to production. Within this bank-controlled system, all lines of communication are open.

The Japanese is shown at the right side of Figure 6. The bank (B) controls only the owner's



Source: Dr. Franz A. P. Frisch, DSMC Paper

Figure 6. External control **of communication**

corporation (0) and the prime contractor at Level I, also synonymous with the designer. Here, the "direct" bank control stops, BUT the Level I operator is the major shareholder of subcontractors, and thus controls the entire production operation, and all parties of the game can communicate completely unrestricted as when designer or architect start the first sketch for a new design. Lower levels can function as co-designer, supporting the process or production needs at their specific levels.

SUMMARY

This paper starts with an observation, declaring the possibility of the design/production integration as a problem of communication.

Necessary communication is product- and process-driven, but necessity and possibility do not always blend. Possibilities are given by the industrial structure, the economic goals of the participants and ultimately by the legal environment, supporting or hindering the necessary communication.

The possible form of formal communication, or the communication environment is compared for the United States, Europe and Japan. However, no judgment is made about the relative possibilities to communicate because each system has **its** strong and weak points and no system can be perfect. There are trade-offs based on value judgments as expressed by the law-of-the-land expressing the philosophy of the Common Law World (the United States) and of the Codified Law World (Europe and Japan).

EPILOGUE

It may be irritating to find that impediments for a design/production integration are dominating the American picture, while the European-Japanese environment fosters integration. This is correct but shall not be the basis for judgment. Think about advantages the American system provides, unknown to others, like freedom of choice, healthy competition and support for entrepreneurial spirit. Our past successes prove this point.

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Considerations For Earlier Design For Production

No. 6B-2

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ABSTRACT

The principal theme of this presentation is advancing the transition of the system design orientation to planning unit orientation to a point earlier in the design phases. Achieving earlier design for production should favorably impact ship cost estimating and therefore bidding, detail design and construction schedule and cost. Recent papers on design for production have principally been concerned with those technical characteristics of the ship that are conducive to the facilitation of production. This paper emphasizes the ship construction method and sequence and how this can be introduced at a stage earlier than the Transition Design. Primary concerns are to develop preliminary build strategy, subdividing of the hull into erection units and modules, and advance planning for the development of work instruction packages during the detail design.

INTRODUCTION

It has been noted that about 30% of the difference in productivity between the typical U.S. yard and good foreign yards can be accounted for by superior design for production in the foreign yards (1). Accordingly any improvement in this stage of ship construction can have a major impact on the cost of ships.

The traditional role of the ship designer has firstly been the preparation of an overall vcsscl design which has performance characteristics satisfying the operational or functional requirements. The concept of design for production, however, requires that in satisfying these requirements, the ship designer must also give attention to facilitation of production. The need for personnel at the design stage to understand production requirements and for production departments to understand design procedures and requirements is greater than ever.

The design stage and process in shipbuilding consists of a sequential series of design phases: Conceptual, Preliminary, Contract, Functional, Transition and Detail. Transition Design is the point at which there is a translation of the design from a systems orientation, necessary to establish functional performance, to a planning unit orientation necessary to establish production requirements. These phases and the product-oriented design process are shown in Figure 1 where the term Basic Design can be taken as the culmination of the Conceptual, Preliminary and Contract Designs.

As the Contract Design is aimed at providing a basis of a contractual arrangement, if the transition to production orientation is emphasized at this point it will both aid in arriving at a less expensive design effort during construction and provide information for cost estimators to more meaningfully introduce the impact of productivity into the quoted price. It will also shorten or eliminate the precious and costly time at the outset of a construction program to establish the Transition Design.

In other cases, the Conceptual/ Preliminary Design may represent the stage at which rough order of magnitude (ROM) price quotations may be required for a timely response to a potential buyer. Failing to incorporate the impact of production enhancements on cost

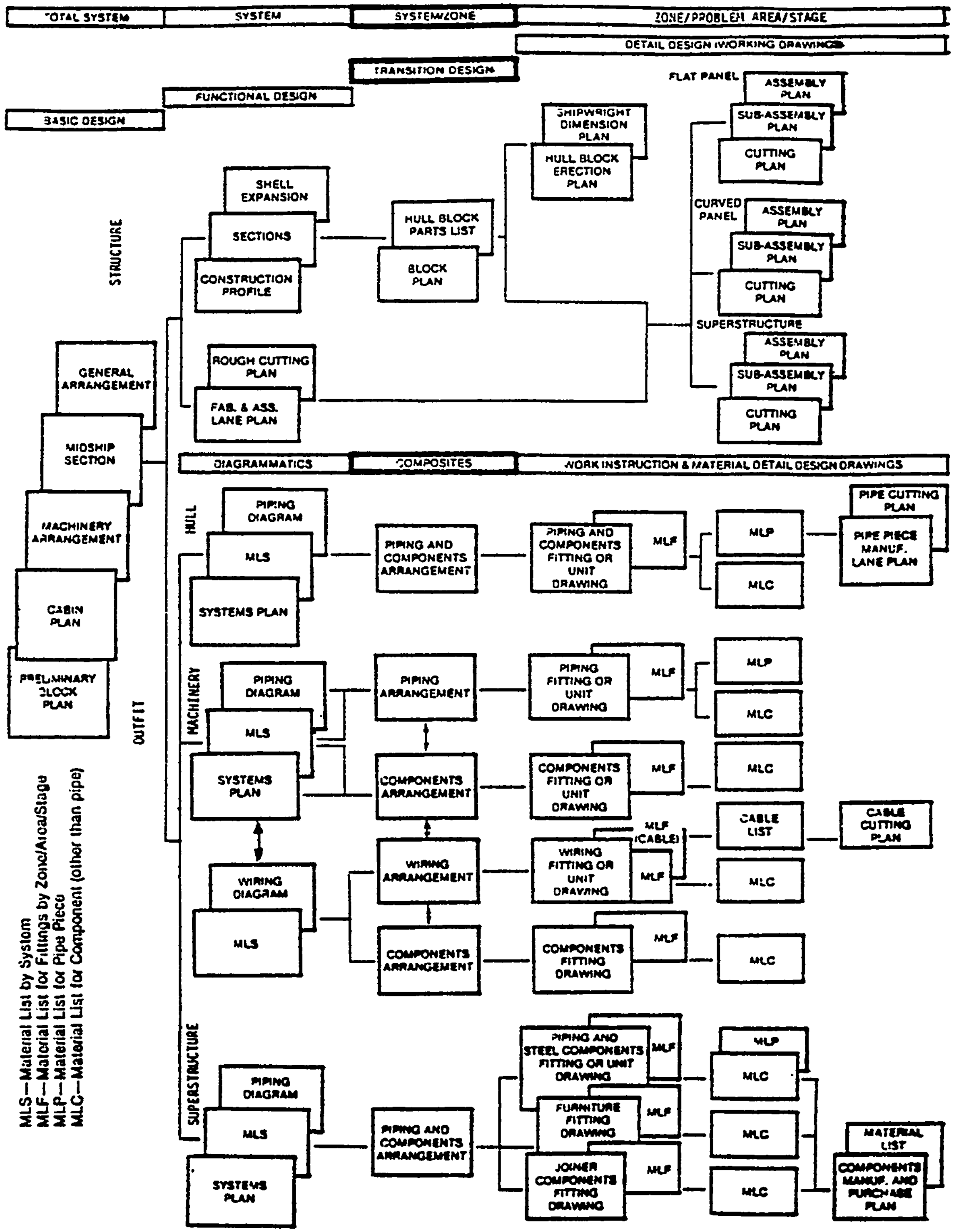

Figure 1: Product-Oriented Design Process (2)

may result in missing the competitive range and the opportunity to enter into a Contract Design.

As a result, this paper suggests emphasizing the ship construction method and sequence during design and considers how this may be introduced at a phase earlier than the Transition Design. Recent papers on design for production have principally been concerned with those technical characteristics of the ship that are conducive to the facililation of production. Both of these matters are very important to ship production but they arc distinct.

The paper first reviews the design phases and the design and production inputs and outputs which are possible. The impact of the source requesting the design on the philosophy behind it is considered from the perspective of a commercial owner, government and private shipyard. The benefit to each in incorporating earlier design for production is addressed as well. The means of incorporating design for production through a Production Directorate are then considered. Conclusions and recommendations arc offered.

DESIGN PHASES

In discussing any aspect of ship design and construction, it is essential to have a basis for definition of the levels of design consistent with stages of development of the ship. As these vary from one case to another, those which have been adopted herein arc consistent with those previously defined by the National Shipbuilding Research Program (NSRP)(1) supplemented with design related definitions (3).

Conceptual/Preliminary Design

The conceptual design phase establishes an overall design to meet an owner's outline specification. It can also define a marketable design as part of a shipyard's product development. Essentially, it embodies technical feasibility studies to determine such fundamental elements of the proposed ship as length, beam, depth, draft, fullness, power or alternative sets of characteristics, all of which meet the required speed, range, cargo cubic, payload or deadweight. Although the main outcome is a design to meet specified ship mission requirements, an account can and should be taken of production requirements. At this stage the designer has considerable flexibility in his choice of dimensions and other parameters which define the vessel and those selected can be for enhanced production.

The preliminary design builds on the concept design with the intent of solidifying certain vessel principal characteristics. These usually include the vessel length, beam, propulsion power, and displacement. Its completion provides a precise definition of a vessel that will meet the mission requirements. Concurrently with the fixing of certain vessel principal characteristics it is possible to further elaborate on the production scenario.

The content of any design phase can be defined as a series of inputs and outputs. For the concept/ preliminary design inputs may be presented in the form of an outline specification or mission requirements. A more complete summary of inputs and output items is as follows:

Design Input

- Service requirements,
- Routes,
- Market forecasts, and
- Critical components and equipment: and

Design Outputs

- Preliminary general arrangement, midship section,
- Preliminary specification,
- Preliminary calculations (dimensions. capacities, etc.), and
- Preliminary hull form body plan and lines.

Simultaneously, at this stage the shipbuilder or production discipline should identify the following essential production inputs and outputs:

Production Inputs

- Shipbuilding policy,
- Type plan,
- Facility dimension and capacities.
- Interim product types, including units and modules, and
- Material and fabrication, choices; and

Production Outputs

- Outline build strategy.
- Preliminary block breakdown.
- Zone identification,
- Material preferences; and,
- Fabrication preferences.

Preliminary Arrangements. The general arrangcmcnt is among the most important aspects of preliminary ship design as it largely dclincs the operational efficiency and functional effectiveness of a vessel. The arrangement drawings must consider the functional spaces, cargo spaces, superstructure, machinery spaces and their relationships. No less important is the provision for access between all spaces meeting operational and regulatory requirements.

The machinery arrangements during this phase may be incorporated in the general arrangement. The principal features are the main propulsion and auxiliary machinery including the main engine and large auxiliaries, electrical generators, switchboards and control areas, shafting, propellers, and the steering gear. The main engine and shafting may be the only machinery actually shown with space allocation provided for the remaining.

The general and machinery arrangements of the nature described provide a blueprint of space allocation which can be utilized for determination of preliminary block breakdown, unit definition and module considerations. It is at this point where major changes to the design to best accommodate these production considerations can be introduced and the arrangements of the vessel altered to suit.

Hull Form. During the conceptual design phase the designer is guided by an outline specification produced by the owner or on information direct from market analysis. In developing the main dimensions, account must be taken of service restrictions, for example, canal restrictions on beam or port restrictions on draft. At the same time, the capacity of various production facilities to build the design can be a consideration in terms of allowable principal hull form dimensions and the impact of length and lightship draft on launching and Fitting out.

The preliminary design process starts with the development of the preliminary body plan and lines. The location and spacing of main transverse watertight bulkheads should be established and calculations concerning flooding and preliminary damage stability conducted. Positioning the bulkheads will be dependent on cargo or other space requirements, and on flooding and stability requirements. At the same time, given the availability of a type plan, the bulkheads can be positioned to address production needs.

The hull form should have characteristics conducive lo producibility which can include parallel midbody, minimization of curvature, straight sheer and camber. Those attributes which are best suited to the shipyard and within the technical, functional and intended service considerations should be adopted.

Preliminary Calculations. At the outset of the Preliminary Design Phase, an estimation of the power required to drive the vessel at the desired speed is obtained and power calculations should continue with the interjection of hull form adjustments.

Estimates of vessel weight must be maintained during all phases in the development of the design. The designer should be aware of the placement of major machinery components and their effect on the balance of the vessel. Weight estimates are needed to establish stability, trim and list of the vessel, in addition to ascertaining the design deadweight. The basic weight calculations form the basis for estimating the cost of the vessel.

Although weight is an appropriate parameter for an initial cost estimate. it must be treated with caution. A reduction in weight will reduce the relevant material cost, but will not necessarily reduce the production cost. In some circumstances it may result in a cost increase as more costly fabrication or equipment may be involved. With the potential improvement in production with a comprehensive build strategy introduced early on. weight can only give a partial indication of cost. Labor costs as affected by producibility should impact more critically than relative changes in weight.

Structural Drawings. Upon completion of the preliminary general arrangement a midship section is developed. This design development will have a profound effect on production. Basic decisions pertaining lo the location of framing must be made along with the establishment of the material to be used in certain arcas of the vessel. Consideration should be given at this time to the standardization of frame spacing, types of structural members to be utilized and the use of a minimum number of different shapes, all in order to simplify fabrication. Methods of structural member fabrication should be considered as well including stiffeners and supports (rolled vs. built-up vs. flanged plate), bulkheads (plate-sliffeners vs. corrugated), etc.

In this phase, the designer has considerable freedom to attempt innovative structural arrangements. As a minimum, he should avoid the USC of fabricated shapes which inherently have greater work content than standard rolled shapes. If it is shipyard practice to utilize fabricated shapes. then this should be re-analyzed.

If weight is a serious consideration, then an innovative approach based on more detailed structural analysis may provide a more optimum solution. Alternatively. a review of the main design parameters can be undertaken with an eye towards relaxation of those having the greatest negative impact. Both of these alternatives should be investigated rather than rigid applications of rules and guidelines to a weight-sensitive design, which may result in a design incorporating complex fabrication and a wide variety of material sizes. On the other hand, as it is to be expected that material costs will be less than labor, where weight is not a serious problem a reduction in stiffening with increased plate scantlings should seriously be considered as a means of reducing the number of welded components and thereby reducing labor.

Contract Design

The contract design phase utilizes the outputs established during the conceptual/preliminary design phase, refines the functional requirements established in the owner's specification. and establishes the basic key information necessary for all subsequent design phases. Furthermore, it establishes the features of a design in sufficient detail to provide the basis of a contractual arrangement.

If the design is prepared by a shipyard, it should be easier to facilitate the introduction of producibility. If an organization external to the shipyard develops the design, e.g. a design agent, it is still possible to introduce producibility through the incorporation of those attributes which should be conducive toe increasing producibility at any shipyard.

This phase can also be defined in terms of a series of inputs and outputs with the major input data emanating from a conceptual/ preliminary design. The principal information will consist of the following:

Design Inputs

- Conceptual/Preliminary design,
- Functional requirements,
- Regulations. and
- Design standards,

Design Outputs

- Building specification.
- General arrangement,
- Midship section.
- Hull lines plan,
- Design calculations,
- Accommodation arrangements.
- Machinery arrangements,
- Piping Diagrams,

- Electrical load analysis, and
- Plan list;

Production Inputs
- Shipbuilding policy,
- Company standards and industry standards including: material sizes, fabrication preferences, module make-up, service runs, block sizes,

spatial analysis:

Production Outputs
- Preliminary build strategy: planning units,
- Equipment identification: long lead ilcms.
- Material requirements: quantities, long Icad. and
- Preliminary list of units and modules.

General Arrangements. As the design continues to evolve and as engineering calculations arc completed, an increasing amount of information concerning equipment becomes available`. This information is incorporated into the contract specification and allows for the furthor detailing of the machinery arrangement drawings, the accommodation and the hull general arrangements.

In developing the arrangements, there is considerable scope for influence on producibility. The designer has an opportunity to reduce ship cost by use of spatial analysis which considers the ship as a set of functional spaces rather than a set of systems. These functional spaces are specific volumes within the ship which contain functionally interrelated equipment and are initially defined in terms of their circumscribing envelope. Detailed internal design and precise locations of equipment within these spaces arc left to a later design phase provided only that it is certain that sufficient space is available. However, very effective strategy can be developed at this point to group equipment and outfit for modularization, standardization and interconnection to system interfaces at the boundary of the functional space.

Service routes can be treated in the same manner. The designer should allocate volume to a series of main and secondary routes. In addition, the priority of the distributive systems should be examined and rearrangement of compartments made where possible to simplify routes, reduce run lengths and simplify installation.

At the same time producibility enhancements are introduced the contract arrangements must exhibit a well thought out access to all spaces within the ship. This will not only be important to the owner whch operating the ship but during the construction process as well.

Hull **Form.** The hull form is established during the preliminary design phase, however, the development of the design may result in some revisions being required. These should be minor, to take account of small variations in weight distribution, wake field as measured in model tests or final fairing.

Structure. The midship section should be completed in terms of structural components and arrangements. Scantling plans depicting the remainder of the vessel's structural arrangement are required as well. Both of these should be produced in a formal to suit classification or other approval bodies, and although preferable, may not yet be fully developed to approval standard. In the case of novel or unusual features, discussions should be held with classification societies and regulatory bodies.

Production input to this stage of structural design is of major value, importance and potential impact. The location and spacing of the principal structural members should be finalized from a production point of view to best suit the production process. The designer should also be guided by production in the selection of the material sizes and fabrication processes used.

Welding techniques, character and inspection should be identified. Potential situations for special welding, such as in thick weldments utilized where castings might normally be incorporated, should be carefully planned.

Machinery Arrangements. At the start of the Contract Design, the machinery arrangement may actually consist of only the outline of the prime mover and shafting system shown on the preliminary general arrangement drawing. In this phase, separate drawings should be prepared.

As the design develops, an increasing amount of information will become available describing the machinery and equipment to be located in the machinery spaces. From a production point of view, the arrangement should facilitate the unit and modular construction approach. In particular, the arrangement of similar equipment in common locations, along with a strategy for producing modules with support structure and piping will signilicantly reduce the planning and potential re-design which might otherwise be required during the Transition Design.

Ship Systems. Calculations pertaining to various piping, electrical and heating, ventilation, and air conditioning (HVAC) systems will be developed and specifications written for each. This information will guide the designer in the development of piping and HVAC diagrams, the one line electrical drawing, and will provide the baseline for future activities. It is important to note that vendor information will be required in order lo develop some of the more complex system diagrams.

Development of the system diagramatics and one line electrical drawing is carried out in stages. A flow diagram or schematic showing the connections between the main and auxiliary equipment is drawn for each system. This flow diagram does not yet show capacity or piping and duct diameters but identifies the functionality of the system. The capacity of each of the major components is then determined and provides the basis for the technical specification. This will identify all the necessary information; for example, voltage, capacity, and pressure. together with any other relevant information which influences the choice of the component.

The flow diagrams arc then completed to give. a preliminary insight as to the pipe diameters, pump capacities, pressure and valve types for all connected equipment. This allows the specification of all items not previously identified to be developed. The flow diagrams are limited in USC from a production point of view as they do not reflect the actual position of systems within the vessel. However, they provide a comprehensive description of all material and equipment making up the system. This affords the opportunity to assure that standardization of components and equipment has been achicved to support availability and stockpiling considerations at a shipyard.

Drawing List. Once all the systems within a vessel have been identified and the structural arrangement has been established. a preliminary drawing list should be prepared. In parallel with the design development a preliminary build strategy should have been developed. This will identify the planning units, structural units, outfit asscmblics. equipment modules and zones based on the functional spaces which make up the vessel. Utilizing this data two sets of drawings can now be listed.

Conventional drawings will include all approval drawings, and those which define the ship from a functional and systems standpoint. In addition, a set of production drawings related lo each planning unit will give all the neccessary production information for manufacture, assembly and installation.

The drawing list should form part of the contractual arrangements. In a more evolved form, it will identify the responsibility and schedule for each piece of information needed in the remaining design process. When a design subcontractor is utilized by the shipyard this bccomos especially important for establishing the extent of the effort requircd. When shipowner furnished material or information is in a critical path. the identification of this input will insure a more orderly arrangement.

PHILOSOPHY OF THE DESIGN PACKAGE

The manner in which a design package is prepared and utilized will generally be dependent on the source responsible for its development:

- Commercial Shipowner,
- Government (Navy, Coast Guard, etc.), or
- Shipyard.

Each of these sources is concerned with the utilization of the design package by different organizations or disciplines although the final desired outcome should be identical: a quality vessel meeting the required needs for a favorable price. Furthermore, the manner in which the outputs of different design phases are utilized.differs as well for each of these sources.

Commercial Shipowners

Commercial shipowners are principally concerned with obtaining a vessel meeting their performance requirements at a favorable price. They are not always interested in developing a custom design and although their staff may be comprised of individuals knowledgeable in design, this is generally not their primary function within the organization. Most likely, there are even fewer personnel on the staff knowledgeable in ship production.

As a result, the shipowner is usually most interested in obtaining shipyard proposals for vessels of their own particular design meeting the owners performance requirements. Following a request, many expect a formal quotation supported with specifications and selected drawings to be submitted to them in short order.

Shipowners may tend to be unconcerned with the distinction between the design phases as long as they arc comfortable that the risk in the price quotation based on a particular design and its stage of development is within the margin they can accept at contract signing. They will seek to understand the character of not only the principal design characteristics but the intended details of the construction and character of the equipment which are to be provided. As it may be unlikely this will all be known from the current design phase development, a comparison to previous designs may be acceptable. In the final analysis, the owner will be less concerned with the design process between the original quote and the detail design for construction than the shipbuilder.

The shipowner's in-depth review of the design will be through the Contractual Plan Approval process consisting of a review of detail design drawings and reports reflecting all aspects of the design. Generally, detail design drawings for review will be a conventional set of drawings, not unit or module production drawings.

Government

The U.S. Government's public shipyards are primarily devoted to modification, maintenance and repair rather than newbuilding. As a result, during new vessel acquisition, the Government may essentially be considered a shipowner. However, the comparison with the commercial owner is only similar at the point of contract signing and thereafter. Beforehand, the Government may behave much more like a shipbuilder in the manner in which the design development is carried out.

A number of Government agencies and departments maintain significant staffs of individuals knowledgeable in craft and ship design. These include the Navy, Coast Guard, National Oceanic and Atmospheric Administration (NOAA), Maritime Administration (MARAD), National Science Foundation (NSF), and others. The Government is generally much more involved in the design of a vessel from the outset, and in most cases of large and costly vessels, has developed the design significantly prior to releasing it to the shipyards for further development and/or bidding for detail design and construction. More recently, attention has also turned to ship production.

The manner in which the Government releases a design to the public may take on several forms:

- Design competition to "Performance Specifications";
- Design competition based on a "Circular of Requirements (COR)";
- "Contract Design" for Detail Design and construction bidding.

Performance specifications presumably reflect the functional characteristics desired by the operators and have probably been supported by feasibility (pre-concept) and conceptual level design studies carried out by the Government. The COR contains a more comprehensive definition of ship technical characteristics and definitions of systems than contained in performance specifications. It is usually based on Conceptual to Preliminary Design type of studies carried out by the Government.

The Government is concerned with avoiding any vessel design attribute that will favor a potential bidder. Accordingly, the characteristics relating to production that may be incorporated into a Government design effort can only be of a general nature or lhose which have been identified as facilitating production under many circumstances.

Shipyards

Shipyards may be simultaneously or separately involved with vessel design and construction programs for both commercial and governmental clients. Accordingly, it is to be cxpected that they may encounter any of the circumstances previously discussed.

Theoretically, a shipyard is free to incorporate the production attributes of the organization into the design process ill any Stage. As personnel most experienced in production may not always be associated with the design departments, successful integration of production into design must involve a coordination of disciplines.

PRODUCTION DIRECTORATE

Having knowledge of the production input and output for various designs phases and the responsibility of the organization in the design sequence, the only remaining ingredient to institute earlier design for production is the provision of a means to effect the integration of the two. The absence of a defined responsibility for introducing the production requirements into the design sequence may result in a haphazard addressing of the subject driven by the interest and knowledge of other participants in the project.

Shipowner

Shipowners are not normally sufficiently involved in the design cycle leading to Contract Design that their involvement will require considerations of shipyard production. However, their interface with the shipyard on alternative approaches that will aid production while not undermining vessel performance, operation and maintenance will be very helpful.

Alternatively, the shipyard which can anticipate a shipowner's needs and propose a vessel optimizing the production aspects will have achieved the desired balance.

Government

The Government's involvement in the design process places it in a higher visibility position with regard to affecting the producibility of a vessel. This is particularly true in those cases where a comprehensive COR or Contract Design is developed.

Any design can be built more effectively by the use of modular construction techniques than by conventional techniques, regardless of the content of the design. Thus, the lack of consideration for producibility in the early stages of design does not preclude a shipyard from using modular construction techniques. However, a Contract Design package that has not taken modular construction practice into account will result in much more potential re-design during the detail design than would otherwise be necessary. This will result in greater engineering costs and a longer design schedule before construction can be started effectively. Riggins and Wilkins (4) have addressed this point in discussing early phase Navy ship design for producibility: "In some contracts, particularly those which are tightly time-constrained, the effort to change the design will be considered impractical, and this will be true whether the contract is cost plus or fixed priced. Thus, the potential cost savings to the shipyard and/or to the government will be lost. Why should the shipyard or the government have to pay extra engineering costs, with resultant delays, to obtain the benefits of reduced production costs, when those arrangements or other detailed requirements in the specifications could have been made before the contract package was issued?"

By considering the basic elements of design for production government agencies can eliminate a great portion of the re-design effort that may otherwise have to take place during the detail design effort. Since a ship designed for modern production can still be built any other way. no shipyard should be penalized by the incorporation of greater producibility into the design.

In order to systematically and effectively introduce production considerations, the Government can provide the interface of a production oriented engineer to work side by side with design engineers. The Navy in I990 conducted a Producibility Workshop (4) which had as one of its recommendations the establishment of extensive training programs to educate Navy engineers in modern shipbuilding methods and in the application of producibility practices.

Hofmann et al (5) have discussed considerations for producibility recently introduced by an alternate "twin skeg" ship design for the T-AO 187 class fleet oiler. There were several proposals introduced to enhance producibility features in the structural area including:

- maximized areas of flat plate,
- maximized areas of single curvature, for remaining shell plating,
- increased frame spacing and reduced numbers of piece parts in structural assemblies,
- standardized brackets and web frames, and use of bilge brackets in lieu of longitudinal stringers in the bilge turn area, and
- carefully arranged erection joints.

The intent of this alternate was to achieve procurement cost savings with an integrated hull form, basic arrangement, and structural configuration which were aimed at improved producibility. Table I demonstrates the results. These objectives and results are not believed to adversely affect the performance of the vessel as it has equal or better projected performance and intact and damaged stability characteristics relative to that achieved with the existing T-AO '187. The authors concluded with a number of guidelines for the application of producibility in feasibility, preliminary and contract design stages of U.S. Navy "T-Ships" which address modular construction of systems as well as the structural aspects just described.

Shipyards

Shipyards are in the best position to introduce production considerations at the earliest stages of design. If a design is being carried out at the shipyard facility, this may be achieved through the interaction of a "Design Director" and "Production Director". If the design activity is being carried out by a subcontractor off-premises, then it is the responsibility of the shipyard to appraise this activity of the shipyard's production preferences and this can be accomplished through the primary points of contact.

In an effort to try and construct an example of the benefits to be gained by earlier introduction of production considerations in design, consider the case of the U.S. Navy's T-AO 187 class ships just previously discussed. Nierenberg and Caronna (6) have compared these vessels as built at Avondale Shipyards utilizing advanced shipbuilding systems to the earlier AO-I77 class fleet oilers also built there, but utilizing a more traditional design and construction approach.

Table I: Producibility Savings for Twin-Skeg T-AO

Item	T-AO 187	Twin-Skez	Difference
Double curvature plate, %	34	10 EST	
Web frames, n	30	18	- 40%
Wing tank struts, n	60	0	- 100%
Longitudinals, n	68	56	- 18%
Frames and floors, n	140	105	- 25%
Transverse bulkheads, n	24	21	17%
Bilge longitudinals, n	8	0	- 100%
Bilge brackets, n	0	36	+ 100%

These authors note that when utilizing advanced shipbuilding systems a general yard practice is to carry out extensive study and evaluation prior to finalization of the basic hull unit breakup to assure that the best compromise of fabrication cost, unit erection and outfitting consideration is achieved. Also, large multi-system machinery/piping package units are one of the most significant improvements in ship construction methods and these have to be defined as well. These considerations were applied by the shipyard to the T-AO 187 vessels as well. However, as the vessels were already at the Contract Design level when awarded to the shipyard, it would seem plausible that had more consideration been given earlier in design to production, precious time, as well as the cost of the studies on hull unit breakup and package units, would have at least partly been saved.

Table II provides the principal characteristics of these vessels and Table III the engineering deliverable parameters reported by the authors. A decrease in the study time at the outset of construction might have also cased the peak engineering manhours as additional time up-front would have been available. Their data indicates that more engineering manhours were utilized for the T-APO 187 than for the AO-177 but that the construction costs were lower in all areas. The boundaries of these reduced costs ranged from the T-AO 187 having erected steel costing 72% of that for the AO-177 to machinery installation costs of 85% of those for the AO-177.

The additional improvements over the T-AO 187 class as reported by Hofmann et al (5) and shown in Table I would have added to these already substantial benefits.

A design and build program incorporating earlier design for production would then appear to offer savings resulting from:

1. Incorporation of enhanced production characteristics,
2. optimized spatial, structural, system. outfitting and machinery arrangements to suit unitization, and
3. time saved in developing optimum unitization.

These could have the effect of advancing the engineering schedule and reducing the peak manhour level or engineering schedule. The latter will most significantly reduce cost as it should shorten the shipbuilding program.

CONCLUSIONS

There are several conclusions to be drawn from the information presented which point to the possibilities of introducing earlier design for production and the benefits to be derived.

There arc adequate means to introduce substantial production design considerations into earlier design phases. These considerations can include the ship construction method and sequence in addition to technical characteristics of the ship that arc conducive to the facilitation of production.

The establishment of a clear understanding of production at the earlier phases will more aptly assure that all parties arc in mutual appreciation of each other's circumstances and that the intended production approach has been accurately introduced into the vessel price. It may be even more important for U.S. shipyards than foreign shipyards to have earlier design phase production integration as design staffs may be external lo their organizations.

RECOMMENDATIONS

The introduction of earlier design for production requires a structured approach to assure that the results are complete and balanced. As an example of an approach, if input and output described for the design phases earlier in this paper are utilized as a check-off list during design as each subject is addressed, then at least the breadth of the matter should have been broached. A structured means of introducing production considerations into early design phases should become an integral part of a design approach.

If personnel involved in a design effort arc not familiar with production considerations, then a production director should be identified who is familiar with such requirements and will interface with the design director to introduce the production considerations in a timely manner.

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Table II: Principal characteristics - U.S. Navy Fleet Oilers

	AO-177 Class	T-AO 187 Class
Length overall	180.29m (59 l-6 ft-in)	206.50 m (677-6 ft-in)
Length BP	167.64m (550-0 ft-in)	198.12 m (650-0 ft-in)
Beam	26.82m (88-0 ft-in)	29.72 m (97-6 ft-in)
Depth	l4.63m (48-O ft-in)	15.24 m (50-0 ft-in)
Design draft	9.75m (32-O ft-in)	10.52 m (34-6 ft-in)
Scantling draft	10.67m (35-O ft-in)	11.53 m (37-10 ft-in)
Block coefficient	0.61	0.64
Midship coefficient	0.977	0.981
Length of parallel midbody	none	none
Cargo capacity	120 000bbl	180 000bbl
Ballast capacity	8 656m^3(305 695ft^3)	11 754m^3(415 077ft^3)
Fuel oil capacity	1 91 1 m^3(67 500ft3)	2 022m^3 (71 400ft^3)
Fresh water capacity	69M^3(2 448ft^3)	118m^3 (4 176ft^3)
Total deadweight @ design draft	18 627MT (18 333LT)	25 974MT (25 564LT)
Lightship weight	9 198MT (9 053LT)	14 947MT (14 711LT)
Horsepower	I9 910KW (26 700bhp)	24 608KW (33 000BHP)
Electrical capacity	3@2500KW	4@250kW
No. of cargo pumps	8	8
Accommodations	200	137
Trial speed. knots	21.4	22.1
Type of propulsion machinery	single screw 4137kPa (600-psi steam)	twin screw medium speed geared diesel
Propeller	Fixed pitch	CRP

Table III: Engineering Deliverable Parameters - U.S. Navy Fleet Oilers

	AO- I77 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 man-hour cost per drawing	1.0	0.90
Peak engineering spending man-hours/month	23000	44000

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Integrated Design Packages: The Link Between Manufacturing and Design

No. 6B-3

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ABSTRACT

The use of product oriented work break down structure is widely accepted as the most efficient ship building strategy for new construction. Much literature has also been published on applying these concepts to overhaul strategies. The intent of this paper is to describe the Philadelphia Naval Shipyard process in applying the concepts of product oriented work break down structure to the overhaul of Naval ships. The specific process described in this paper will be the development of Integrated Design Packages (IDP's). An IDP is the link that will provide an integrated design instruction that incorporates engineering, manufacturing, and producibility attributes into the design product at PNSY. This paper will provide a history of IDP development, describe its uses and also predict future uses. I will try to impress upon the reader the flexibility of the approach by relaying the many different applications of the IDP to date. Photogrammetry will alSO be addressed as a means of gathering large amounts of shipcheck data needed to develop the IDP. Also to keep things in perspective IDP's are one part Of thc OVerall Zone Technology concept that has been implemented.

ACRONYMS

IDP - Integrated Design Packages
CAD Computer Aided Design
CAD/CAM - Computer Aided Design/ Computer Aided Manufacturing

BACKGROUND

Conventional drawing development and installation Strategy for the Overhaul of ships havc traditionally been by system. Although the system approach has been gradually changing to a product strategy. it is beneficial to review some of the inherent problems the traditional system approach forces on the mechanic. Traditionally. conventional drawing strategies are developed by system. There are obvious needs for system design. Performance requirements, system integrity and testing all require a system type analysis. However. the next step is critical because after systems performance is addressed, product similarities and geographic constraints should take precedence and be of primary concern to the work instruction. Generally. the transition from a system approach to a product approach does not take place. The traditional approach to work definition i.e.. drawings, routings etc. is to continue the system approach. Therefore. drawings. routings, and work instructions are all issued in a system format.

This creates a basic conflict between how work is issued and how work is executed. The mechanics' efficiency is limited by the geographic constraints of his or her surroundings. BulksheadS. ladders and other access interferences into an area limit the ability of the mechanic to do work. In addition, if like work is not identified for the mechanic to accomplish at the same time in his or her geographic area. a great opportunity to rcalizc efficicncy Of action is lost. The results of issuing and executing work by system are lack of integration. interferences, delays. and rework. This shipyard transitions the system approach into a geographic/producl approach using Zone Technology. Under the moniker of zone Technology lies Several initiatives. This paper attempts to explain one specific initiative under Zone Technology that is called an Integreated Design Package (IDP) whose benefits are targeted at solving the

Iack of integrated work resultant from a system approach.

DEFINITION

The definition of an IDP is simple. It is a design document showing all work in a limited area that provides a more producible installation with no major interferenees. It consists of an:

isometric engineering composite.
composite plan views and arrangements.
- installation views.
. prefabrication. list of materials. and
- preoutfit.

The isometric engineering composite is the road map to the IDP. It provides the users. which are many, with an "at a glance" idea of the complexity of the project. the isometric is arranged to show the most information possible, taking into account the objects hidden by the isometric view. The isometric also references all other work show11 on the IDP. e.g.. composites. on which Sheets the installation appear. where prefab and preoutfit information appear. etc. Along with the isometric are technical notes required to accomplish the installation.

Composite plan views are probably the most critical phase of IDP development. 1t is in this phase that producibility concepts are reviewed. However ephemeral some concepts appear to be, producibility is not one of them. The savings in this phase are real and will be discussed in detail under IDP dcvCloplllcnt.

Installation views and associated list of materials are the next part Of the IDP. The installation view shows all locating dimensions necessary for the mechanic to install the components. Separate sheets arc provided for this step. A traditional approach might advocate including all locating dimensions on the composites. This argument has merit but after reviewing several composites it was determined that the amount of information becomes so great on the composite tbat it was not always easy to discern dimensions and that it may lead to the possibility of mistakes. To make it easier for the mechanic, a separate installation section for each IDP is included with easy to read uncluttered information.

Prefabrication is determined in engineering and forwarded to production. Traditionally it was left to the production department's discretion as to what areas were prefabricated. Sadly the history behind this strategy was attributed to the inaccuracies of design documents. Because the production department did not have a high a level of confidence in the design drawings. they were first verified to assure the information was correct. Inaccurate design drawings result in incorrect perfabrication pieces that could not be used. The IDPs are developed to a higher degree of accuracy allowing prefabrication information to be taken directly from IDPs without verification.

Also included in an IDP. where applicable. are the preoutfit instructions. N , elements that can be installed into structures before erection onto a ship. Anything installed in the shop is usually cheaper and safer to install versus shipboard. IDPs detail what is preoutfitted. Preoutfitting provides tremendous opportunities for cost and schedule savings.

The best way to view an IDP is to envision it as a file of information to install a complex area Of a ship. The IDP approach is not used for the entire ship. It is directed at complex areas of the ship that have multiple engineering disciplines and production shops involved that an integrated approach benefits.

DEVELOPMENT

The development of an IDP is based on shipcheck information. It is importante to start with an accurate baseline of information because new systems to be installed must integrate with the existing systems. Because much Of the information on an IDP has the potential for prefabrication accurate information is necessary. This requires the area to be verified with shipboard visits, i.e. shipchecks. "As-built" drawings do not provide the necessary accuracy and are not used directly. A shipcheck for an IDP area requires that the existing conditions of a compartment be documented. The IDP area is shipchecked for remaining systems that will not be affected by the overhaul. General ly the compartment structure is shipchecked along with piping. ventilation.

electrical and foundations that will remain. After shipcheck a Computer Aided Design (CAD) model is created showing the existing conditions as determined by shipcheck. This model is the baseline for an IDP.

As new systems are developed they arc integrated into the existing model essentinlly creating a composite model of the area showing both new and existing systems. Although IDP can be developed without the use of CAD equipment, the ability of CAD to manipulate information and communicate to many users makes it essential to this type of project. CAD also affords the potential to automate many aspects of the manufacturing process. This feature will be discussed later.

Once a CAD model has been developed a producibility review begins. The simpleste and shortest definition of producibility is an attribute of a design product which allows it to be manufactured effectively with its available facilities. Some attributes that are reviewed for are (Reference I):

- evaluate complexity of design.
- simple measuring.
- simple manual layout,
- work position,
- accessibility.
- proximity of hull structure.
- Straight piping,
- parellel pipes. and
- simple shapes

In general producibility aspects of overhnul designs have been ignored. It is the responsibility of the IDP to address this topic. After producibility improvements the model is reviewed for interferences. This step is automated with CAD developed models. The model is checked for "hits" and when identified they arc highlighted in the model. These interferences are resolved, forwarded back to the technical code for incorporation into the drawing. lnterferences are not limited to hard hits between systems. Other problems such as inadequate maintenance areas accessibility of equipment. door swings. etc. are also reviewed and resolved.

At this point in the IDP development process the model of the compartment is free of interferences and the package is reviewed for manufacturing information. The IDP is reviewed for prefab opportunities. Piping and ventilation systems are broken into assembly drawings and forwarded to the manufacturing facilities for make up. As mentioned earlier this is a significant departure from a traditional approach of prefab at PNSY. Traditionally. prefab decisions were made in production, which required another set of drawings. In this IDP process assembly drawings are developed directly from the model.

Another manufacturing review is for preoutfit opportunities. Preoutfitting is the installation of foundations, equipment and systems into a Iarge structural unit prior to its attachment to a ship. Preoutfitting has proved to be very cost effective in that anything worked in the shop versus shipboard tends to be a safer and less costly installation. When applicable. the IDP provides preoutfit instructions which tell the production shops which assemblies are to be preoutfitted.

GOALS

There are many objectives to this philosophy. Primarily IDPs create an interference free work area with the resultant benefits of minimizing rework or delays. The IDP also attempts lo provide the mechanic with an easier product installation by reviewing producibility aspects of design. By being developed on CAD equipment it creates an electronic database of information that can be shared among many users. The information is shared among various engineering sections aS well aS with production and manufacturing sections. The IDP acknowledges the product approach to engineering in that it shows all work in an area, not just a system by system installation. This allows like work to be identified, scheduled. and planned more efficiently. The IDP acknowledges the physical constraints of the work site by providing a work package in a defined area of the ship in which mechaincs can accomplish a number of tasks without leaving the work site.

In addition there was an unexpected gain in the area of field support. When problems arose in compartments for which IDPs were developed, the changes, if required were able to be made quickly and in an informed manner. This benefit can be directly attributed to comprehensive knowledge the IDP designer has of the IDP compartment. The designer knows what the impacts of change will be to all other systems and is also able to decide quickly which alternative provides the Ieast disruption to the space.

SELECTION CRITERIA

What makes a compartment a good candidate for the development of an IDP? Large Complex alterations tend to be good candidates for this type Of effort. These are areas that a failure or delay in completion Would cause a major impact on the project. In addition. historical data may indicate areas that are critical and will likely effect problems. Other considerations are preoutfit opportunities. Preoutfit is actively solicited because of the potential savings that can be realized in this area. Compartments are good candidates for IDPs if many different engineering and production shops are involved. This integrated approach along with the interference control allows for a more organized and directed approach toward compartment completion. Also, compartments that are gutted provide opportunities for IDP development.

EXAMPLES/HISTORY

The IDP process began with two test projects to validate the COllCept. The first Iwo projects were accomplished for the air conditioning plant installation on the CV-63. USS Kitty Hawk (see figure I). As can be seen from the figure the composite is strictly a piping composite. no other detail information is included. At the time of development of the 1DP the experience of the CAD operators was limited to piping. In addition. the CAD software was relatively undeveloped in other areas of modeling such as ventilation. However rudimentary the initial packages were, positive feedback was received from the production department. There were fewer installation problems in the two compartments for which IDPs were developed.

The next generation IDPs were developed for the USS Constellation, CV-04 (see Figure 2). IDPs were developed for air conditioning plant installations. rotary retraction installations. radar installations and various other installations. A total of twenty IDPs were developed. It is obvious that at least

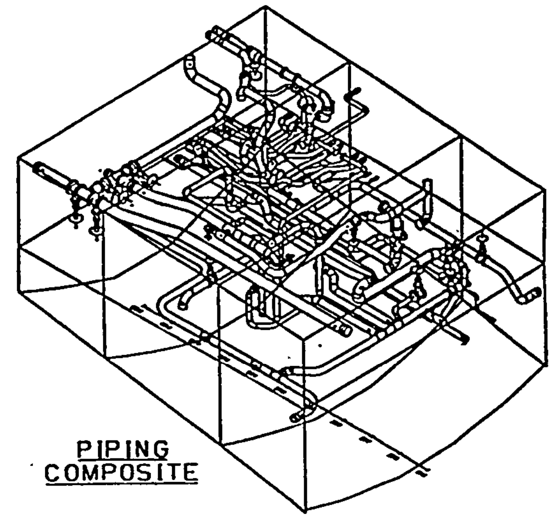

Fig. I CV-63 Piping composite. Air conditioning piping

the knowledge of modeling increased from the first efforts. This particular model (Figure 2) includes not only piping but also ventilation, cableways, equipment. lighting and foundations. This model is more complete, approaching the goal of a composite showing all information, integrating the entire design. and providing prefabrication information. all directly developed from the CAD model. The IDPs are developed on full size drawing sheets to Show all the necessary details.

Figure 3 is an IDP which provided information for ventilation along with a full structural, piping, ventilation and cableway model. Figures 4 and 5 are plan views of this model showing composites. These figures (3.4, and 5) show all systems being installed in the compartment and was a great improvement over the initial IDPs described earlier. Figure 4 illustrates a simple benefit of an integrated approach that is not always obvious. Lighting fixtures are often the first hardware to be installed during the availability for the obvious necessity. Historically the lights are installed and modified numerous times during the availability because of continuing interferences. Once the composite is completed and checked for interferences the light locations are determined and can be installed without the need for modification due to interferences. This is a simple but effective application.

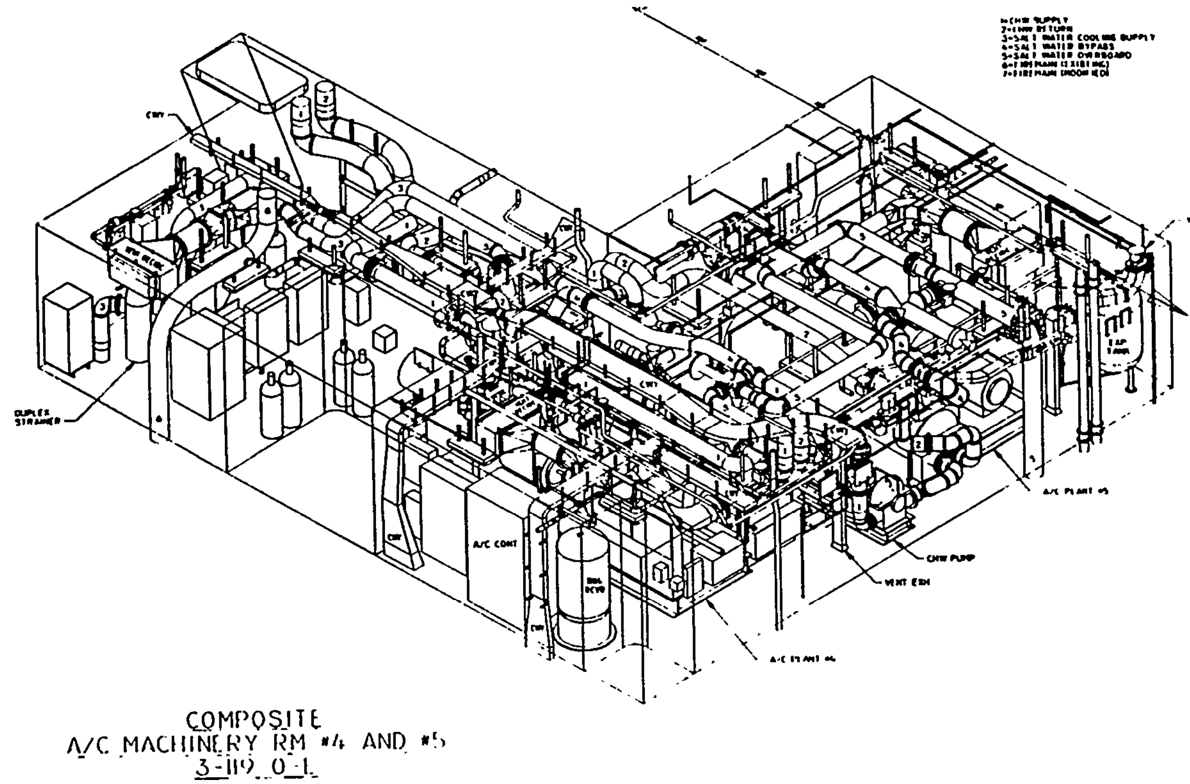

Fig. 2 CV-64 Integrated Design Package composite

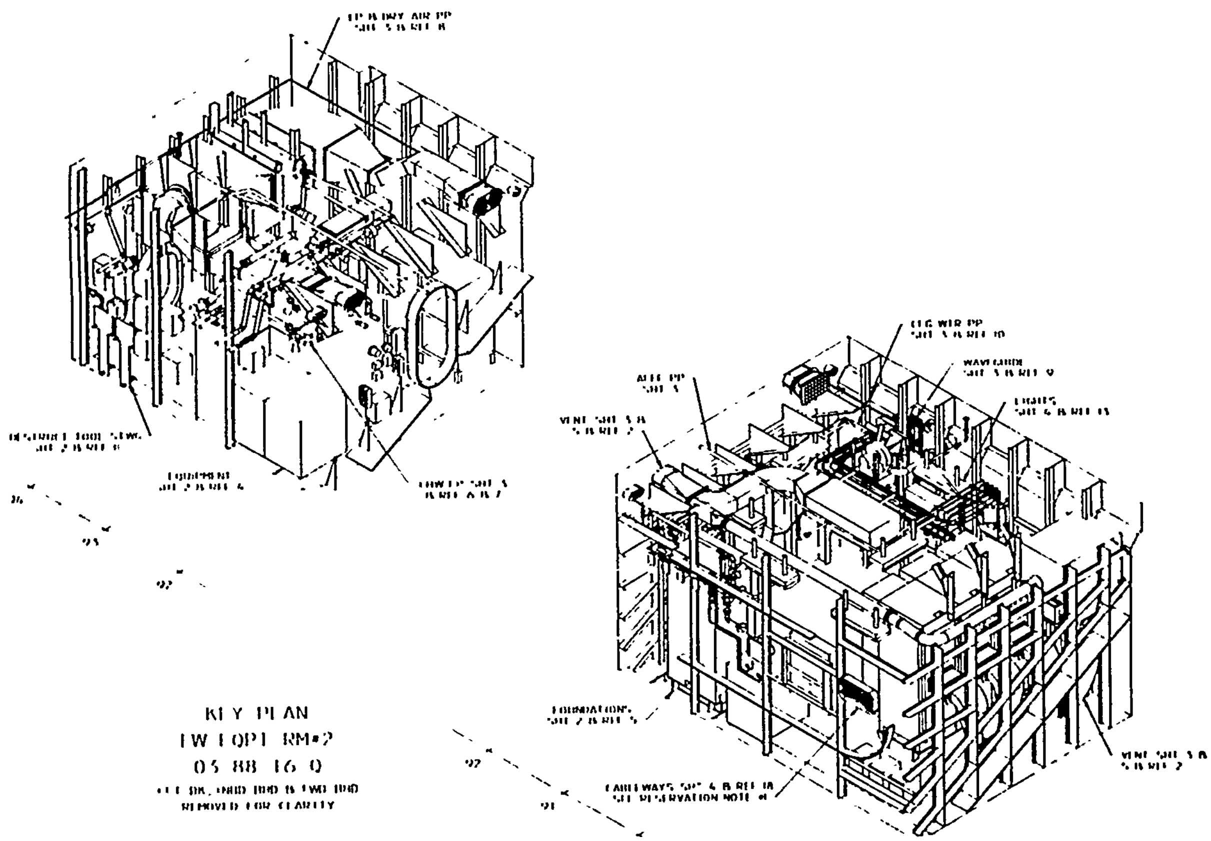

Fig. 3 CV-64 Integrated Design Package composite E.W. Eq. Room #2

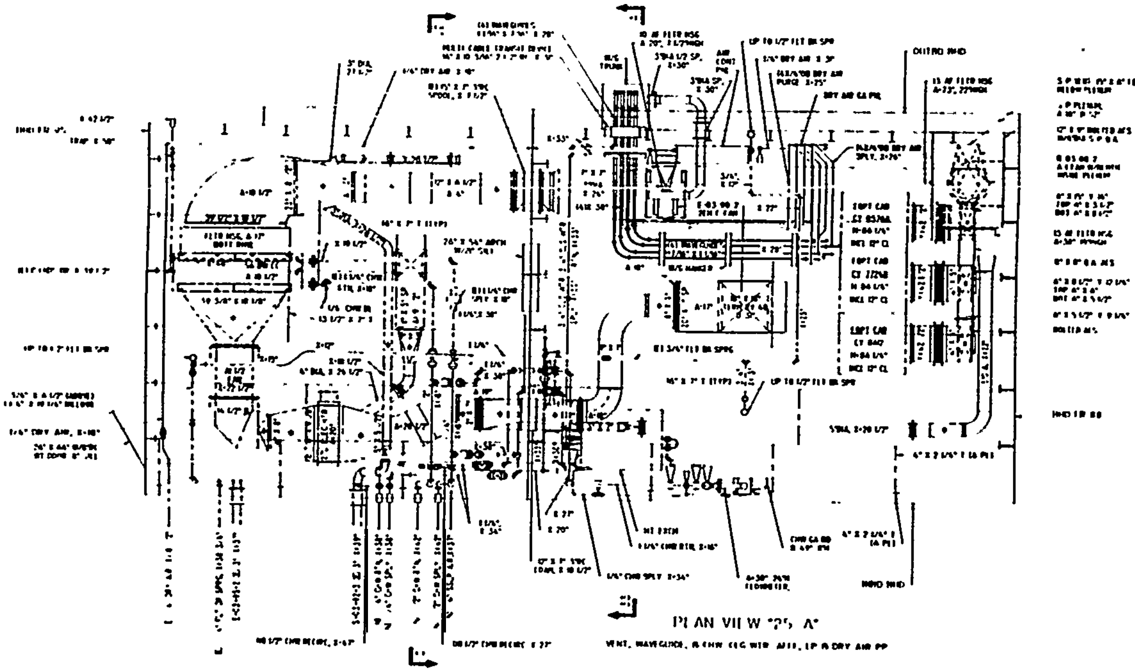

Fig. 4 CV-64 Plan view E.W. Eq. Room #2 from model.

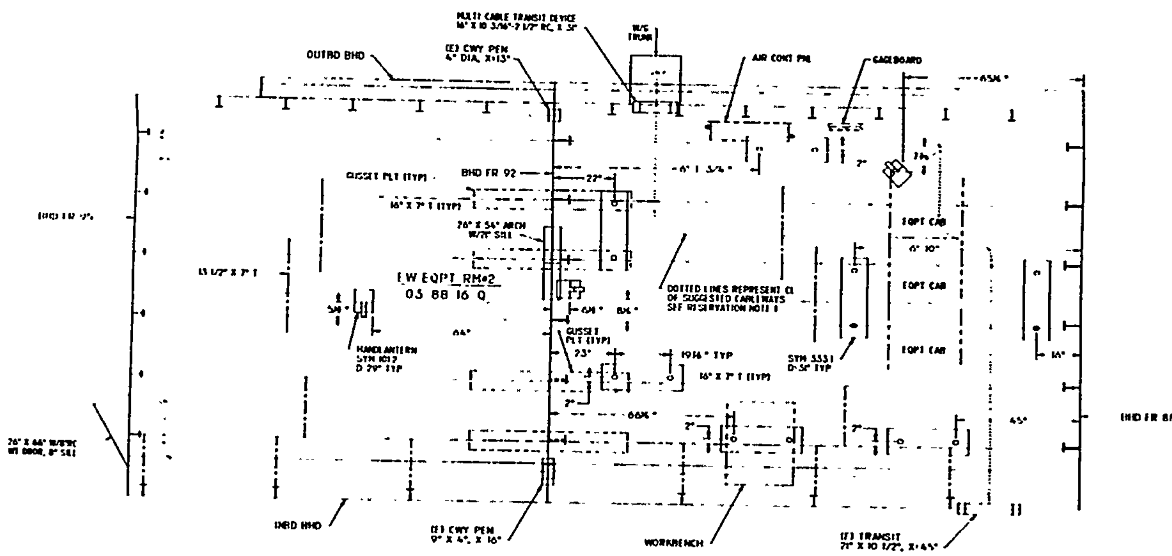

Fig. 5 CV-64 Plan view E.W. Eq. Room #2 from model.
(lighting and cableways)

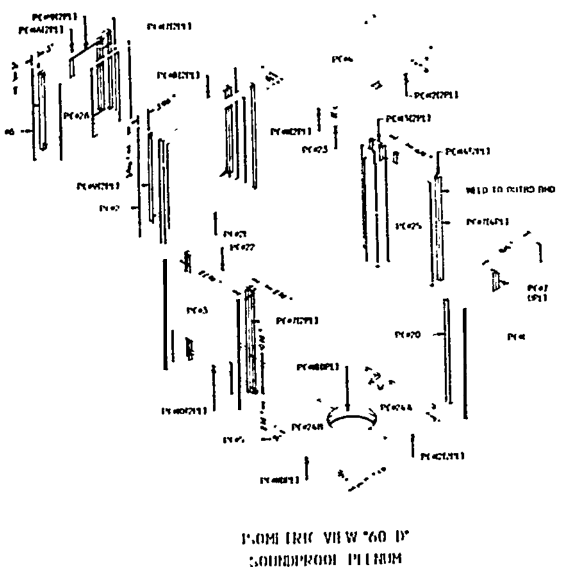

Fig. 6 CV-64 E.W. Eq. Room fabrication detail

Figure 6 is the detailed fabrication information for a ventilation plenum. The point to be emphasized with this example is the flexibility of the information that can be developed once the model is created. This type of information would never have been provided from the engineering division.

OPPORTUNITlES

lntegrated Design packages provide many opportunities for improved work. They provide opportunities to enhance the sequencing of work. Since an IDP Shows all work in an area it allows for planning schedule and sequence work more efficiently.

Other opportunities exist in Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) interfaces. Since IDPs are developed on CAD equipment. more opportunities exist to pass the information electronically to the manufacturing and production departments There is no need to recreate information for CAM development if it has already been developed in engineering. The other benefit is that all departments work from the same baseline information Ill addition to maximizing CAD/CAM usage another opportunity exists to maximize the uses of IDP information in planning Ill effect at every opportunity the information should be shared. The electronic information developed for the IDP can be used in the entire planning process as well as manufacturing and production. For example the IDP can be used by other engineering disciplines in developing drawings. The information can be passed to material ordering, work packing. scheduling, and estimating. Sharing information also intrinsically standardizes the information The goal is to create the information once in a format that satisfies all user requirements.

Photogrammetry has also provided the opportunity to gather the large amount of shipcheck information necessary to develop an IDP. In essence,. photogrammetry lends itself nicely to shipcheck applications because of its ability to gather information accurately. With the use of photogrammetry to gather shipcheck information and CAD/CAM IO transfer data from engineering to manufacturing. a complete electronic transfer of information is realized.

FUTURE

It is the intent of the IDP process to maximize CAD/CAM transfer of information. In addition, the use of photogrammetry to gather large amounts of information is a prime area of investigation. This technology may provide the vehicle to cheaply gather large amounts of information that will allow more IDPs to be developed. I IDPs are shipcheck intensive but the use of photogrammetry to shipcheck may resolve this problem.

Producibility has only been addressed superficially. This is the one area where the greatest return on investment may come. More attention needs to be focused on how a mechanic performs his or her work and how the engineering design supports their efforts. All too often existing designs are reused without at least a circumspect look to see if it is indeed efficient. To date the IDP has bccn only at the tip of the iceberg in this area.

The usc Of CAD II equipment is also eagerly anticipated. CAD II is the new hardware/software Computer Aided Design equipment being purchased by the Navy to replace existing antiquated equipment. This new hardware will also speed the IDP process. With the old CAD hardware the development time would increase with the number of components in the model. Large complex models would generally take an inordinate amount of time lo recreate

'The process is continually being refined to standardize, simplify and share information Compartments that have had the IDP process applied have been successful production installations which has encouraged further projects on future ships. Above all and not to be forgotten is the human resources to make the IDP process work. Dedicated, knowledgeable personnel are the key ingredient to IDP development.

SUMMARY

The integrated Design Package has proven to be a cost effective method of increasing production efficiency by improving the quality of the engineering product. The essence of the process is to integrate the system by system approach into a composite model. The integration that allows the designer to address certain attributes of the design that can not always be accomplished in the traditional system approach. These models mustbe accomplished on CAD for numerous reasons. CAD affords the designer the flexibility to manipulate information. It also allows the information to be shared. Not only can the information be shared among the engineering division, it can also be shared in production via CAM interfaces. The important attributes that must be achieved in any design are standardization. simplification, and shared information. The Integrated Design Package is the vehicle the Philadelphia Naval Shipyard uses to achieve these principles.

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An Approach to a New Ship Production System Based on Advanced Accuracy Control

No. 7A-1

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ABSTRACT

Mechanizing and automating have been accelerated in shipbuilding in order to respond to current situations such as decreasing numbers of skilled workers and increasing difficulty in recruiting new workers.

For effective implementation of mechanization or automation, current hull fabrication systems should be reviewed in order to make them suitable for intended mechanization or automation because geometric inaccuracy hampers implementation and necessitates voluminous work adjustments.

This report proposes a new ship production concept based on using advanced methods to keep the accuracy of the hull structure at a high level, such as numerical simulation of heat deformation in burning, welding and bending, mechanizing to reduce deviations dependent on human skill, and a three-dimensional measuring system for advanced accuracy control together with some examples of its actual application to checking block shape at the assembly stage and shipwrighting at the erection site.

INTRODUCTION

To maintain the competitiveness of a shipyard bearing the hardships surrounding the Japanese shipbuilding industry mentioned in the abstract, the extensive application of mechanization and automation is recognized to be indispensable at Ishikawajima-Harima Heavy Industries Co., Ltd, (IHI) and this can only be realized by upgraded accuracy. From this standpoint, to make an accurate block and to erect it accurately are the major task of current hull personnel in the shipyard.

This paper describes the recent efforts of how the company is rising to the challenge of accuracy of hull structure.

RECOGNITION OF THE PROBLEM

Since the latter half of 1950s when the idea of quality control was introduced in Japan, hull accuracy control concepts have been developed and widely used in each stage of hull work and with this a remarkable productivity improvement has resulted. However, looking at the final goal of having assembled blocks fitted and welded at the erection site without any remedial adjustment, it must be said that the present situation is still far from ideal.

Some recent analyses at the shipyards are explained below to demonstrate the current situation.

Manhour Analyses on Fitting and Welding at Erection Stage

Fig. 1 shows the percentages of expended manhours of fitting and welding work in the hull erection stage based on random sampling carried out in one shipyard recently.

1) Fitting. It is found that main work (essential tacking work) accounts for only 1/6 of the total fitting manhours, while manhours for adjustment work, such as trimming or back-stripping for correction of inaccuracy and

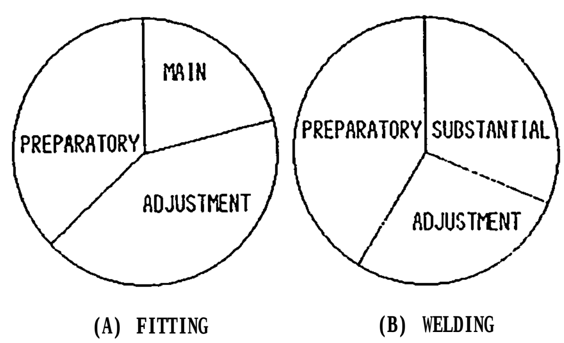

Fig.1 RANDOH SAMPLINC ANALYSIS OF ERECTION WORK

additional fitting of pieces for hammering or jacking, account for nearly 1/2, and manhours of preparatory work, such as cleaning after work, movement to a next work spot and preparation of tools or jigs, account for nearly l/3. It is obvious that the shipyard's target is to eliminate adjustment work, which accounts for half of the total fitting manhours.

2) Welding. As it can be seen, only 1/3 of the total welding manhours are used for substantial welding. Another 1/3 are expended by the preparatory work, such as preparation of tools, cleaning after work and movement to a next work spot, while the remaining 1/3 are consumed by various work making adjustment, such as welding of carried-over weld from assembly, remetaling to get neat edge-preparation, grinding for finishment and so on.

In addition, though it was difficult to analyze accurately, it was obvious that some portion of the substantial welding manhours in Fig. l(B) were expended for depositing excess filler metal due to wider gaps very often seen at joints. The influence of an inaccurate butt joint to the increased welding time is shown in Fig. 2. It is obvious that substantial manhours can also be saved, as well as eliminating manhours for the adjustment work, by improved accuracy.

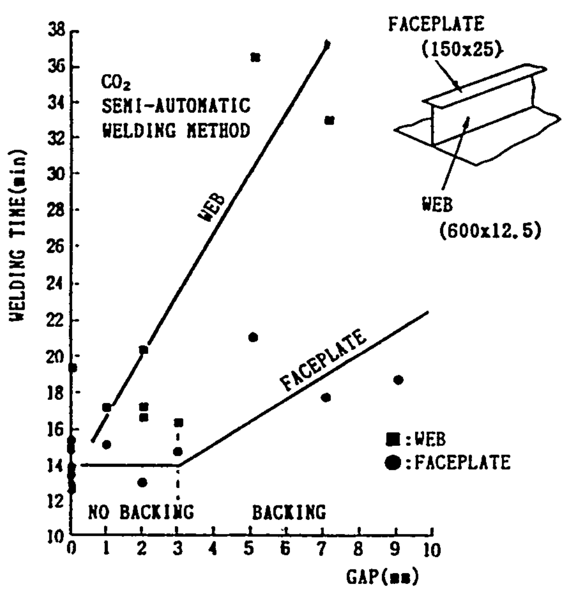

Fig.2 INCREMENT OF WELDING TIME DUE TO JOINT GAP AT ERECTION BUTT

INTRODUCTION OF A THREE-DIMENSIONAL ANALYSIS SYSTEM

As the existing measuring method was linear and planar, deflection and twisting of the three-dimensional blocks could not be accurately checked. The necessity for an instrument capable of measuring three-dimensional blocks of over 10 meters square within an accuracy of several millimeters has been sought for many years. The development of a new measuring technique was taken up in 1982 by the working group for three-dimensional coordinates measurement in the Super Modernization Committee of the Shipbuilders Association of Japan, with the participation of the following five companies: SOKKIA CO., LTD. as an instrument manufacturer, IHI and other three shipyards.

At the beginning, efforts were made to examine the applicability of two types of instruments, an electronic theodolite based on a triangular measurement method and an electronic distance-angle measuring instrument. It was found to be difficult to keep an accurate distance between the two instruments essential for the triangular measuring method. Moreover, due to the instability of the power source, inconvenience of transportation, and the requirement for three or more measurement technicians, it was decided not to take the dual theodolite and to concentrate to develop the application of the distance-angle measuring instrument.

During five years' effort of the working group, the distance-angle measuring method was proved to be applicable, subject to further improvement of the instrument for more accurate measurement and easier handling. After the working group dissolved, the manufacturer continued the efforts and finally reached "NET 2" as a product model in 1989 and "MONMOS" as a total measuring system in 1990, which are actually used in some shipyards in Japan.

The three-dimensional measuring instrument NET 2 was introduced in a Tokyo shipyard immediately after it came into use. Since then a hull block measuring system (hereinafter called the three-dimensional analysis system) by a personal computer incorporated with the MONMOS system has been developed so as to get the actual shape of blocks on a CRT. Other shipyards in the company have also introduced the MONMOS and another application for the ship repair field has been established. That is, to measure actual shell form in the vicinity of damaged shell plates for the purpose of defining the shape of replacement sections.

The MONMOS System

The following is an outline of the MONMOS system. The MONMOS system consists of a measuring instrument and a control terminal for data control. (See Fig. 3)

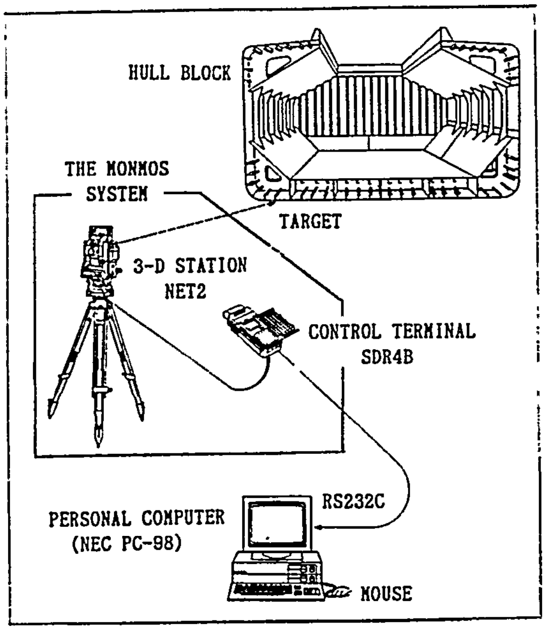

Fig.3 CONFIGURATION OF THE THREE-DIMENSIONAL ANALYSIS SYSTEM

Measurement ; Distance and Angle measurement using near-infrared rays.

Measuring accuracy ; Angle ±2 second Distance $\pm(1+2\times10^{-6}D)$mm Where D is measuring distance in millimeter.

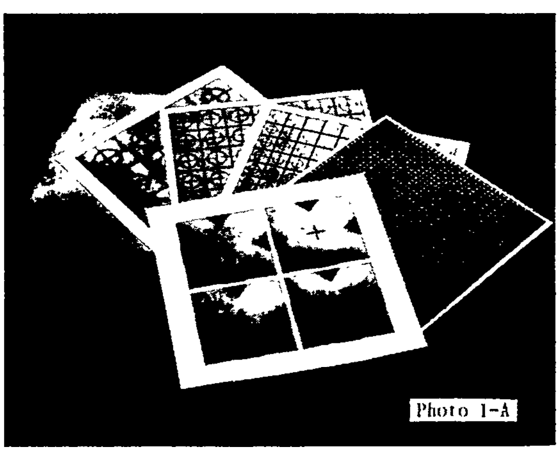

Photo 1-A

Measurable distance ; 2 to 100 meters

Target for the ray ; Microprism reflection sheet (10 to 90mm square), Rotary target (See Photos 1-A and 1-B) and etc.

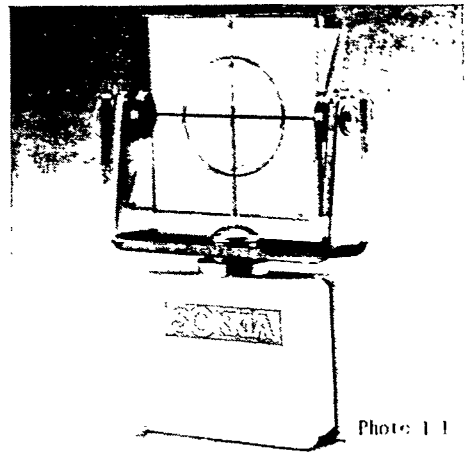

Photo 1-B

Measuring principle ; Triangulation by measuring two sides distances (I-O and I-Pi) and included angles (vertical angle and horizontal angle) (See Fig. 4)

a. The vertical direction is defined to be the Z-direction.
b. The first measuring point (0) is defined to be the origin of the coordinates axis.
c. The X-direction is

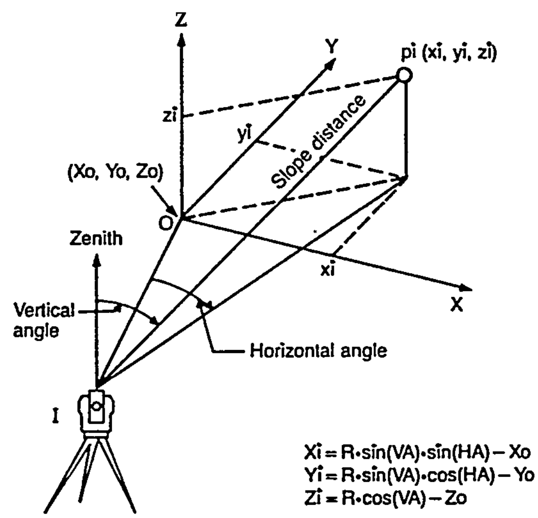

Fig.4 MEASURING PRINCIPLE

defined by the second measuring point and the X-axis is defined on the X-Z plane at normal to Z-axis.

d. Subsequent measured values are converted into coordinate values (X, Y, and Z) and recorded in the control terminal.

The main features of the system are as follows.

a. Measurements can be carried out by one person because one instrument is capable of measuring any size.
b. Coordinates can be combined, i.e. measurement of the back side which cannot be seen is possible by the function that stores measured values as coordinate values. Measurement can be continued with the same coordinate axis by measuring two known points (for example A and B in Fig. 5) even after moving the instrument to another point.
c. Since the measured values are recorded as coordinate values, various kinds of numerical analyses are possible by development of analyzing software.

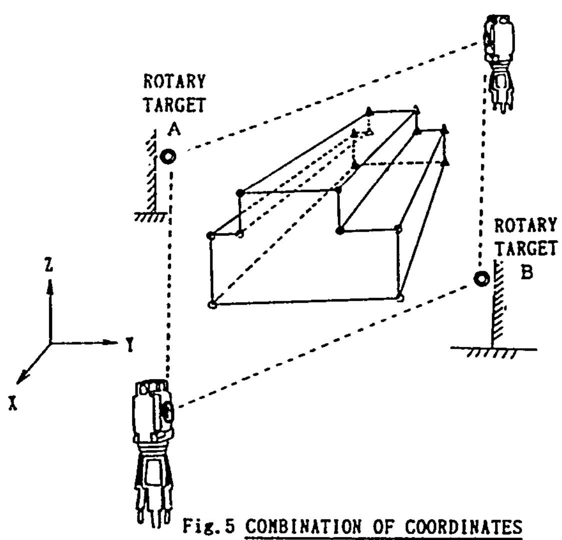

Fig.5 COMBINATION OF COORDINATES

Outline of the Three-dimensional Analysis System

For a long time after the introduction of the hull accuracy control concept in the company, the activity of accuracy control on assembled blocks was limited to measuring length, breadth or height by a linear tape-measure for later evaluation by manual data analysis.

When more precise blocks were called for, the traditional measuring method was not sufficient and measurement of points on any position of a block in terms of coordinate values was highlighted. But the measured points could be more than a hundred (infinitely great theoretically) and automatically the aid of calculation software became necessary to get various measured dimensions required for comparison with design data.

Thus, the company's three-dimensional analysis system was developed to comply with the above necessity with extensive applications for shipwright (this word is used to mean adjusting of a block's position properly after the block was erected and before it is fitted with adjacent blocks.) at the erection stage, the process of which is explained in Fig. 6 and summarized below.

a. Points on a block to be measured are specified based on a standard prepared and updated through experience.
b. Measured coordinates in a local axis are converted into coordinates in the ship's axis for comparison with design data. The conversion is generally carried out using three control points which are defined on a block and matched with the designated position in the ship's axis. When deviation from design data after conversion is found to exceed tolerances on some points due to improper matching by the above procedure, further adjustment by means of small rotation or parallel movement for closer matching can be carried out by manual operation in order to get smaller deviations.
c. Correction work on a inaccurate block is carried out based on the deviation from the above mentioned process taking into account of a result of a simulation for forecasting joint condition with adjacent blocks. After adjacent blocks are erected, a simulation of the joint condition between those erected blocks and this assembled block, using the shipwright data of those blocks and the measured data of this block is generally carried out, whenever this block is accurate or not.
d. The forecasted joint condition data by the above-mentioned simulation are used as a instruction for shipwright.

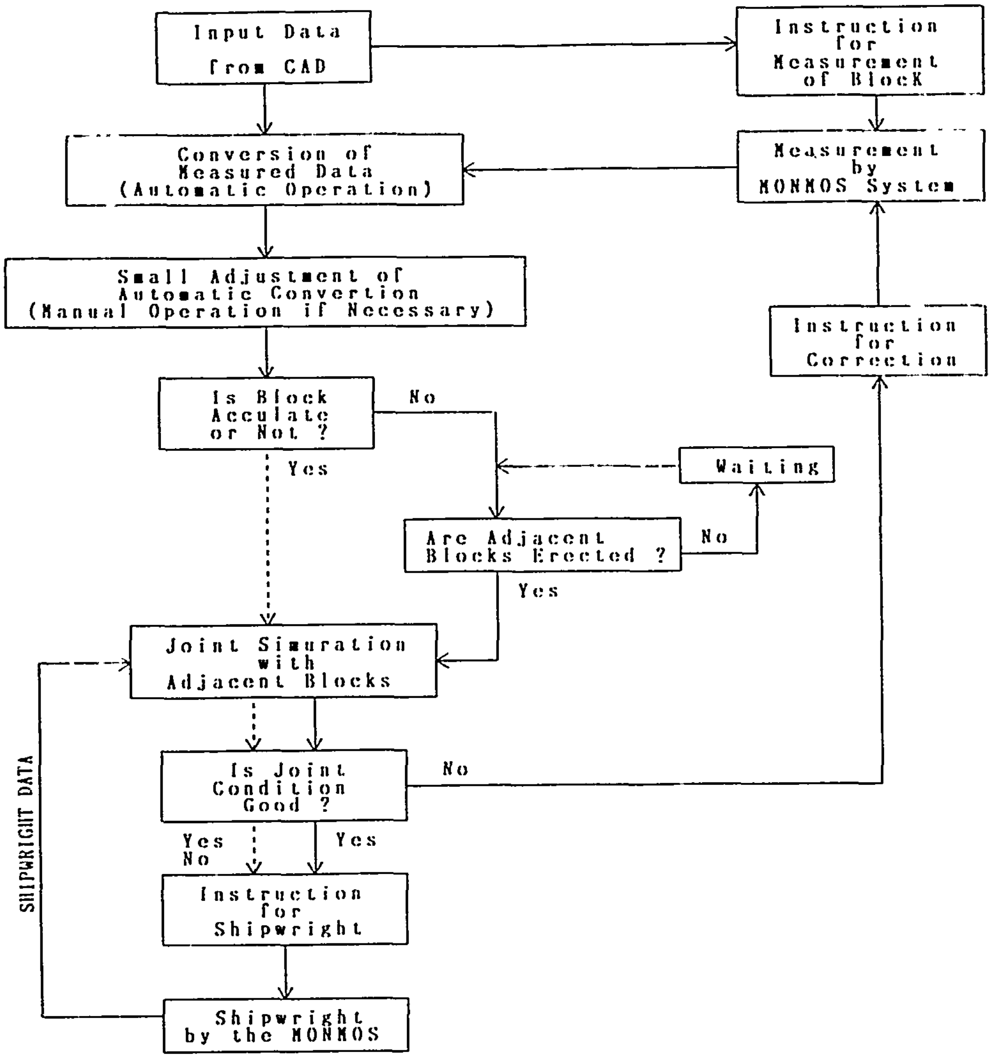

Fig.6 PROCESS FLOW OF IHI'S THREE-DIMENSIONAL ANALYSIS SYSTEM

Example of Measurement and Analysis on an Assembled Block

The following is an example of using the system on **33,000** DWT Bulk Carrier blocks.

Positioning of Targets. Reflection targets were attached on more than **80** positions covering four sides and root or top of transverse webs and longitudinal on an assembled block on the ground, rotary targets were set on two points (for example, A and 13 in Fig. 7) for the combination of measured data at different locations of the instrument.

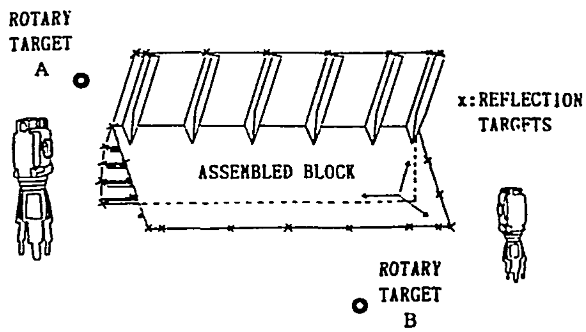

Fig.7 POSITIONING OF TARGET

Measured results. Measured data were transferred into the analysis system and converted into the ship's axis. Calculated results were illustrated on the CRT as shown in Fig. 8.

Evaluation of the results. Figure 9 is an illustration of a displayed results for the explanation purpose.

a. The block length was longer by as much as 14mm at the top but was nearly normal at the middle and bottom. Bigger discrepancy of top length in this case was attributed to

SHIP NO : IHI
FILE NAME : GSL8P. SDR

	STANDARD	LIMIT
LENGTH	± 3	± 5
BREADTH	± 3	± 5
HEIGHT	± 2	± 3
LEVEL	7	15

NO		(mm)	ERROR
1	MEMO	F-2	
	L	12750.0	0.0
	B	11986.0	0.0
	H	6335.0	0.0
2	MEMO	A-2	
	L	-2.0	+2.0
	B	14870.0	0.0
	H	5540.0	+4.0
3	MEMO	F-10	
	L	12753.0	+3.0
	B	7449.0	-1.0
	H	1852.3	-9.7 ▲

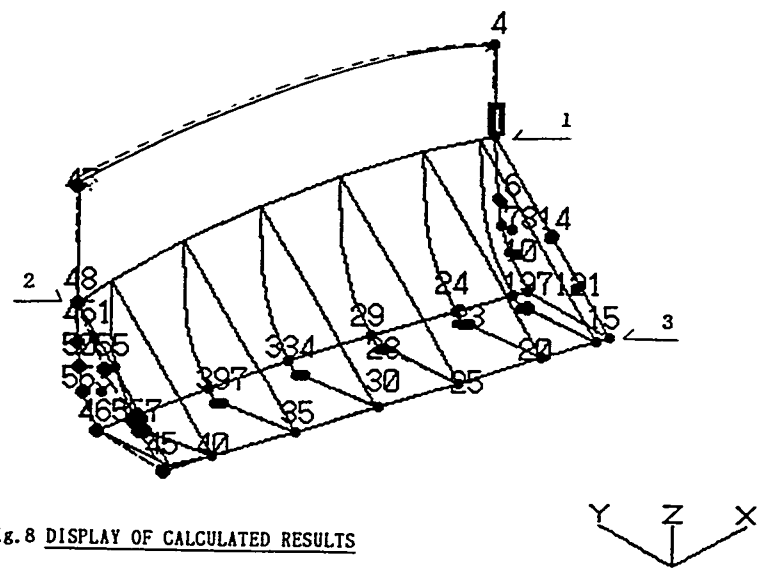

Fig. 8 DISPLAY OF CALCULATED RESULTS

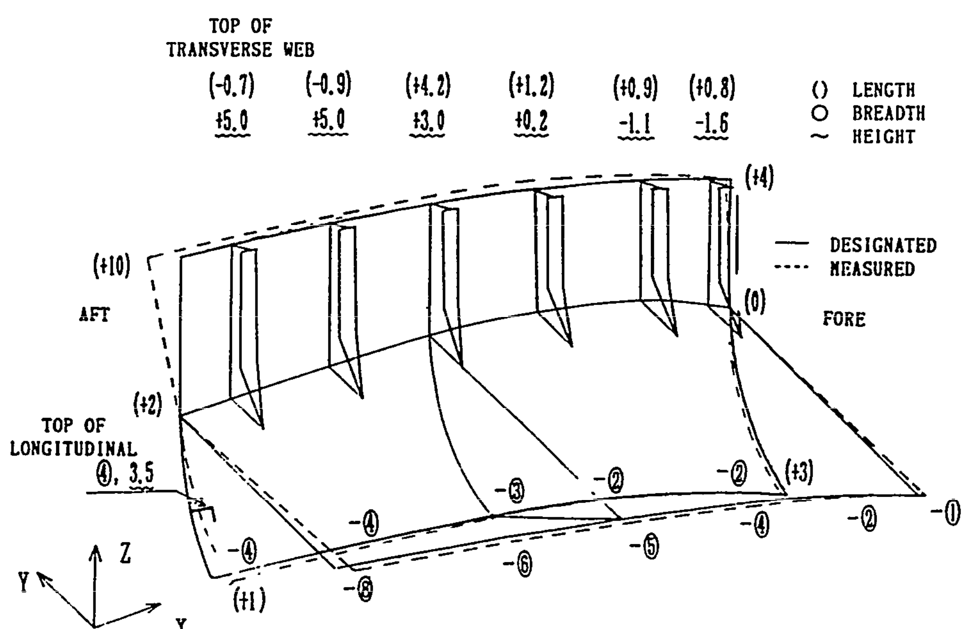

Fig. 9 EXPLANATION OF DISPLAYED RESULTS

smaller shrinkage than the expected value.

b. The breadth of the block tends to decrease at the bottom, especially at the aft. The block was found to be twisted.

c. Some dislocation of the frame top was seen in the longitudinal and vertical direction.

Actually this block was erected without correction and the detected phenomena were fed back to the next ship.

Application to Shipwright at Erection Stage

Previously, the positioning of each block at the erection stage was generally carried out in order to get good relative position with adjacent blocks and the importance of positioning a block in the ship's absolute coordinate system was not widely recognized.

Now the MONMOS system can be utilized and the policy of the shipwright has been changed to position every block onto the designated position in the absolute ship's coordinates axis one by one in favor of more accurate assembled blocks.

The following explains how the system is utilized at the erection stage in the shipyard.

a Two or three targets are attached at designated positions for shipwright on every assembled block before it is erected.

b. The absolute ship's coordinate axis is always used as a local coordinate axis of every measurement by the MONMOS system (See Fig. 10).

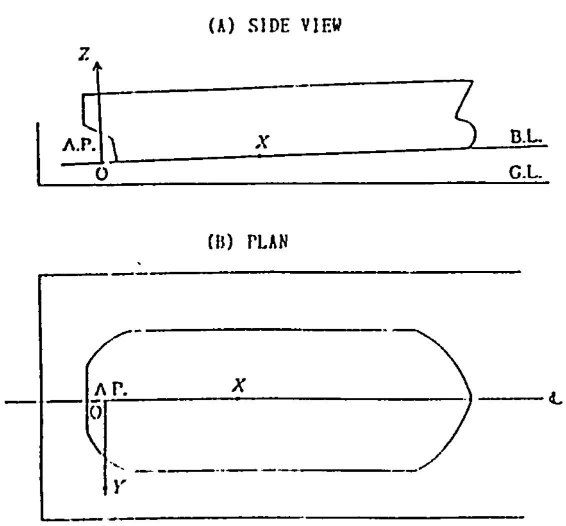

Fig.10 SHIP'S ABSOLUTED COORDINATES AXIS

c. From time to time during the process of shipwright of a block after releasing lifting wires. measurement by the MONMOS system is carried out in cooperation with shipfitters.

d. Final shipwright data of each block is transferred into the personal computer for the simulating calculation with subsequent blocks.

As blocks are positioned accurately one by one, by the new shipwright method. the extent of rework at the erection stage reduces remarkably. In addition, this method requires only one person for measurement instead of several persons as in the past. As the measurement for shipwright can be done at any convenient position using targets attached on a block beforehand, the access to higher clevation for measurement purpose is not required and this leads to safer working conditions (See Fig. 11).

Further Improvement of the Three-dimensional Analysis System

On the application of the system to actual production, accepting measurement errors to some extent cannot be avoided. These can be categorized as below.

a. Mechanical error of instrument : Read error in vertical direction.

b. Errors during data processing : Calculation error at combination or conversion of coordinate data.

c. Errors due to environment

i) Heat, moisture, electricity, magnetism and etc. : Unexpected movement of instruments.

ii) Vibration, wind, etc. : Dislocation of instruments.

iii) Backlight, heat wave, shade, etc. : Eye-reading errors.

d. Errors accompanied by a measuring method : Target setting errors, error of measured angle or measured distance due to improper angle or distance.

Errors of category a. can be minimized

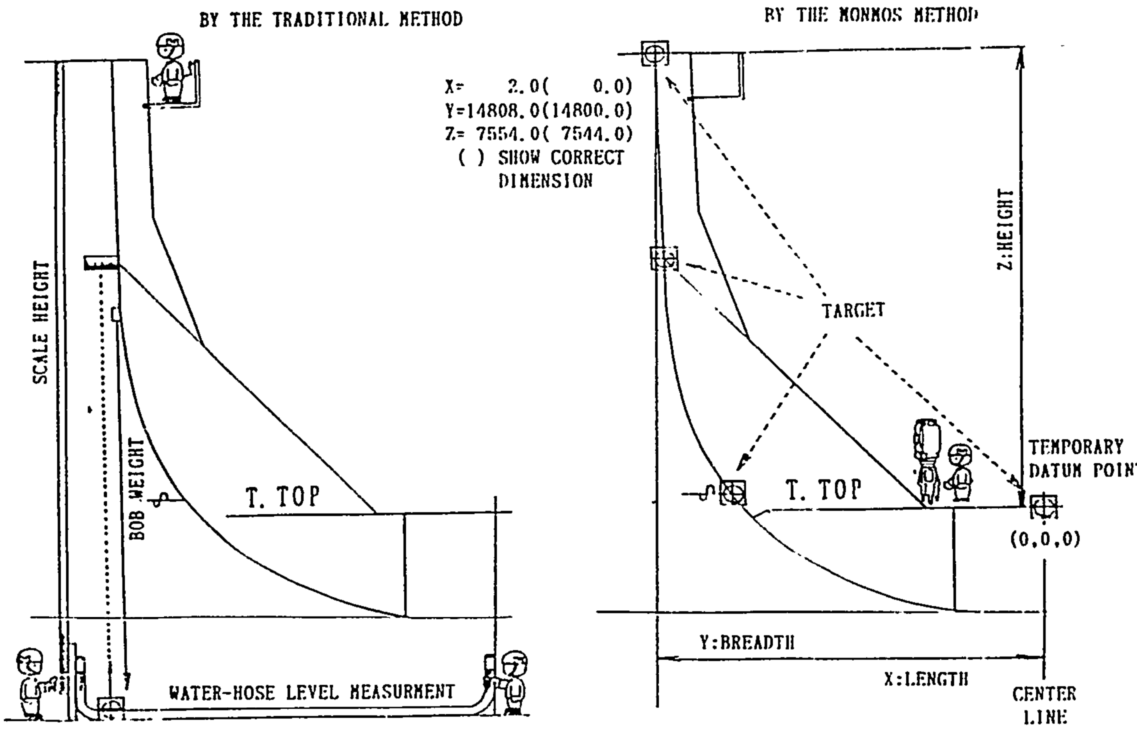

Fig.11 IMPROVEMENT OF MEASURED METHOD

depending on future improvement of the measuring instrument, while b. can be solved by improvement of the calculation software. Though a kind of an error such as category c. i) is always inevitable to almost all measurements in production sites, analyses as to cause and effect are not yet done subject to future examination. Errors such as c. ii), and iii) are expected to be reduced by preparation of a firm and covered station for the measurement, while d. is to be improved by training and education of measurers.

In addition to countermeasures to reduce the above-mentioned errors, which are rather inherent to the instrument, further improvements arc desirable on the application procedures. At the erection stage, as the combination of measured data is very often accomplished using common points for data connection, arrangement of these common points must be examined and improved by planning efforts. In assembly, it can be almost said that the accurate measuring and analyzing system of hull blocks in any size and shape has been established if numerous measurements are acceptable. However, for economical application suitable to production, there are many points to be improved further such as: determination of the minimum numbers of points on each block in order to specify the actual block shape, feeding of design data into this measuring and analyzing system in respect to the above determined measuring points, preparation of enough geometric space for measurement, scheduling to take time for the measurement, manhours saving of target fitting and so on.

CHALLENGE TO IMPROVE ACCURACY OF HULL BLOCKS

Measurement of assembled blocks by an improved method, the correction work on blocks before erection taking into account of shipwright data and a accurate shipwright method are introduced as described above. However, these are not the right way to improve the accuracy. In parallel with these, step by step accuracy improvement through various stages of work up to completion of hull blocks has been enhanced by recognizing the following two points as the right direction to solve the problem.

- Minimization of dimensional variation by mechanization.
- Accurate prediction of thermal deformation during burning or welding by simulation using numerical analysis software.

Efforts on the latter have been started

recently as a breakthrough to adjust parts data at the beginning of the data generating stage. These efforts will be reported on separately in the future after something has been established. Therefore, the approach to the former is explained hereunder.

Suggestion for Mechanization through Analyses of Variation

Fig. 12(A) and (B) show how the mean values and the standard deviations at each step of fabrication change by accumulated errors, taking block length on the skin plate and length of longitudinal stiffeners as examples. In the case of block length, it can be seen that the final deviation has been doomed before plate cutting process and the mean value changes by welding shrinkage. In the same manner, it can be said that the deviation is doomed by cutting at prefabrication process and that the mean value changes by welding shrinkage in the case of longitudinal stiffeners.

Fig. 13(A) and (B) show actual variation data of longitudinal stiffener fillet welding to the skin plate and variation of shrinkage of skin plate per one stiffener spacing due to fillet welding. From this, it is observed that fillet welding is carried out so as to keep the designated fillet size at a minimum within variation, resulting excess deposit metal and excess heat input on the average, and that the transverse shrinkage of the panel varies accordingly.

Both of the above examples are suggesting the most effective points for future action. The source work creating the above mentioned fatal variations can be mechanized or automated with great possibilities and at the same time unavoidable welding deformation and shrinkage will be able to be predicted by the simulation for feed back to original parts definition.

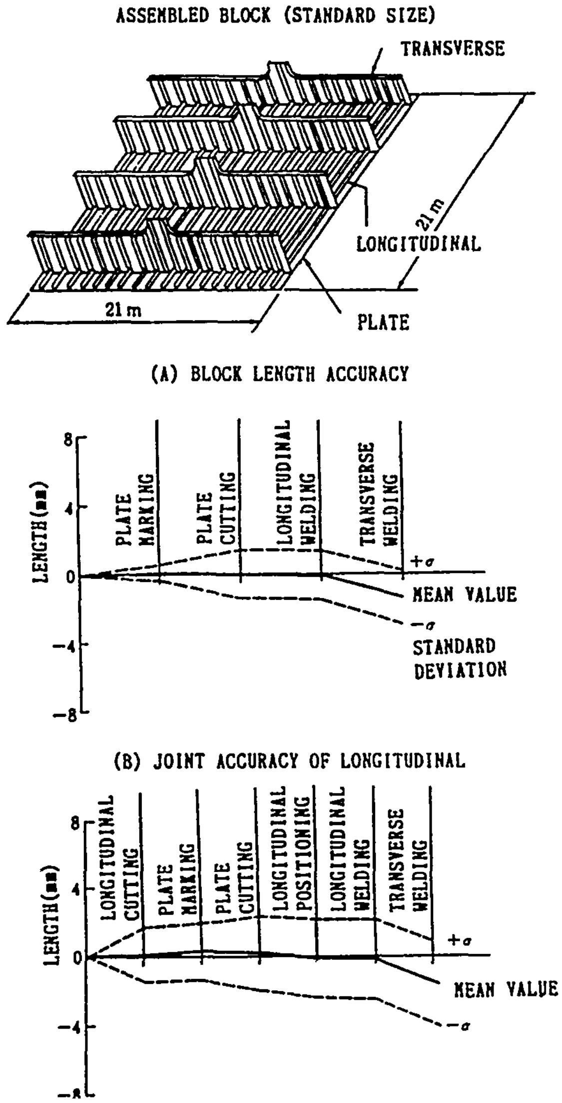

Fig.12 ACCUMULATED ERROR OF BLOCK SHARE

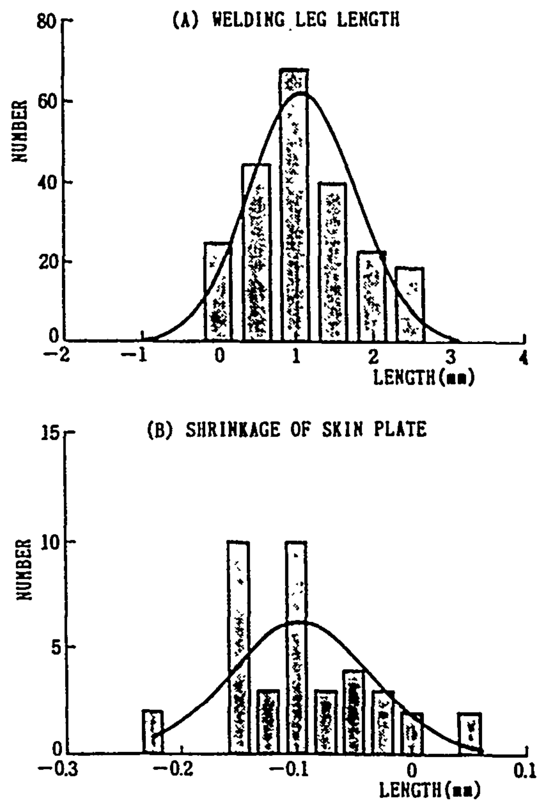

Fig.13 VARIATION OF TRANSVERSE SHRINKAGE DUE TO FILLET WELDING

Expected Improvement in the Hull Structural Work

The final goals of efforts by the new accuracy control concept, incorporated with reduction of variations by mechanization or automatization, heat deformation analysis for original adjustment of parts data and the development and application of the three-dimensional analysis system to assembly and erection stages, are placed on the following points:

- extensive manhour savings by eliminated rework,
- simplification of work by accurate parts or blocks for less dependency on skilled workers,
- higher quality of the ship itself, and
- more mechanization or automatization by more improved accuracy in continuous cyclic manner.

CONCLUSION

Accuracy control efforts in IHI supported by the new concept have been explained above. As will be accepted by everybody, this new step has been very much dependent on the materialization of an accurate three-dimensional measuring system. In this respect, the endeavor by the working group in the Shipbuilders Association of Japan especially the same by SOKKIA CO., LTD. have to be much appreciated.

A super-rationalized hull erection stage is envisioned, where adjustment burning and backing-strip fitting are no longer necessary, and a wide extent of automated work is taking place. Efforts are continuing to realize this.

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Paper presented at the NSRP 1992 Ship Production Symposium. New Orleans Hyatt Regency. New Orleans. Lourstana. September 24.1992

Photogrammetry and Multi-Headed Theodolite Systems as Complementary Tools

No. 7A-2

Eric L. Boyer, Visitor and Peter L. Sparacino, Visitor, Philadelphia Naval Shipyard

ABSTRACT

Foundations for wet accumulator bottles (WABs) are large, complex structures that require fabrication in accordance with exacting dimensional tolerances. WABs are those tanks that store steam for the launching of aircraft off aircraft carriers. The traditional process for fabrication and installation of WAB foundations is a high risk venture not only from cost and scheduling perspectives, but also from a geometrical perspective. The WAB foundations consist of two units, each with four structural members and two padeyes that require fabrication and installation with respect to an imaginary WAB centerline. Through the complimentary use of photogrammetry and a multi-headed electronic theodolite system, the foundations can be fabricated in the shop to the correct shipboard geometry, and installed within tolerances, and within cost and schedule. With all of the fabrication completed in the controlled environment of the shop, all structural, fabrication, and installation problems can be alleviated before the actual shipboard installation. This paper explains the methods and techniques for using photogrammetry and a multi- headed electronic theodolite system as complimentary tools. It explains the practicality of collecting dimensional data from the existing ship structure using photogrammetry, and using a multi-headed electronic theodolite system to assist in the fabrication of the WAB foundations.

BACKGROUND

The efficiency of an aircraft carrier depends upon the speed of its aircraft launching operations. Therefore, a compact and efficient device for getting all aircraft into the air within a short time is needed. This requirement is met by the modern carrier catapult. The catapult permits controlled application of a predetermined amount of power at any desired instant. Through the controlled power of the catapult, the aircraft on the catapult is safely accelerated from a standstill to flying speed within the limited space available on the flight deck of a carrier.

During the 1950's, the British investigation of steam as the source of power for catapults attracted the interest of the U.S. Navy. The principle component of the steam catapult is a cylinder/piston assembly - two power cylinders and two pistons per catapult. The spear-tipped pistons, which in the launching operation are forced at high speed through the cylinders by steam pressure, are the assemblies that, along with the aircraft's engine thrust, actually propel the aircraft down the flight deck. Power to drive the pistons and the aircraft load comes from expanding steam piped to the catapult from the main boilers of the ship. This steam is placed under pressure in large tanks - called accumulators or receivers - located under the launching catapult on the hangar deck. From the receivers, the steam is transferred at the moment of launch into the power cylinders. Steam pressure acts directly on the piston and propels the piston/shuttle assembly through the cylinders, thereby launching the aircraft.

As part of the Service Life Extension Program (SLEP) for aircraft carriers, the obsolete aircraft catapult dry receivers were replaced by new wet accumulators. The replacement required the removal of eight vertical steam receivers, four each from #l and #2 catapults (catapults #3 and #4 were overhauled in a similar fashion). The dry receivers extended vertically from the main deck to below the flight deck, under both #l and X2 aircraft catapults. After removal of the dry receivers, an intermediate deck was installed between the 01 and 02 levels, under each cata- pult. With the installation of the decks completed, the WAB foundation assemblies were installed, followed by the WAB installations.

A

PLANNING

The initial plan called for the completion of a photogrammetric survey of dry receiver spaces #l and #2 aboard the USS Constellation (CV64) while at port in San Diego, during February of 1990. The photogrammetric survey was to consist of the interface points between the existing ship's structure and the *new* WAB foundations. The photogrammetric data was to be modeled using a computer aided manufacturing (CAM) system. The CAM model was to be downloaded to a computerized plate cutting machine, whereby the WAB foundations were to be cut to exactly match the ship's existing structure, within a tolerance of 0 cm (0 in.) to 0.5 cm (0.1875 in.), the required root opening of the weld. The initial plan would have allowed for a first-time fit of each WAB foundation. However, upon inspection of the two (2) dry receiver spaces while on shipcheck in San Diego, the spaces were found to be too congested with the existing dry receiver tanks and foundations. Clear lines of sight required for photogrammetry could not be established, and physical constraints were too *severe.* The initial plan would have insured that the photogrammetric survey and data reduction were completed before the start of the design of the WAB foundations. The WAB foundations could have been designed and fabricated using exact ship dimensions. Due to the inability of obtaining the photogrammetric data on shipcheck, it seemed the first-time installation could not be achieved.

A new scheme was developed whereby the photogrammetric survey was accomplished only after completion of both the removal of the existing dry receiver tanks and foundations, and the installation of the intermediate decking. This required that the photogrammetric survey be completed while the CV64 was in drydock at the Philadelphia Naval Shipyard in February of 1991, severely impacting the production schedule. All of the design and 25% of the fabrication and installation were to be completed by this date. To hold schedule; a fast-tracking approach was developed whereby an electronic theodolite system was employed to transfer the photogrammetric data to the fabricated WAB foundations as they became ready for assembly on the shop floor. This would allow for a final cut in the shop, and a first-time fit aboard the ship.

Under the new scheme, the design of the WAB foundations were completed using as-built plans and the ship's book of offsets. The design dimensions were modeled on a CAM system where 5 cm (2 in.) of excess was added to the foundation sections. The excess allowed room to lay the cut lines *on* the foundation sections using the electronic theodolite system. The CAM model was then downloaded to an electronic plate cutting machine. The plates were cut with the excess and delivered to the shop floor. During the same time span, the photogrammetric surveys of dry receiver spaces #l and X2 were accomplished, and the photogrammetric data was reduced to ship's coordinates. As WAB foundation sections were assembled on the shop floor, the photogrammetric data was transferred into a local coordinate system (a coordinate system generated from the imaginary bottle centerline) for each of the four (4) foundation sections. This assured that the foundation units were fabricated, and that the photogrammetric data was applied to the prefabricated units, concentric to one another, thus having the same "Y" and "Z" coordinates about the centerline of the WAB. When the first foundation section was assembled, the electronic theodolite system was used to align the two (2) horseshoe assemblies and the two (2) cradle assemblies with respect to the WAB centerline. Once aligned, the assemblies were tack welded in place, and the cut lines, as generated from the photogrammetric data, were transferred to the sections using the electronic theodolite system. As the cut lines were transferred to the first foundation section, the second foundation section was assembled. This general sequence was followed for all four (4) foundation sections. Finally, the foundation sections were cut to the exact ship's dimensions, production welded, delivered to the pier, and installed with a first-time 100% fit-up within the allotted schedule.

PHOTOGRAMMETRIC SURVEY

The modified wet accumulator spaces #l and #2 (formerly the dry receiver spaces #l and #2) are essentially rectangular shaped boxes (see Fig. 1). The bottom of each box consists of the new intermediate decks located between the 01 and 02 levels. The front and back sides are the frame 54 and frame 64 transverse structural bulkheads respectively. The two (2) sides are the outboard longitudinal bulkheads and the ship's shell, and the spaces are open to the flight deck level above.

In order to establish control lines and foundation interface lines for targeting the photogrammetric survey, a standard transit survey was performed on February 8 and 11, 1991 for wet accumulator spaces #l and #2 respectively. To locate the transit, the longitudinal and transverse centerlines of each wet accumulator space were determined. The intersection of the longitudinal and transverse centerlines created centerpoint which actually located the centerpoint of each WAB. The longitudinal and transverse centerlines were obtained from design dimensions. The transit was aligned and leveled over each space's centerpoint. To establish the control required by photogrammetry, a 24.5 m (80 ft.) waterline was established, and the WAB's vertical and transverse centerline points were located on the forward and aft bulkheads. Using the transit, the forward centerline point and the aft centerline point were connected by starting at the forward centerline point and extending the centerline down the forward bulkhead, aft on the new intermediate deck, and up the aft bulkhead to the aft centerline point. These two (2) control lines were required to assure vertical and horizontal control (see Fig. 2). Upon completion of the control lines, the interface lines between the new WAB foundations and the existing ship's structure were surveyed. Six (6) interface lines were surveyed in each space, three (3) for the forward foundation structure and three (3) for the aft foundation structure. The three (3) interface lines consisted of one (1) for the forward horseshoe assembly, one (1) for the two (2) cradle assemblies, and one (1) for the aft horseshoe assembly (see Fig. 3). Upon completion of the six (6) interface lines in each wet accumulator space, the transit survey was completed.

After centerpunching each surveyed line and snapping chalklines along the surveyed lines, the targeting began. The targeting sequence began February 12, 1991 and was completed February 15, 1991. The camera simulation revealed that the required target size was 0.75 cm (0.30 in.). The target type was adhesive-backed vinyl. The target numbering scheme was simple and unique. Each target was identified by a four (4) digit number. The first digit identified the wet accumulator space, (1) for wet accumulator space #l, and (2) for wet accumulator space #2. The second digit identified the various surveyed lines. A list of the second digit designators is shown below.

XlXX	Forward WAB foundation, forward horseshoe assembly;
X2XX	Forward WAB foundation, center cradle assemblies;
X3XX	Forward WAB foundation, aft horseshoe assembly;
X4XX	Aft WAB foundation, forward horseshoe assembly;
X5XX	Aft WAB foundation, center cradle assemblies;
X6XX	Aft WAB foundation, aft horseshoe assembly;
X7XX	WAB transverse centerline;
X8XX	24.5 m (80 ft.) waterline; and
X9XX	Fill-in targets.

The final two (2) digits were simply sequential designators (sequential from 01 to n). This numbering sequence may seem cumbersome and excessively detailed, however it proved to be most useful throughout the remainder of the project. The target numbering scheme proved to be most helpful in data review and in production assembly sequences which took place over a month after the actual photogrammetric surveys.

The targets were spaced in two (2) distinct patterns. The control line targets, those targets that defined the longitudinal WAB centerline and the waterline, *were* spaced approximately every 0.60 m (2 ft.) to 0.90 m (3 ft.). The interface line targets, those targets that defined the interface points between the new foundations and the existing ship's structure, were spaced approximately every 0.30 m (1 ft.). In addition, where butt lines existed and where dips and bulges existed in the bulkheads and decks, more frequent targeting was used to better define these abnormalities. Frequent targeting was important because the existing contour lines of the ship were transferred onto the prefabricated WAB sections in the shop. The key to this entire effort was to assure a first-time fit aboard the ship.

After the target numbering and placement was completed, the photogrammetric survey began. On February 16, 1991 the photogrammetric survey of wet accumulator space #2 was completed. Wet accumulator space #l was completed on February 17, 1991. The exact contours of the bulkheads and decks, along targeted interface lines, were required. To obtain this contour data, a convergent *survey* was accomplished. Due to the rectangular shape of each space, a P31 Super Wide Angle glass plate film camera was chosen to accomplish the photogrammetric survey. This type camera was chosen for its high accuracy and its wide range of coverage. The survey used twenty (20) camera stations in a two (2) tiered scheme in each wet accumulator space (see Fig. 4). The first tier stations were low shots (approximately 1.5 m (4 ft.) above the new intermediate deck) angled up. The remaining stations were high shots (approximately 2.5 m (8 ft.) above the new intermediate deck) angled down. The camera station placement and aiming angles assured both excellent

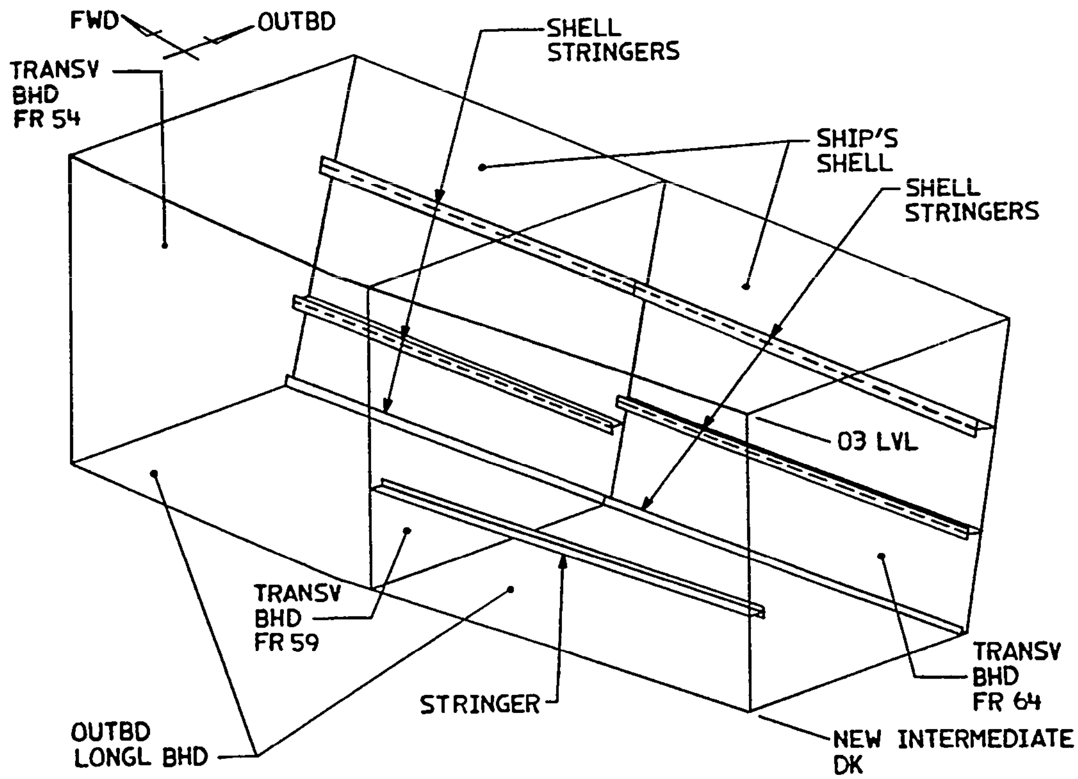

Fig. 1 WAB Compartment Configuration

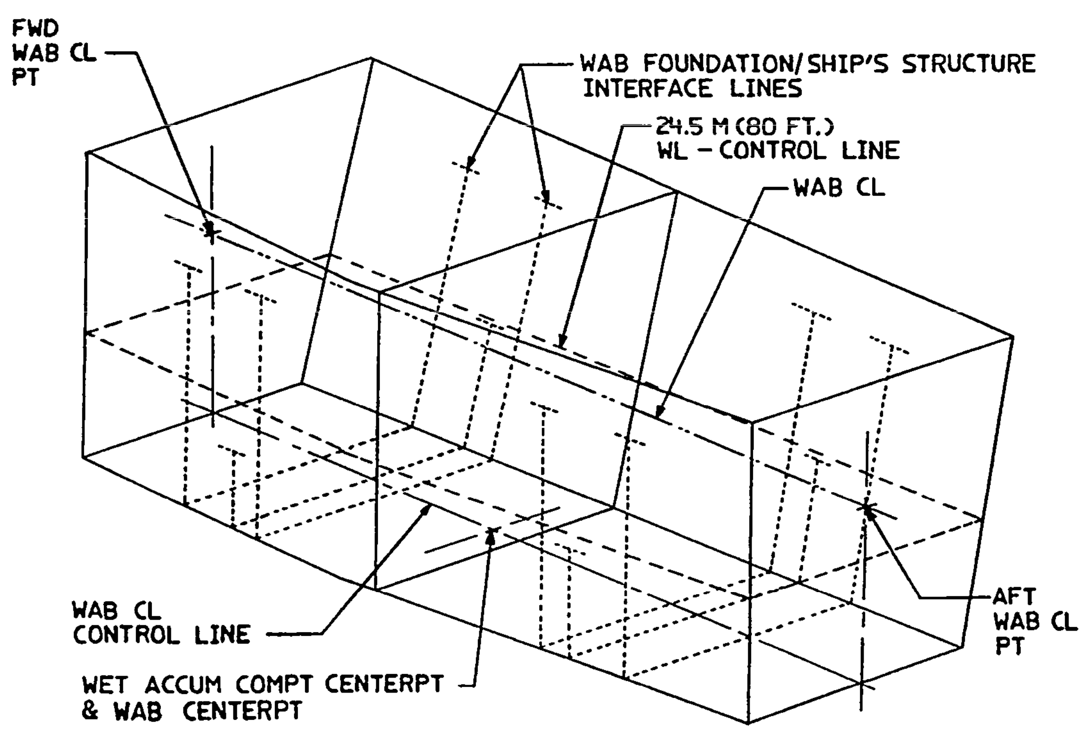

Fig. 2 Control/Interface Lines

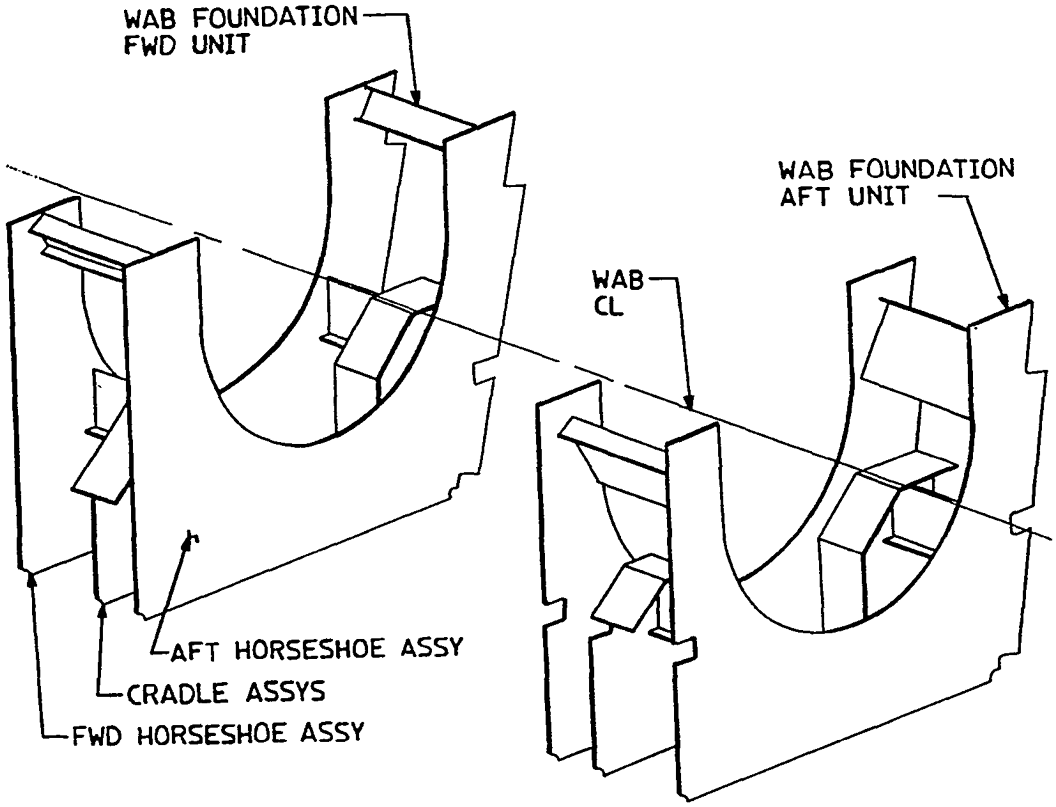

Fig. 3 WAB Foundation Configuration

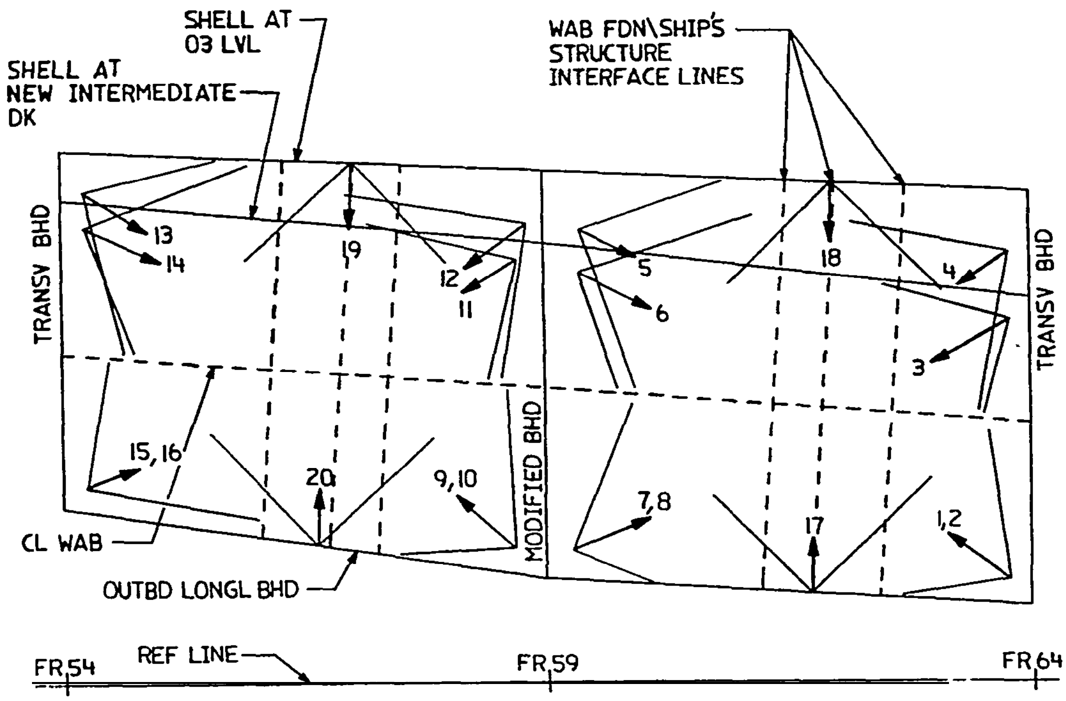

Fig. 4 Camera Plan

geometry for triangulation of the targets and complete coverage of all the targeted lines. The final step in the photogrammetric survey process was to generate scale. Scale was taken by measuring the two (2) most distant targets on longitudinal WAB centerline. The targets were measured using a 15.5 m (50 ft.) steel tape with a 45 kg (10 lb.) pull. The length was measured three (3) times to assure that an accurate scale was used later in the photogrammetric triangulation.

Upon completion of the photogrammetric survey, the glass plate negatives were developed at a nearby site to assure clarity of target images and total coverage of all the targeted interface lines (see Fig. 5). In addition, point sketches were drawn of each wet accumulator space. The point sketches served as "road maps" used as references with respect to the ensuing multi-headed electronic theodolite surveys. As questions arose during the theodolite surveys, the point sketches were used to identify targets and to identify what was actually targeted well after the photogrammetric survey was completed. The SLEP schedule called for the sandblasting of each wet accumulator space immediately after the photogrammetric surveys were completed. As a result, all interface lines and the centerpunch marks defining these lines would have been obliterated. The interface lines were preserved by taping over the centerpunch marks that defined each interface line. All production personnel were notified that the taped centerpunch marks were to be avoided. Without the existence of the initial centerpunch marks, the WAB foundations could not have been landed on the surveyed lines.

MULTI-HEADED ELECTRONIC THEODOLITE SURVEY

During a three week period extending from February 22 to March 11, 1991, the photogrammetric data reduction and analysis was completed. The photogrammetric contractor reduced the data from the glass plate negatives and forwarded it to the shipyard in a predetermined format. The photogrammetric data was first reduced to ship's coordinates. ship's coordinates are those coordinates measured from the ship's origin. The ship's origin designates the forward perpendicular as 0 on the "X" axis, the ship's centerline as 0 on the "Y" axis, and the ship's baseline as 0 on the "Z" axis. Once the ship's coordinates for each target were generated, the coordinates were then transferred into four (4) separate and distinct local coordinate systems, one for each of the four (4) WAB foundation units. The local coordinate systems were composed of those coordinates measured from the WAB centerlines. The WAB centerline origin designates the WAB centerpoint as 0 on the "X" axis, 0 on the "Y" axis, and 0 on the "Z" axis. Once the photogrammetric data was translated to the local coordinate systems for each foundation unit, the theodolite surveys began.

The particular theodolite system used was the Cubic Precision, Analytical Industrial Measuring System, version II (AIMS II). The AIMS II system consisted of two (2) theodolite heads interfaced with a personal computer containing the measurement software and routines.

The theodolite plan called for the theodolite surveys of each foundation section to be accomplished on each WAB foundation unit as it was assembled on the shop floor. As the first WAB foundation unit was assembled, the theodolite system was used to align the two (2) horseshoe sections and the two (2) cradle sections with respect to an imaginary WAB centerline (see Fig. 3). After the four (4) foundation pieces were aligned in accordance with the design specifications, the separate pieces were tack welded together.

The cut lines were then laid out by transferring the localized photogrammetric coordinates to the theodolite system in a point by point fashion (see Fig. 6). The photogrammetric coordinates were transferred to each WAB foundation unit with four (4) separate theodolite setups. A typical theodolite setup involved several distinct steps. First, the two (2) theodolite heads were placed so as to maximize their coverage of the WAB foundation unit, while maintaining a geometric configuration required by the theodolite system triangulation software. The theodolite placement was followed by the theodolite leveling sequence, which is a theodolite system software routine that defines both the location of each theodolite head relative to one another, and the scale which is determined by measuring a highly accurate scale bar. After the leveling sequence was completed, the transfer of photogrammetric coordinates to the foundation units was performed. Because of the complex configuration of the foundation units, not all the photogrammetric coordinates were transferred with the initial setup. Before the initial setup was broken down, several pass points were located and measured in the vicinity of the WAB foundation unit. At least three (3) of these pass points had to be visible from both theodolite heads at each of the three (3) ensuing setups. Once the theodolite placement, leveling, and scaling was completed for a subsequent setup, three (3) pass points were measured. Once the pass points were

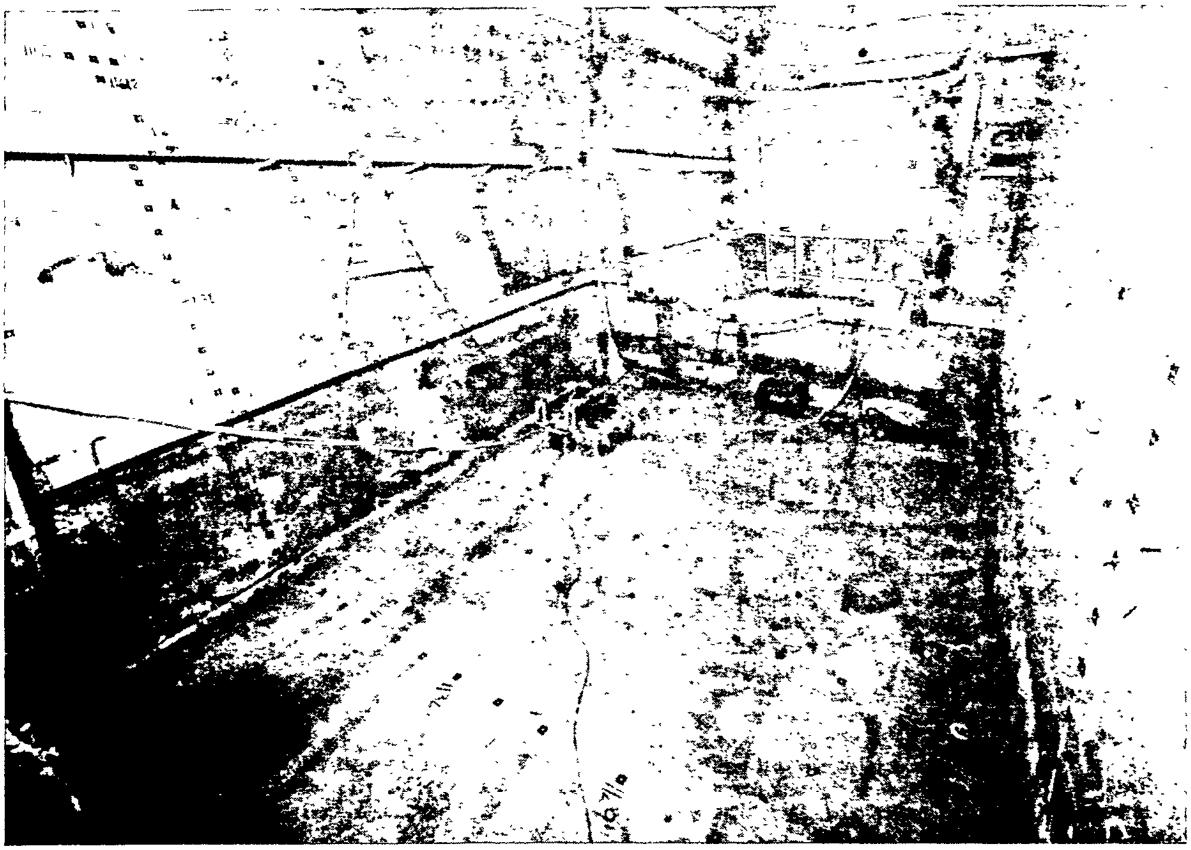

Fig. 5 Typical Photogrammetric Glass Plate Negative

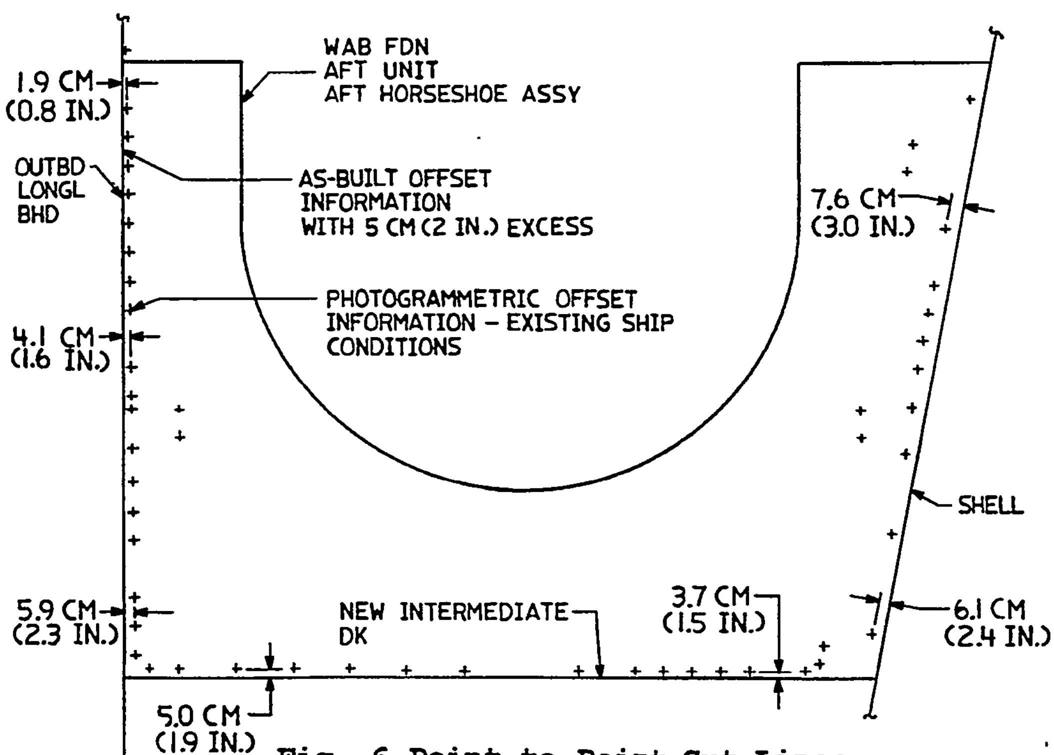

Fig. 6 Point to Point Cut Lines

A

measured, the initial values for those pass points were manually entered into the theodolite system's tripoint routine. Subsequently, the new setup was transferred into the original coordinate system as established by the initial setup. After the original coordinate system was re-established, further transfer of the photogrammetric coordinates to the foundation units was performed. Of the four (4) theodolite setups, the first setup allowed for the transfer of the points to the first horseshoe section. The second and third setups allowed for the transfer of the points to the two cradle sections, and the fourth setup allowed for the transfer of the points to the second horseshoe section.

Once all the points were transferred to a foundation unit, the transferred points were centerpunched, and scribe lines were constructed to connect each transferred point. The scribe lines and the data points defined the exact contour of the ship's structure laid out on the WAB foundation unit (see Fig. 7). All structural beam interferences, all deviations in the decks and bulkheads, and all alignment data were now "mapped" onto each unit.

In addition to mapping out the cut lines, the padeye locations and alignments for each foundation unit were determined by the theodolite system. The padeyes, which span between the horseshoe sections of each WAB foundation hold the steel straps that actually support the WAB. These padeyes, by design specifications, were to be located at 60° (+- 1°) from the horizontal. With the theodolite system angle between planes routine, the padeyes were located within tolerance.

At the culmination of the theodolite survey of the first WAB foundation unit, that unit was production welded, and the contour lines were cut. While the production welding and cutting was accomplished on the first unit, the theodolite survey was accomplished on the second WAB foundation unit. At the same time, the third WAB foundation unit was assembled on the shop floor, and the fourth WAB foundation unit was in its final stages of prefabrication. This fast-tracking technique was used throughout the theodolite survey. All of the theodolite surveys took place between March 12 and April 3, 1991 at the Philadelphia Naval Shipyard.

RESULTS

On May 7, 1991 the final assemblies were ready for installation aboard the CV64 in drydock at the Philadelphia Naval Shipyard. Each final assembly was approximately 4.5 m (15 ft.) wide from side to side, by 3.5 m (12 ft.) high from top to bottom, by 1.5 m (4 ft.) deep from front to back. Because of the

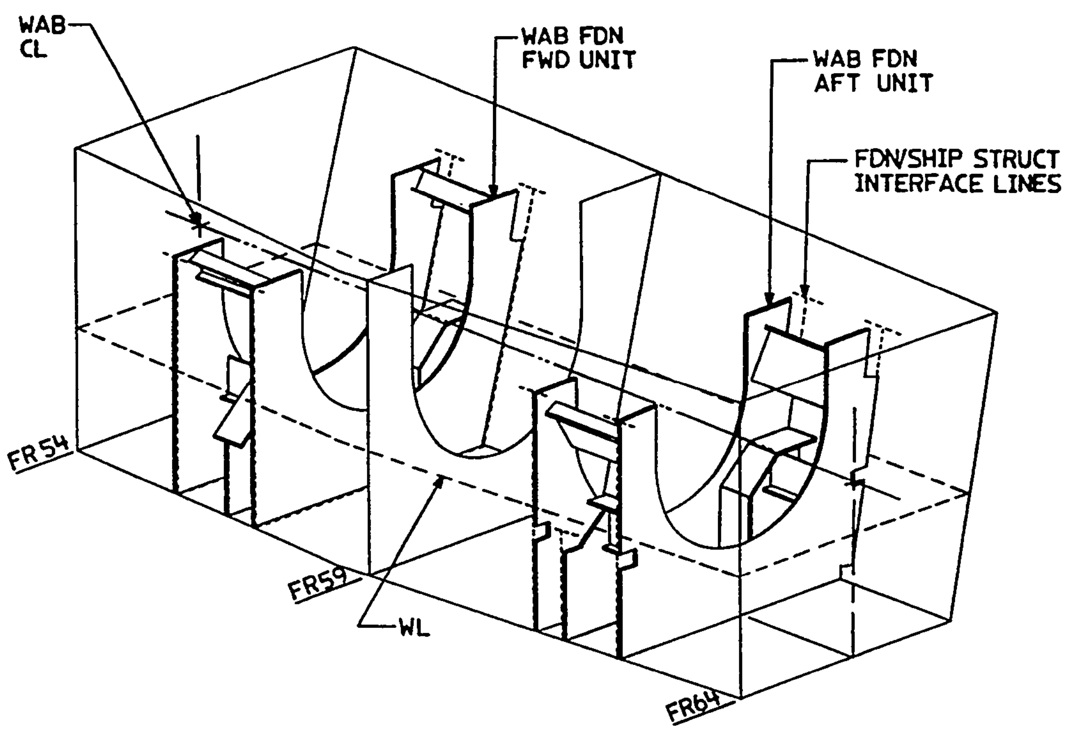

Fig.7 WAB Foundation Fit-up

size of each unit, careful handling and extensive maneuvering was required. Each entered the ship horizontally, and as it was lowered, was rotated into its final position. The resulting gaps between each unit and the inboard and outboard bulkheads was 0 cm (0 *in.) to* 0.5 cm (0.1875 in.). This gap was the actual tolerance allowed for the root opening as called for in the governing specifications. The fit-up was so consistent around the entire perimeter of each unit that production welding was initiated the following day.

The photogrammetric data made it possible to pick up discrepancies in the existing structure before the units were installed. This data revealed that the structural stiffeners located on the shell of the ship were skewed; when the as-built design drawings called for the stiffeners to be parallel to the ship's baseline. In addition, photogrammetric data identified discrepancies with respect to several stiffener sizes given by as-built drawings. Each unit assembly was modified prior to arrival on the waterfront to match the existing ship's conditions. This eliminated the need for costly and time consuming rework *on* the waterfront.

Finally, the theodolite system was used to lay out both the photogrammetric data on the unit for the final cut, and to serve in guiding the accurate final assembly of each unit. The padeyes that hold the strap from which the WAB is suspended were also set using the theodolite system. This angular dimension was critical in that it insured a 7.5 cm (3 in.) diameter pin, which secures the strap to the padeye, fit the first time without the need for rework in the field.

CONCLUSIONS

Including time spent for prefabrication of the units and preplanning for the photogrammetric/theodolite surveys, this project ran for approximately four (4) months. This time frame included several important steps:

(1) the planning and executing of the photogrammetric *survey;*

(2) the reduction of the photogrammetric data;

(3) the transformation of the photogrammetric data to the theodolite system;

(4) the laying out of the photogrammetric data with the theodolite system in the shop;

(5) the trimming of the excess from the WAB foundation units in the shop; and

(6) the installation aboard ship of the foundation units ready for production welding-

This project exhibits the following advantages of using advanced measurement technology in the shipbuilding industry.

(1) Photogrammetry and multi-headed electronic theodolite systems can be used effectively as complimentary systems.

(2) Scheduling impacts can be avoided with first-time fits.

(3) Performance figures on the CV64 as compared to previous SLEP overhauls for basically the same modification were significantly lower. This cost savings was attributed to the absence of rework.

(4) Flexibility and innovation *in* using these systems allows the ability to work around scheduling obstacles. *A*

(5) The elimination of rework allows for the ability to plan and maintain a close production schedule.

In summary, the success of this project has demonstrated the need to expand the use of advanced measurement technologies to their fullest extent in the shipbuilding and repair industry. These technologies allow first-time installations within tolerances, cost, and schedule.

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Measurement of Shipboard Piping Using a Portable Coordinate Measuring Machine (PCMM)

No. 7A-3

James E. DeFoor, Visitor, (to be presented by E. Earl Wilson, Visitor, Norfolk Naval Shipyard)

ABSTRACT

This paper describes available technology for a Portable Coordinate Measuring Machine (PCMM) which can be hand carried onboard naval vessels. The PCMM can perform measurements in confined spaces throughout a vessel on pipes, tubes and assemblies, as well as their end fittings and support devices. Al though portable, the PCMM can also be used in a stationary position for repetitive measurements.

The PCMM is composed of four major components: an articulated six- axis digitizing arm, control unit, contact and non- contact probes, and tube and surface three-dimensional measurement software. The PCMM arm, lightly constructed, duplicates the articulation and reach of the human arm elements (shoulder, elbow, and wrist). various contact and non-contact measuring probes attach easily to the wrist of the machine.

The PCMM control unit performs all the necessary mathematical and geometric calculations without the use of external computers or templates. It also contains sufficient data memory so that the operator is able to measure and Inspect geometric features such as points, lines, planes, arcs, circles, spheres, and cylinders, as well as defined surfaces along lofting lines, and complex surfaces at coordinate points.

BACKGROUND

The design of a ship includes an infinite variety of unusual shapes and configurations to which the piping systems must adapt. The miles of pipe running throughout ships must be constructed, assembled and fitted to go around, over, under and through ship's components. They must also be placed so as not to interfere with the operations and maintenance of machinery, doors, hatches or openings. Therefore, it is necessary for piping systems to contain hundreds of bends and fittings. In addition, the design and placement of pipe helps absorb the stresses and strains placed on the pipe when the ship is in motion.

If pipefitters used only straight lengths of pipe, making a bend would require hundreds of different fittings, a situation which would not be practical. Accurate measurements for bending pipe are critical if the pipe is expected to fit and function correctly. Proper fit reduces the chance for leaks and equipment failure due to leaks. Hence, correct and accurate pipe measurements for pipe bending can reduce rework and cost.

Present Measurement Method

The following is a brief description of a typical manual method for measuring pipe aboard a naval vessel by naval shipyard personnel. Although there are many major elements involved in replacement of shipboard pipe (i.e.. measuring, templating, cutting, end prepping. bending, fitting-up, purging, and welding), this paper deals only with measurements and how the measurements are used to bend pipe.

After a pipe replacement job has been identified, a pipefitter completes the following tasks: reviews the job order, reviews blueprints (if available) of the pipe section that is to be replaced, plans his or her work, gathers the necessary tools (ruler. framing square, protractor, calculator, sketch paper, and pencil), and goes to the ship to commence the job.

The pipefitter determines the location of the pipe to be removed from the job order. For this particular case, the pipe will remain attached until the new replacement pipe is manufactured and ready for installation.

The blueprint does not always specify, identify or give dimensions of the section of pipe to be replaced. Therefore, the pipefitter must prepare hand sketches of the pipe and determine the exact dimensions within l/16 of an Inch.

In the example below, the section of pipe to be replaced is determined to have two bends and a rolling offset as shown in Figure 1. The exact location of the end cuts, if not specified, are determined by the piping engineer, foreman and pipefitter.

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Pipe Sketch

The pipefitter must prepare a sketch to tell the pipe bender precisely how the pipe is to be shaped. The views needed are Plan. elevation, and right side as shown in Figure

2. Dimensions and calculations are measured and calculated to the center line of the pipe.

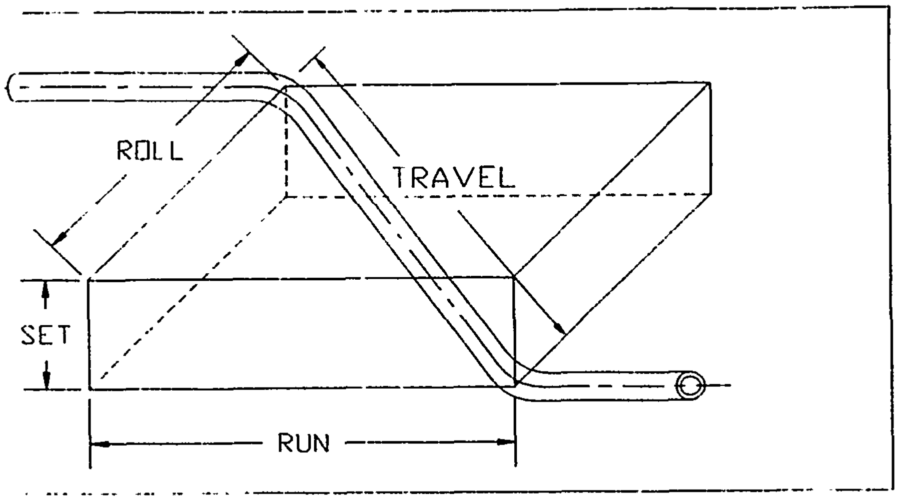


Figure 1. Run, Set, Roll, and Travel

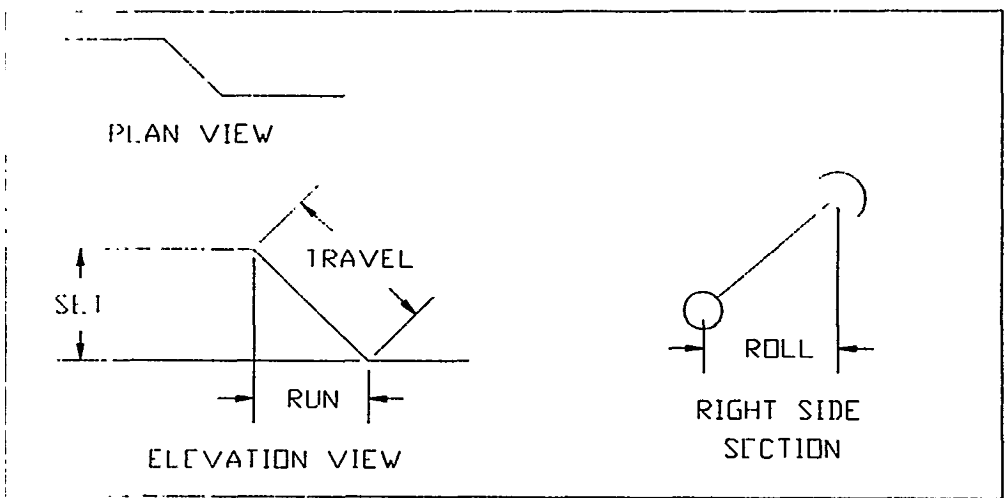


Figure 2. Typical Pipe Center Line Sketch

Measurement and Calculations

The kinds of measurements and/or calculations required by the bender in accordance wlth reference (2) are as follows: set, run, radius of the bend, angle of the bend, roll, travel, and true end- to-end length. A modification of the Pythagorean Theorem is used to calculate the true distance (travel) between bends for a rolling offset.

$$H = a^2 + b^2 + c^2 \qquad (1)$$

where H = travel
a = run
b = set
c = roll

Actual measurements with rules and framing squares are determined to l/16 inch. Calculations are rounded to the nearest 0.254 mm (0.01"). Measurements and calculations are made to the center line of the pipe. Actual dimensions shown on sketches are in fractions to the nearest 1.587 mm (1/16").

True length (end-to-end) is needed to determine the amount of material necessary to bend the piping run and to ensure proper fit-up. The total length (end-to-end) for a bend is determined by subtracting twice the cut-off (Co) from the plan length (PL) and adding the distance around the bend (DAB).

True length (end- to-end) = PL - 2(CO) + DAB (2)

The information needed from a bend is identified in Figures 3 and 4.

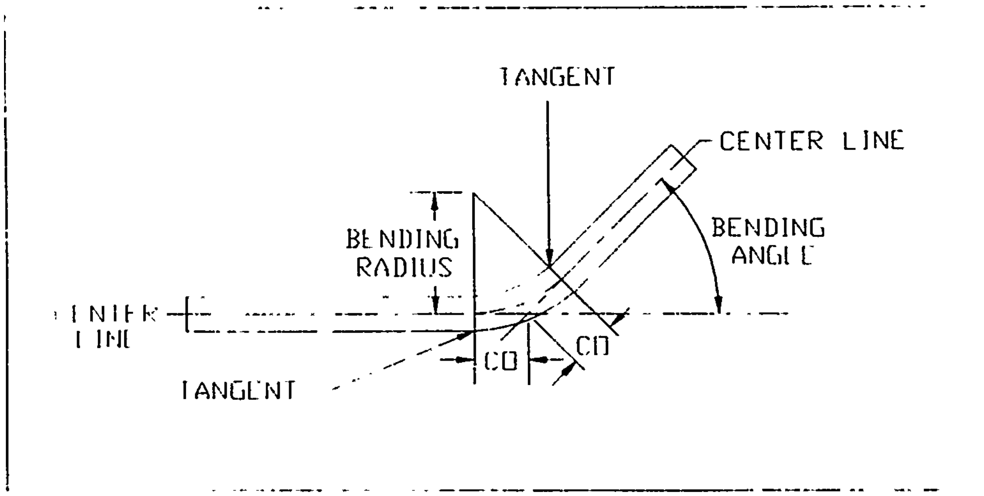


Figure 3. Features of a Bend

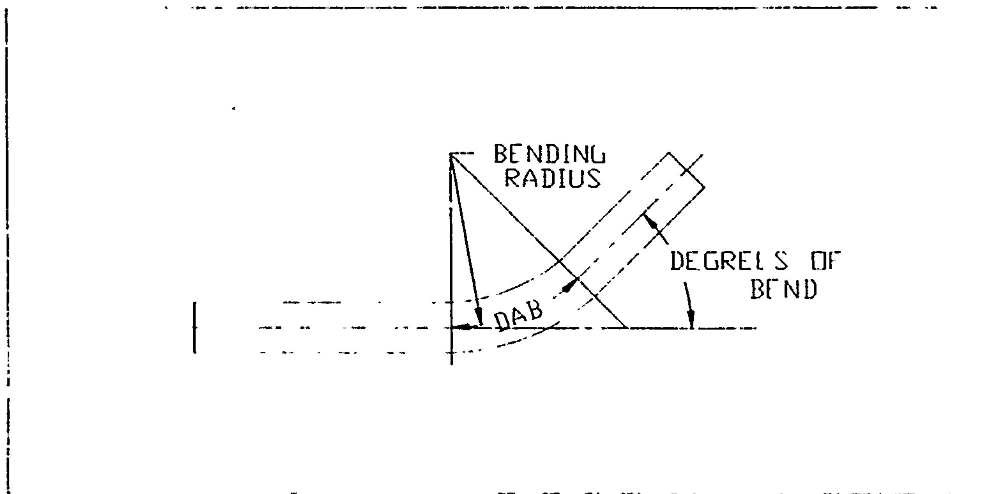


Figure 4. Distance Around a Bend (DAB)

The equation for finding the length of a cut-off (CO) is:

$$CO = C \times R \quad (3)$$

where C = numerical value which changes according to the bending angle or degrees of bend
R = bending radius

The two most common bend radii used at Norfolk Naval Shipyard (NNSY) are 3D and 5D; 5D is preferred.

The equation for finding the distance around a bend $_{(DAB)}$ is:

$$DAB = D \times R \times 0.01745 \quad (4)$$

where 1) number of degrees in bending angle,
R 2 bending radius in degrees
0.01745 = numerical constant in radians/degree

The value 0.01745 radians is the length of 1 degree of arc.

A

Segments of the plan length (PL), Fiqure 5. may be measured, calculated or given.

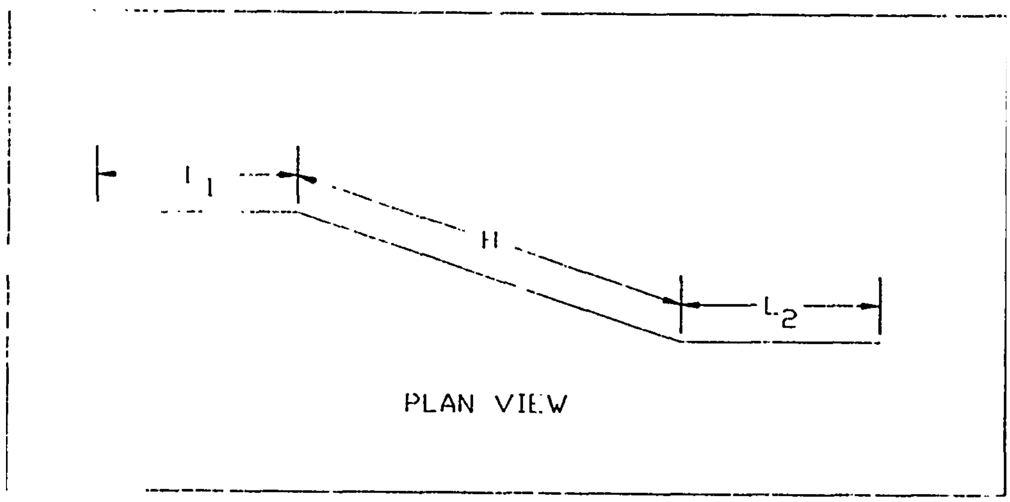
The formula for determining the plan length for Figure 5 is:

$$PL = L_1 + H + L_2 \quad (5)$$

where PL = plan length
L_1 = length of pipe from cut off to firsl bend
H = travel
L_2 = length of pipe from second bend to cut off

The true length (end to end) is calculated using the formula:

True length (end- to end) = PL 2(CO's) first bend - 2(CO's) second bend 1 DAB first bend + DAB second bend.



Flgure 5. Plan Length

After the sketch has been completed and all required dimensions are determined and checked, the sketch is ready for the pipe bender. The sketch may be re checked by a piping engineer or a foreman or given directly to the bender. The pipe is then manually bent.

The manual method of pipe measurement is labor intensive and is susceptible to errors in measurement and calculations. Errors lead to rework and increase the labor and material cost of the pipefitting process.

DISCUSSION

Manual measurement of shipboard pipe has not changed much in decades. The wooden six foot folding rule and the framing square are still the basic tools of the trade. The slide rule has given way to the hand held calculator for performing calculations. Efforts are underway to design ship systems using Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) Systems, which will provide more accurate drawings and dimensions if the configuration data and drawings represent "as built" systems and are updated as changes are made. lt remains to be seen whether or not CAD/CAM designed ships and ship's systems will improve the measurement of pipe spools or pipe systems to be replaced.

Proposed Pipe Measurement Method

A new measurement tool (new to shipboard pipe measurement) has recently been introduced, the Portable Coordinate Measuring Machine (PCMM). The PCMM is presently being used in the aircraft automotive and medical fields with excellent measurement results. Tubing, sheet metal parts, subassemblies and various surface configurations are measured and digitized. The digitized X, Y and Z coordinates can be uploaded to CAD systems and downloaded to computer Numerical Controlled (CNC) machine work stations for manufacturing.

This paper will describe the manipulation of a PCMM In general terms, and will not attempt to explain the design of the equipment or development of the software.

PCMM Measurement Demonstration

Recently a PCMM was successfully demonstrated in the pipe shop at the shipyard. A piping run was measured by digitizing the x. y, and z coordinates and then the coordinates were downloaded into a CNC pipe bender. on command, a pipe spool was bent automatically to the coordinates previously measured.

The pipe measurement demonstration was performed three times. Each time the PCMM generated x, y, and z coordinate data which was downloaded to a CNC pipe bending machine. The bent pipe produced by the bending machine was indeed an accurate representative of the pipe measured.

Description of PCMM

The PCMM demonstrated at the shipyard consists of four major components.

1. An articulated arm which has the same shoulder, elbow, and wrist movements as the human arm.

2. A control unit (lap top PC) which has all the necessary mathematical and geometric operations and contains sufficient data memory that the operator is able to measure features such as points, lines, planes, arcs, circles, spheres, and cylinders as well as define surfaces at coordinate points without the use of external computers.

3. Contact and non contact probes.

4. Tube and surface three dimensional measurement and calculation software.

PCMM Measurement

Figure 6 represents a pipe configuration similar to the configuration used to illustrate and dcscribe manual pipe measurement . This configuration is also similar to the actual pipe spool used for the PCMM test and

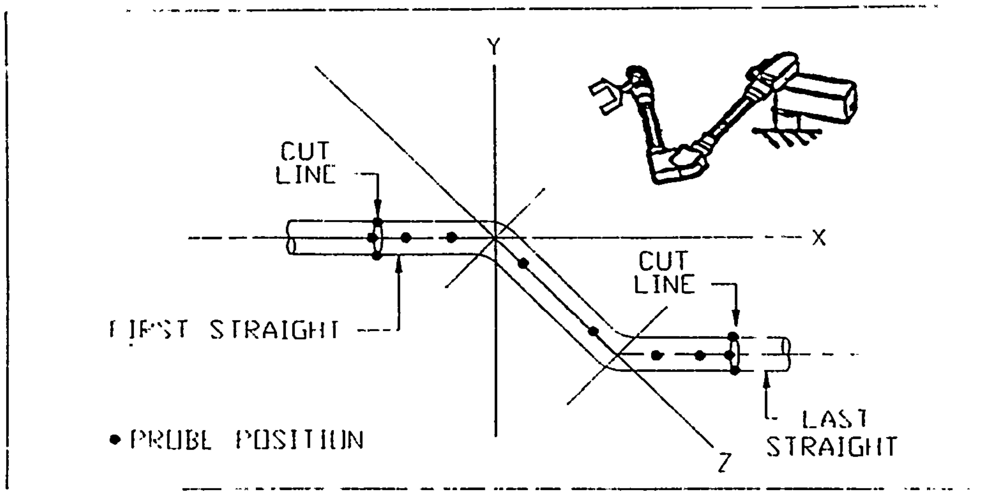


Figure 6. Typical Pipe Configuration Measured by PCMM

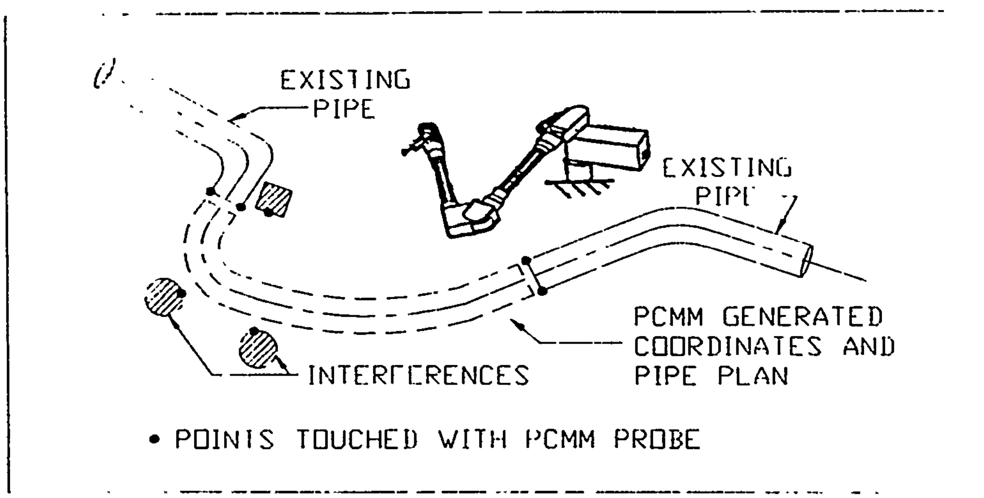


Figure 7. PCMM Generated Pipe Design

evaluation at the shipyard. A method for measuring and digitizing the x, y, and z coordinates of the pipe spool for replacement is described below.

The measurement is performed using a non-contact, light beam probe. The measurement is started at the designated end cut on the first straight, as shown in Figure 6. The pipe is measured as a “new part” by measuring two points per straight. The length of each straight is automatically calculated after “new part” measurements are completed.

The bend radius of each bend is determined from measurements of the adjacent straights to the bends and from the x, y, z coordinates spacial relationship of the straights. The PCMM software also automatically calculates the end- to- end length of the desired replacement pipe.

The specially designed and developed PCMM software manipulates the data and generates x, y, and z coordinates for the pipe diameter, pipe end cut lines, bend angles, rolling offset, bend radii, and end to end length of the replacement pipe. The data is then downloaded into a CNC pipe bender and a pipe spool is bent automatically. The data may also be uploaded into a personal computer (PC) with CAD capabilities to produce the necessary pipe drawings.

Figure 7 represents the new piece of pipe measured with a PCMM and designed to a “best fit” arrangement by the PCMM software during the second series of PCMM tests and evaluations.

Using a ball point probe for surface contact, one end of the cut pipe is touched to measure and digitize the x, y, and z coordinates of the end cut. Then the probe is moved to the inter ferences where the surface of each obstruction is touched and the x, y, and z coordinates digitized. The probe is then moved to the other pipe; that pipe end is probed, and x, y, z coordinates are generated.

The specially designed and developed PCMM software manipulates the data and generates x, y and x coordinates, pipe diameter, pipe end configuration, bend angles, bend radius and the end to end length of the required pipe spool to get the best Eit through and around the interferences. This design data can be downloaded into a CNC pipe bender where a pipe section can be bent. In addition, the data can be uploaded into a PC with CAD capabilities to produce pipe drawings.

Two such tests were performed with excellent results.

CONCLUSIONS

Five demonstrations of measurement tests do not necessarily prove that the PCMM is the final answer to all pipe measurement. But the tests strongly indicate that a PCMM might provide a significant breakthrough in automated pipe measurement and bending. Measurement by PCMM and bending by CNC vine bending machines could reduce vine measurement and bending time from shifts to hours. Additonal tests are needed in a shipyard environment, aboard ships, and in confined spaces to determine the exact value of the PCMM.

The shipyard prepared a Naval Repair Technology Project Brief that described a PCMM and its potential for cost reduction. The Project Brief was approved for the requested funds to procure a PCMM for further testing and evaluation. A PCMM is expected to be available for testing and evaluation prior to this paper being presented at the 1992 Ship production symposium.

Pertinent information regarding any new tests and evaluations will be addressed at the Symposium.

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Reducing the Construction Contract Cycle for Naval Auxiliary Ships

No. 7B-1

Mark H. Spicknall, Associate Member, University of Michigan, Transportation Research Institute, and Michael Wade, Associate Member, Carderock Division - Naval Surface Warfare Center

ABSTRACT

A Mid-Term Fast Sealift Technology Development Program producibility study was undertaken by the Manufacturing Systems Division (Code 125) of the Naval Surface Warfare Center, Carderock Division (NSWC) for the Naval Sea Systems Command Computer Aided Engineering Division, Ship Design and Engineering Directorate, SEA 507. The producibility project team was initially tasked to identify and evaluate possible design improvements with regard to their potential impact upon the cost of construction for the Baseline (BL) Oa rough order of magnitude (ROM) geared-diesel option. This particular design varient is a 30 kt twin screw, 289 m (948 ft.) roll-on/roll-off (RO/RO) vessel with four 18 PC4.2V medium speed diesels producing 85,619 kilowatts (114,817 h.p.) of installed power. The construction cost estimate developed by NAVSEA for this particular design varient is $385 million per ship (I). In addition to the NAVSEA-assigned task, the team reviewed the producibility aspects of the Navy auxiliary ship procurement process with regard to finding methods that would facilitate major reductions in the construction contract cycle, as time is now recognized as a major cost driver in ship procurement (2). The construction contract cycle is defined as the amount of time from construction contract award to delivery, and was estimated by NAVSEA to be 42 months for this particular design varient (3).

ACRONYMS

AII - Avondale Industries, Inc.
BL - Baseline.
CAD - Computer-aided design.
COR - Circular of requirements.
FSS - Fast Sealift Ship.
GBS - Generic build strategy.
GT - Group technology.
NASSCO - National Steel and Shipbuilding Company.
NAVSEA - Naval Sea Systems Command.
NSRP - National Shipbuilding Research Program.
NSWC - Naval Surface Warfare Center, Carderock Division.
PBI - Peterson Builders, Inc.
PODAC - Product oriented design and construction.
PWBS - Product-based work breakdown structure.
ROM - Rough order of magnitude.
RO/RO - Roll-on/roll-off.
SWBS - Ship system-based work breakdown structure.
UMTRI - University of Michigan Transportation Research Institute.
VFI - Vendor-furnished information.

INTRODUCTION

The purpose of the Mid-Term Fast Sealift producibility task was initially to examine the Mid-Term Fast Sealift Baseline (BL) Oa rough order of magnitude (ROM) geared-diesel design option to identifying alternative product characteristics that could reduce construction costs. The NAVSEA estimated construction duration for these ships was 42 months at a cost of $385M per ship (1,3).

The Computer Aided Engineering Division, Ship Design and Engineering Directorate, SEA 507, tasked the Naval Surface Warfare Center, Carderock Division, Code 1253, with creating a team to address producibility issues. The Naval Surface Warfare Center, Carderock Division, used an existing National Shipbuilding Research Program (NSRP) contract vehicle with Peterson Builders, Inc. (PBI) to place PBI, Avondale Industries, Inc. (AII), National Steel & Shipbuilding Company (NASSCO), and the University of Michigan Transportation Research Institute (UMTRI) under subcontract for this task.

The participating shipyards were selected based on their size and experience in designing and building naval auxiliaries. PBI is a small shipyard with considerable experience in designing and building small naval auxiliary vessels. Their role in this task was to provide contract management and to provide some technical input from the perspective of a smaller shipbuilder. Both AII and NASSCO were selected for their considerable experience in designing and building large naval auxiliary vessels. The Marine Systems Division of UMTRI was asked to participate because of their knowledge of ship production methods and technologies, and because of their perspective on the implications of the sealift program for the domestic shipbuilding industry.

This project team examined the producibility of the Mid-Term Fast Sealift BLOa ROM geared-diesel option as originally tasked. In addition, the team identified procurement policy and process improvements, and design and production technologies that could potentially reduce the construction contract cycle for the Mid-Term Fast Sealift ship, as time is now recognized as a major cost driver in ship procurement (2). The construction contract cycle was defined as the amount of time from construction contract award to delivery.

Producibility, also known as design for production, was defined to include the following processes:

- rationalization of the ship acquisition/procurement process;
- organization of design and production in accordance with a product-based build strategy;
- development of an understanding of the limitations of existing ship production technology;
- continuous scrutinization of the product, and the design, procurement and production processes to simplify them; and
- continuous scrutinization of the product, and the design, procurement and production processes to create standards.

Rationalization of the ship acquisition process results in a thorough understanding of all aspects of the procurement process as it presently exists. This rationalization results from the detailed description of individual process functions and their relationships, along with the identification of the time and resources required to perform these functions. Upon completion of this rationalization, intelligent choices can be made as to where within the process improvements are possible (4). The Mid-Term Fast Sealift Producibility team worked from an assumed understanding of the present Navy and commercial procurement processes. However, the team believes that a formal and detailed analysis of these procurement processes would be beneficial.

A build strategy is a basic construction plan (5). This plan describes how the ship will be manufactured and also specifies the types of engineering and design deliverables required to build the ship efficiently. Modem build strategies are based upon product-oriented design and construction (PODAC) methods which, in turn, are based upon group technology (GT) and product work breakdown structure (PWBS) (6). A detailed definition of the "generic build strategy" (GBS) concept is provided in the "Goals and Definitions" section below.

The build strategy should reflect an understanding of how best to manufacture the ship within the existing and expected future capabilities of the industrial base. This requires a thorough knowledge of the current manufacturing capabilities of all major domestic shipbuilders. Shipbuilder participation in build strategy development will assure that the build strategy takes into account the production capabilities of the industry. Shipbuilder participation should be augmented with studies of worldwide state-of-the-art ship production methods and technologies. A build strategy is considered "generic" when it facilitates the construction of the ship at all shipyards with certain minimum capabilities.

Design for production also requires continuous scrutinization of the product, and procurement and production processes in order to simplify and improve them, and to create product and process standards. The continuous simplification, minimization, and standardization of interim products and components is essential to improving the production process. In addition, it is important to assess the applicability of existing commercial standards and standardized interim products and processes already developed for other naval ships.

This paper addresses producibility in the context provided above. The remainder of the paper describes the goals and further definitions underlying the Mid-Term Fast Sealift producibility project, presents the specific producibility task achievements, and then provides conclusions and recommended actions in the areas of "product," "policy," "process," and "technology" which would support more cost-effective procurement of the Mid-Term Fast Sealift ships.

GOALS AND DEFINITIONS

Several additional goals and definitions were established at the outset of the project to provide direction for the team. The overriding goal of the producibility project was to document how the adoption of modem ship construction and procurement methods can benefit the Navy and the industrial base. NAVSEA's own process improvement efforts have identified that "the U.S. Navy is not fully realizing the significant benefits which could accrue from modem shipbuilding methods. These benefits include reduced construction cost, improved quality, and reduced construction time" (7). Specific producibility project goals and definitions are described in detail below.

Justification of Time as the Dominant of Performance

Time was selected as the dominant metric of performance for the procurement of all naval vessels. NAVSEA has identified through its own process improvement efforts that too much time is required in the present design and procurement environment to take a ship from concept through construction, and that this excessive time drives up procurement costs significantly (7). Therefore, a primary task of the producibility team was to identify and examine product characteristics, procurement policy and process improvements, and technologies that might reduce the construction contract cycle for these ships.

Navy studies aimed at lowering costs and improving productivity have traditionally been based on the identification of ship system work breakdown structure (SWBS) -based cost drivers. However, in a product-oriented environment new metrics must be found in lieu of these traditional methods. Modem commercial manufacturers focus upon metrics such as "time to market," and "throughput coefficients" to quickly respond to changing customer requirements, maintain market share, and drive costs per unit of production lower. These metrics use the component of time to measure effectiveness; emphasis is placed on identifying throughput inhibitors rather than cost drivers. Japanese shipyards invest significantly in reducing cycle time through continuous rationalization and improvement of products and production techniques; this type of investment has a higher priority than investment in capital improvements because the potential payback is considered much greater (8).

Recent international trade negotiations attempting to "level the playing field" with regard to subsidies on behalf of the U.S. shipbuilding industry are only addressing part of the problem. Even if these negotiations are successful in eliminating foreign shipbuilding subsidies, the fact still remains that it would take up to twice as long to build a particular ship (from construction contract award to delivery) in the United States as it would take elsewhere in the world (4). Current data shows construction contract cycles for large foreign-built commercial ships of various complexities to be 12-24 months in length (9). The most recent construction contract cycle performance for the construction of a moderately complex commercial container ship in the U.S. is approximately 28 months.[1,2] If the U.S. Navy wants to maintain a viable shipbuilding industrial base, it must find ways help U.S. shipbuilders address the "time to market" issue through improved procurement practices, contract policies, product development processes, and product and manufacturing technologies.

Definition of the Present Construction Contract Responsibilities

When a construction contract is awarded for a naval auxiliary ship within the present procurement environment (see Figure 1). NAVSEA provides the contracted shipbuilder(s) with Navy/design agent-developed functional (system) guidance drawings and specifications. The information and drawings provided are usually unsized and/or incomplete, and are almost never certified correct. Some material procurement is done by the Navy prior to

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1 Source: Matson Navigation Co., San Francisco, for vessel presently under construction at NASSCO.

2 The inability of the U.S. shipbuilding industry to build ships within a competitive time frame places the United States at both a strategic and competitive disadvantage. A future would-be adversary might exploit this weakness in U.S. shipyards' ability to replace shipping assets in a timely manner. In a commercial venue, customers usually want their ships as quickly as possible. Late delivery of a new ship may represents lost revenue while loan payments are being made. Also, a longer construction contract cycle drives up the time-related portions of construction costs making a ship more expensive to acquire. Owner/operators are likely to take their business elsewhere if a shipbuilder is incapable of supporting a competitive construction contract timetable.

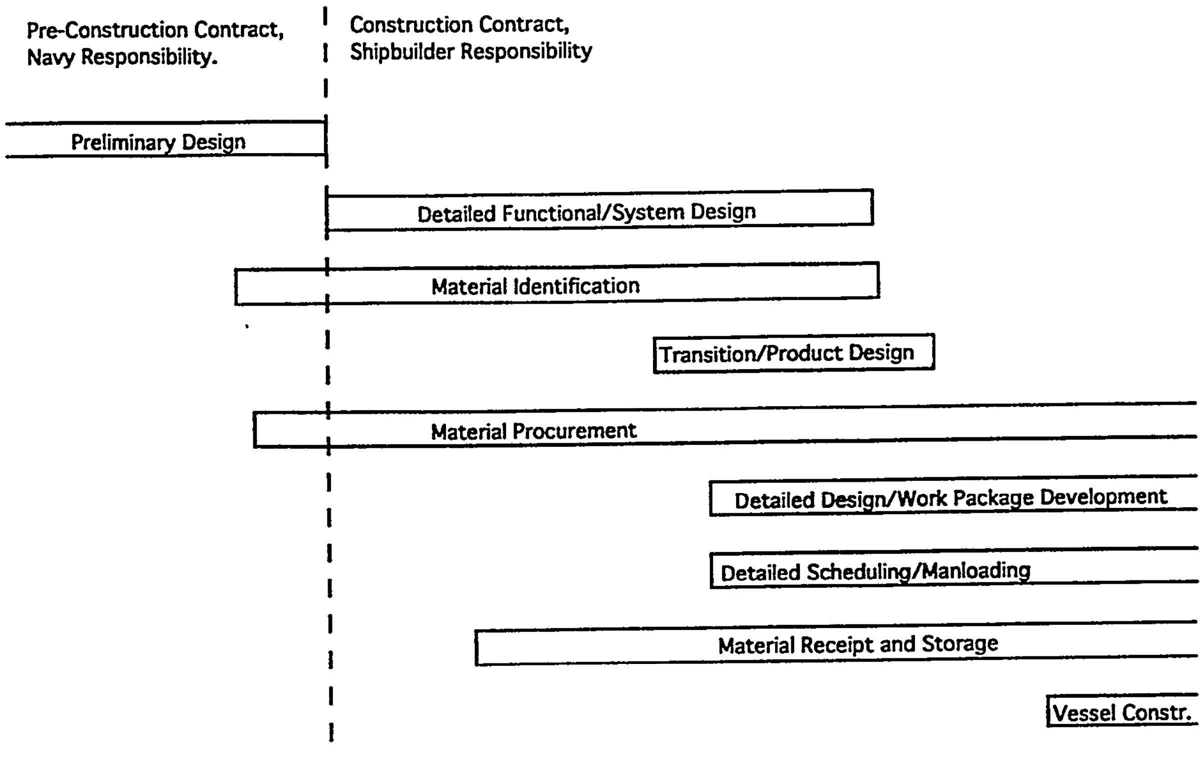


Figure 1. Present Procurement Environment Responsibilities.

construction contract award. As part of the construction contract, each shipbuilder is then responsible for completing and checking functional design, and for accomplishing any transition and detailed design work they require to support their way of doing business, developing system-based and product-based bills of material, procuring most material, and finally building and testing the ship. Transition design includes the development of multi-system composites and the definition of the ship's product structure. Detailed design includes the development of shipyard-specific plans, production documentation and drawings, and schedules supporting construction.

Development of FSS Construction Contract Targets

Recent naval auxiliary construction contract durations contrast sharply with construction contract durations associated with commercial procurement of similar ships. The best recent performance for a U.S. Navy auxiliary lead ship construction contract was 46 months on a naval fleet oiler program (TAO-187) (10). A commercial variant of this ship was acquired in the United States in 30 months during the early 1980s (4). That same commercial variant can be acquired on the world market in 20 months.[3] Reference is also made to past domestic design and construction performance on RO/RO ships at Sun Shipbuilding and Dry Dock Co.: these vessels required one year to design and one year to build (11). The producibility team chose 24 months as its initial construction contract cycle target for the Mid-Term Fast Sealift ship because this cycle time lies between the best current domestic and foreign construction contract cycle times. A secondary target of 18 months was identified to account for the potential development and adoption of future productivity-enhancing design and production technologies, and the potential adoption of procurement policies which support continuous production from ship to ship in a shipyard.

Estimation of Potential Cost Savings Resulting From Shorter Construction Contract Cycles

NSWC, Code 1253, conducted a basic cost analysis to estimate what a 24-month construction contract cycle could save in dollars. In support of this analysis, construction cost return information from the Cost Assessment Office, Code 1210, was reviewed for a recent naval

3 Source: Bremer-Vulkan AG, Bremen, Germany.

auxiliary in the LSD-41 (Dock Landing Ship) class. This review lead to the identification of six cost categories. These categories, along with their respective percentages of total cost, are listed below.

LSD-41 Cost Breakdown

1.	Direct Labor - Work related	14%
2.	Direct Labor - Time related	2%
3.	Variable Overhead	7%
4.	Fixed Overhead	15%
5.	Material	55%
6.	Profit	7%

These categories and their respective cost percentages were then applied to the estimated construction cost of the Baseline Oa design, assuming a 42-month construction contract cycle and a $385M price as estimated by NAVSEA (1, 2).

42-month Construction Contract Cycle
Cost Breakdown

	% Total Cost	$ (Mil.)
Dir. Labor-Work rel.		54
Dir. Labor-Time rel.	2.0	8
Variable Overhead	7.0	26
Fixed Overhead	15.0	58
Material	55.0	212
Profit	7.0	27
Total	100%	$385

In estimating costs for a 24-months construction contract cycle, the "direct labor, time-related" cost category was reduced proportionally to the overall schedule reduction of 43 percent. Both the "variable overhead" and "fixed overhead" cost categories were also reduced proportionally to the overall schedule reduction resulting in a 43 percent savings. For the purposes of this exercise, material escalation was estimated at 5 percent per annum; the 18-month time reduction translated into a 7.5 percent reduction in "material" cost category. The "profit" cost category remained at 7 percent of the total cost. However, due to the overall cost reduction, the dollar value for the profit would be reduced by approximately 15 percent. The "direct labor-work related" cost category remained at $54.0M meaning that the direct labor work content was assumed to remain constant. The following table shows the resulting cost figures for a 24-month construction contract cycle.

24-month Construction Cycle
Cost Breakdown

	% Total Cost	$ (Mil.)
Dir. Labor-Work rel.		54
Dir. Labor-Time rel.	1.4	5
Variable Overhead	4.6	15
Fixed Overhead	10.2	33
Material	60.2	196
Profit	7.0	23
Total	100%	$326

The resulting estimated cost savings for a 24-month construction contract cycle are approximately $59M per ship, or 16 percent, while holding the direct labor work content constant. However, it is important to recognize that a traditional procurement represented by the 42-month construction contract cycle includes a considerable amount of functional and transition design, material and vendor-furnished information (VFI) procurement, and test planning that would have to be done prior to construction contract award to support a 24-month construction contract cycle. If it is assumed that this work costs 2.5 percent[4] of the NAVSEA procurement cost estimate of $385M, or about $10M, and that the cost of this work will not change when it is conducted prior to the award of the construction contract, the savings will still be about $49M per ship, or 13 percent, while holding the direct labor work content constant.

The development and adoption of advanced design and production technologies, and the use of procurement policies which support continuous production from ship to ship could, over time, help reduce construction contract duration and direct labor man-hours. Following is a NSWC-developed cost analysis for an 18-month construction contract cycle. A

18-month Construction Contract Cycle
Cost Breakdown

Cost Category	Total Cost	$ (Mil.)
Dir. Labor-Work rel.	14.7	43
Dir. Labor-Time rel.	1.2	3
Variable Overhead	3.8	11
Fixed Overhead	8.5	25
Material	64.8	191
Profit	7.0	21
Total	100%	$294

4 UMTRI estimate based on shipyard-provided information.

The additional cost savings resulting from an 18month construction contract cycle (beyond those savings already realized from a 24-month construction contract cycle) is 8 percent, or $32M per ship. This 8 percent savings includes a conservative 20 percent estimate of the reduction of direct labor costs resulting from the use of new production technologies. These savings when added to the savings already obtained from reducing the construction contract cycle to 24 months (and taking into account the design, procurement, and test planning costs shifted prior to construction contract award) would result in a cumulative savings of approximately $8 1 M per ship. This cumulative savings translates to 21 percent of the NAVSEA acquisition cost estimate for the BLOa design.

Definition of the "Generic Build Strategy" Concept

The generic build strategy (GBS) was identified by the team as being a tool that could play a significant role in reducing the construction contract cycle to 24 months by serving as a focal point for overall procurement process improvement. A generic build strategy is a basic plan for the construction of the ship based on the proven principles of group tcchnology (GT) and product-oriented design and construction (PODAC) (5). One objective of GT and PODAC is to design the ship so that it is can be broken into groups or families of similar component parts, or interim products, based upon their manufacturing characteristics. A manufacturer can then optimize the application of his manufacturing resources to produce each of these product families. Another objective of PODAC is to outfit and test on-unit and on-block to the greatest extent possible, and to outfit on-board by zone (6). The development and use of it well defined product work breakdown structure (PWBS) in lieu of the traditional ship system work breakdown structure (SWBS) is essential to support GT and PODAC principles.

A GBS serves as a guide for all product development and production work, including all SWBS-based system/functional design work. The GBS also identifies all information content and formats required for production. The GBS for the mid-term fast sealift ships would encourage the incorporation of producible product attributes and globally accepted commercial standards during product development.

L i s t O f

a. Assessment of industrial base capabilities (vendors, shipbuilders)
b. Hull block definition
c. Zone definition
d. Dimensional reference system
e. Alignment procedures for propulsion equipment
f. Molded lines definition
g. Accuracy control plan
h. Required tolerances
i. Mat'1 & design selections for hull structure
j. Mat'1 & design selections for deckhouse structure
k. Hull outfitting schemes
1. Deckhouse outfitting schemes
m. Machinery space outfitting schemes
n. Definitions of design and production information requirements
o. Assessment of existing industrial base work load
p. Basic high level schedules (material, information, production)

The shipbuilders on the producibility team have emphasized that the Navy and shipbuilders must work together to define a meaningful GBS which supports a 24-month construction contract cycle. The level of cooperation required between the Navy and shipbuilders during all stages of product development to support a meaningful GBS will, in turn, require that significant changes be made to existing product development policies and processes. Traditionally, functional/system design, and any transition and detailed design considered necessary to support the shipbuilder's construction methods have been completed by the shipbuilder as part of the construction contract, as shown in Figure 1 above. In contrast, Figure 2 shows that some of this work would have to be done prior to construction contract award as part of a GBS which supports a 24month construction contract cycle. Some of the specific activities which would have to be much more complete prior to construction contract award are: 1) functional and transition design (this includes all composite drawings and product definition), 2) identification of nearly all of the material, equipment, and supporting VFI, and ordering of all schedule-critical material, equipment, and supporting VFI, 3) development of much test planning and some supporting documentation, and 4) development of cost estimating tools which accurately assess the cost of PODAC-based ship construction.

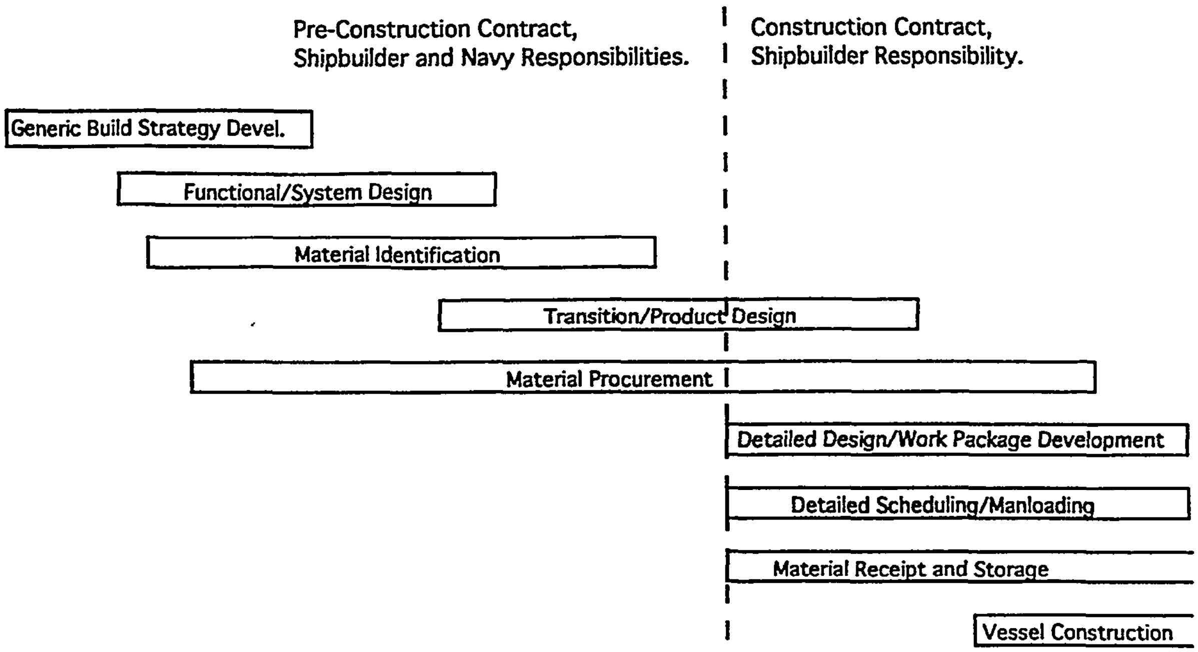


Figure 2. Possible Procurement Responsibilities.

The content and format of each of the elements of the GBS must be defined such that the information provided by the GBS is useful for detailed product development and construction. Each shipbuilder would agree to use the GBS as a construction guideline if they were to win a construction contract. In this regard, the GBS must be useful for contractors without intruding upon the detailed management of their manufacturing operations. The purpose of the build strategy is to establish the direct linkages needed between design and manufacturing so as to optimize the overall ship acquisition process, and to facilitate the organization of production work by a variety of individual U.S. shipyards to suit their individual needs. The GBS is not intended to dictate how contractors and vendors manage their people and facilities.

HIGH-LEVEL BUILD STRATEGIES FOR THE FSS BLOa

Both of the larger shipyards on the producibility team produced high-level build strategies for the BLOa design based on their experience with designing and building similar vessels. In the following discussions of build strategy these shipyards are refered to as "Shipyard A" and "Shipyard B."

Structural Build Strategies

Both Shipyard A and Shipyard B would use 15.24 m (50 ft.) long structural erection blocks. Both shipyards indicated that there would be a need to expand their present pin jig/curved block assembly areas to accommodate the large percentage of curved structural units/blocks associated with this hull shape. Both shipyards would define the innerbottom blocks to extend to where the innerbottom meets the side shell, and would choose to erect innerbottoms without side shell attached.

Shipyard A would define other structural blocks to include a single deck and the single-level shell and bulkhead adjacent and below. These structural blocks would be approximately half-breadth with erection breaks defined just to one side of centerline (see Figure 3). Shipyard A

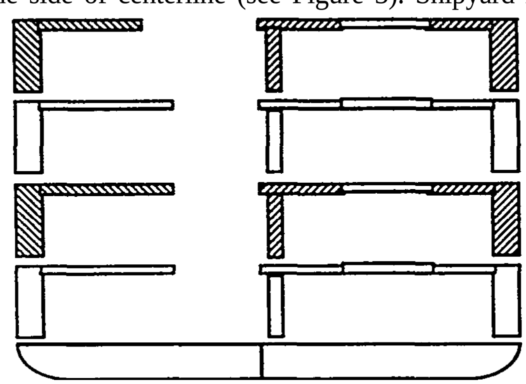


Figure 3. Shipyard A Erection Units With Modified Hatch Openings.

A

assumed that there would be centerline columns in the holds. Shipyard A moved the hatch openings toward centerline to decrease the number of erection units (see "Structural Product Considerations" section below). This product structure resulted in 199 structural erection blocks including stem ramp, rudders, and cranes.

Shipyard B would define side shell blocks two decks high, and each individual 15.24 m (50 ft.) section of deck and each bulkhead would be a separate erection block. The transverse structural blocks would be approximately half-breadth with erection breaks defined just to one side of centerline (see Figure 4). Shipyard B also assumed that there would be centerline columns in the holds. Shipyard B assumed that a skeg would be part of this baseline design. Shipyard B's structural product structure definition resulted in 263 structural erection units/blocks including stem ramp, rudders, cranes, and skeg.

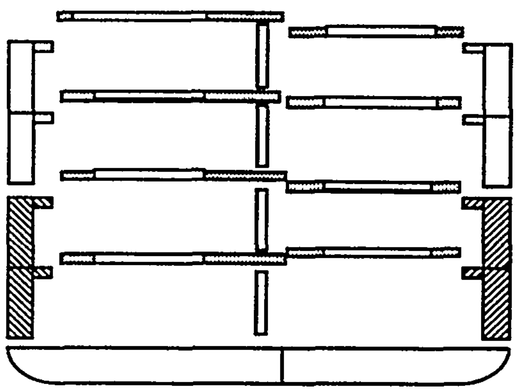


Figure 4. Shipyard B erection units.

Outfitting Build Strategies

Both shipyards expect that this ship's, or any other sealift ship's, product structure would he based on a product/zone oriented work breakdown structure which would facilitate pre-outfitting to the maximum extent possible.

Both shipyards would pre-outfit as many moveable ramps, hatches, and watertight doors as possible to their respective decks and bulkheads before these decks and bulkheads are erected. Because of the dimensional criticality of these components, final alignment, fitting, and welding of these ramps, hatches, and doors would be completed after erection.

Both shipyards would pre-outfit and test distributive system piping, hydraulic power units for ramps and doors, ventilation systems, light fixtures, local junction boxes and wiring, etc. to the maximum extent possible prior to erection.

Both shipyards expect that pre-assembled and tested outfitting components would be specified to the maximum extent possible. These components would include cranes, mooring winches, anchor windlass, etc.

Shipyard B defined its engine room around the machinery arrangement provided by NAVSEA for this study. Following are the important characteristics of Shipyard B's main machinery space:

1) The equipment on the 3.96 m (13 ft.) level would be broken into 9 outfit package-units/assemblies which would fit around the main engine, the reduction gears, and the SSDG's (see Figure 5).

2) Equipment on each upper level would be divided into 4 to 6 outfit package-units/assemblies which would cover most of each level.

3) All of these outfit package-units/assemblies would be pre-assembled and tested to the maximum extent possible prior to erection.

Shipyard A has proposed an alternative engine room arrangement which could greatly enhance the producibility of this ship. This arrangement differs from the NAVSEA-provided arrangement in the following ways.

1) The main engines and reduction gears are moved aft in the main machinery space as far as possible while maintaining reasonable access to the aft side of the gears.

2) The uptakes/stack(s) are moved aft of the deckhouse rather than being integral to the deckhouse. This arrangement would, to some extent, remove ship accommodations work from the critical path associated with main machinery space outfitting and testing. This arrangement would have the additional benefits of simplifying the paths for exhaust uptakes and air intakes, and removing a major source of noise and vibration from the middle of the accommodations spaces.

3) Most other main outfit components, and the machinery control room (MCR) are incorporated within three "cores" arranged transversely forward of the main engines. These "cores" are multi-level assemblies of outfit package-

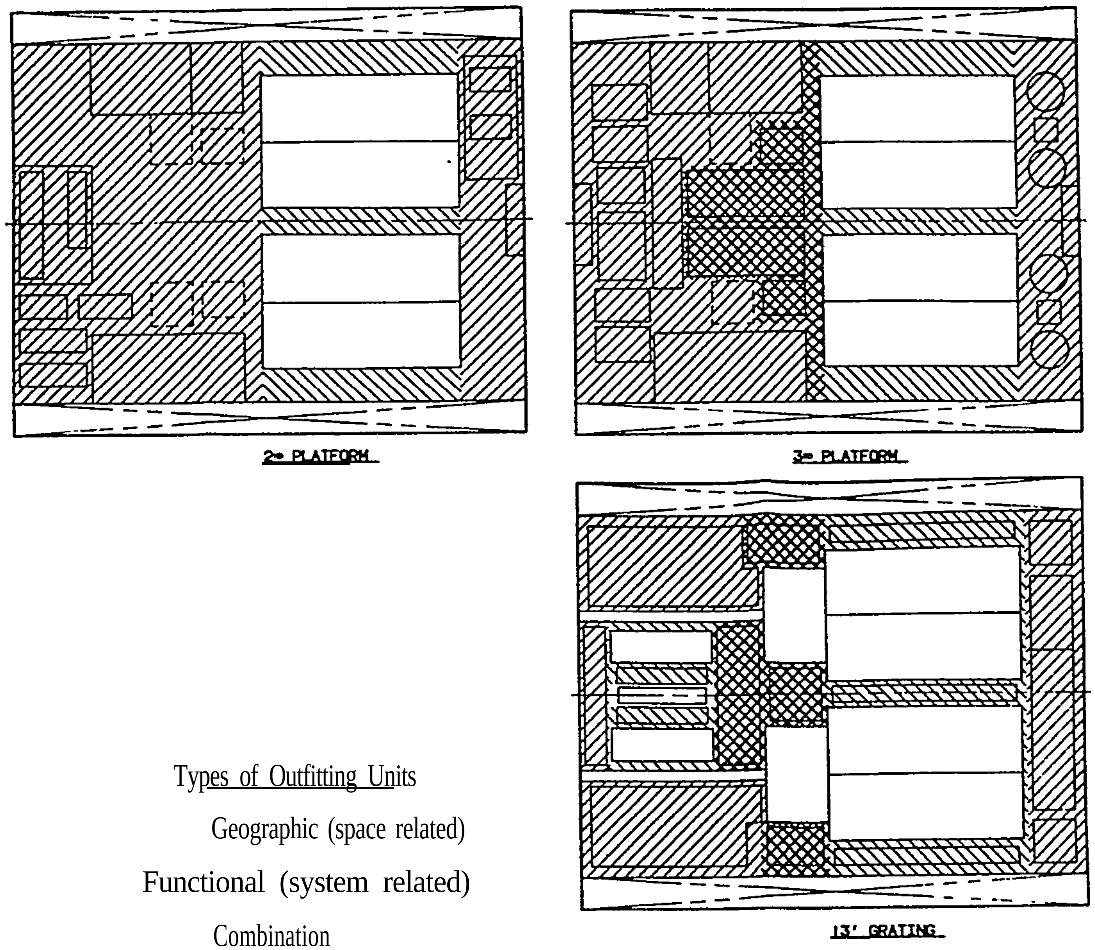


Figure 5. Shipyard B Outfit Unit Definition and Layout.

units/assemblies with their associated support structure, foundations, wireways, catwalks, etc. (see Figure 6). The cores would weigh 100-200 tons complete and could be erected either as singular erection lifts, level by level, one outfit unit at a time, or component by component depending on the capabilities of the shipyard erecting the ship. This arrangement would provide maximum flexibility for the shipbuilder to conduct outfitting work and testing on-unit and on-block either at the shipyard or at subcontractors, and would also provide maximum access around and above the main engines and reduction gears. The MCR would also be moved from above the main engines and reduction gears which would prevent the MCR from restricting uptake routing, and would significantly reduce noise and vibration within the MCR.

4) Long-lead auxiliary equipment such as SSDG's, auxiliary boiler, HVAC units, etc. am arranged on upper levels making this arrangement less schedule-critical (see Figure 7). Being able to erect the cores complete, level-by-level, one outfit unit at a time, or component-by-component provides some schedule flexibility for late components. This arrangement would have the additional benefits of preventing auxiliary system failure due to lower-level flooding of the engine room, and also moving these systems closer to air intakes and exhaust uptakes.

5) Main wireways and junction boxes are located on the forward engine room bulkhead to allow easy access.

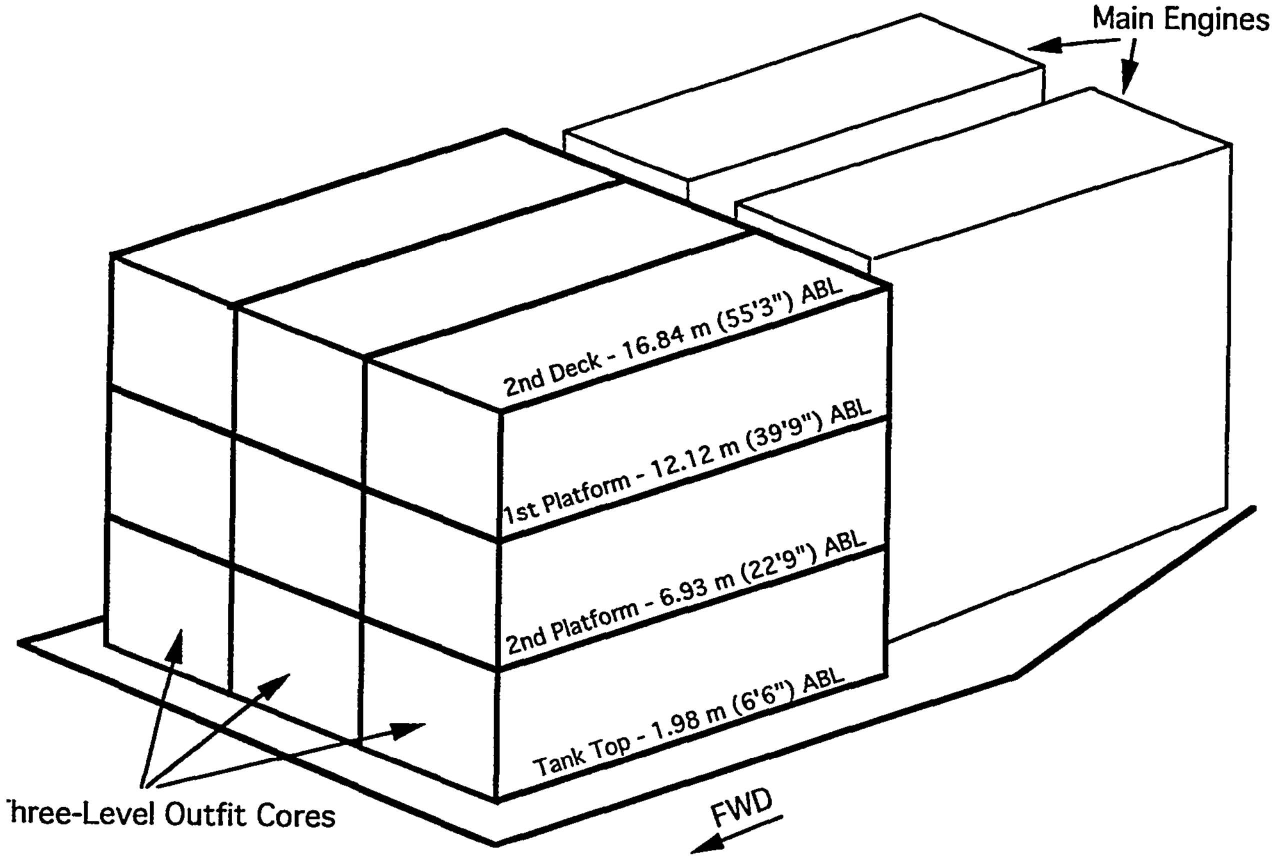


Figure 6. Re-Arranged Engine Room With Outfit Cores.

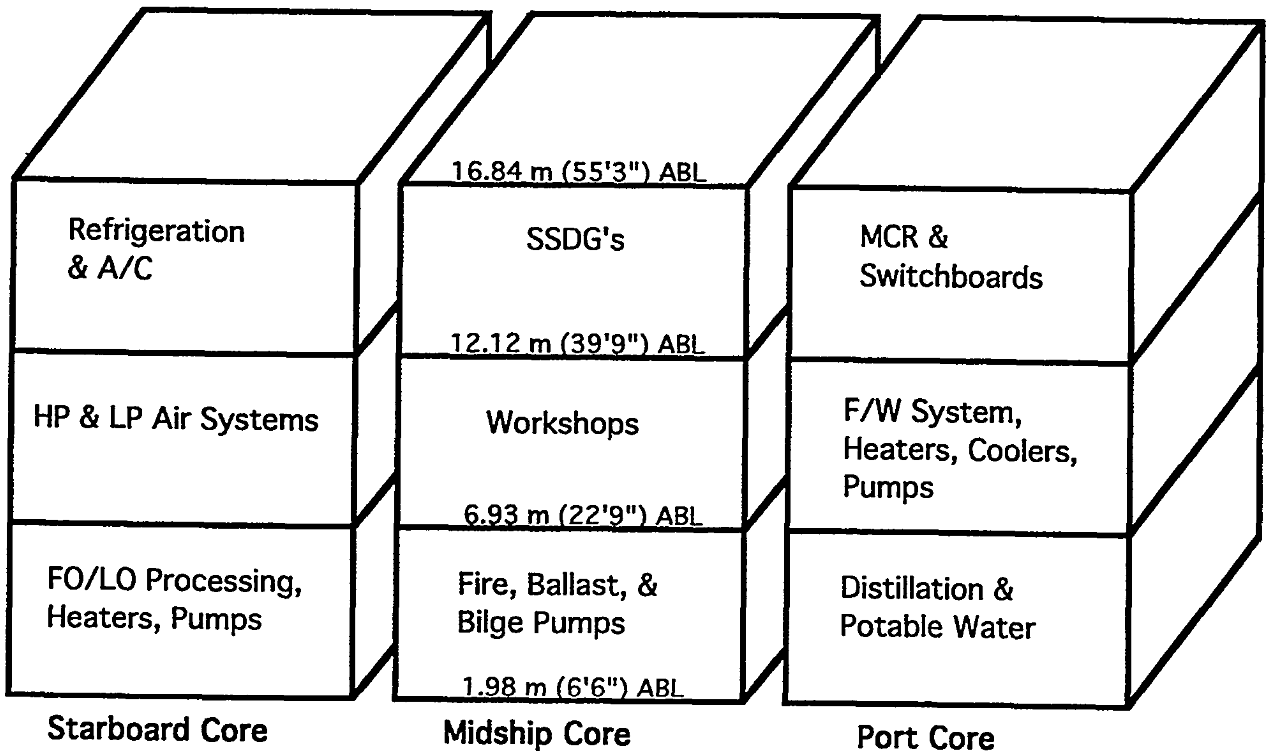


Figure 7. Possible System Arrangement Within Outfit Cores.

PRODUCT-RELATED RECOMMENDATIONS

Improving the producibility of the product itself would contribute significantly to the reduction of the construction contract cycle to 24 months. Following are the results of the producibility critique of the FSS BLOa ROM design as it existed in September 1991.

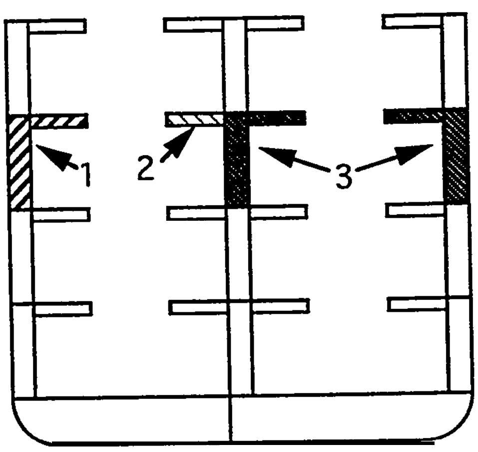
Structural Product Considerations

Hull Shape. The BLOa design has a significant amount of complex hull shape and no parallel mid-body. For this baseline design, NAVSEA should consider altering the shape of the hull near and above the design waterline to provide more flat and simple curved structure. The labor hours per ton cost difference is significant between flat/simple curved blocks and complex curved blocks. Flat shell plate and associated structure require no forming and shell plate with simple curvature and associated structure can be easily machine formed. Complex curved shell plate and associated structure require a combination of more difficult machine forming and heat forming. Flat and simple curved blocks can be welded using mostly automatic and semi-automatic methods. Complex curved blocks require much more manual welding. Also, the labor hours required for layout, fitting, and accuracy control are significantly higher for complex curved blocks. Finally, complex curved blocks are not repetitive and require either unique fixtures or pin jigs for assembly at a substantial capital cost. The hull shape may not be as much of a problem for other baseline designs.

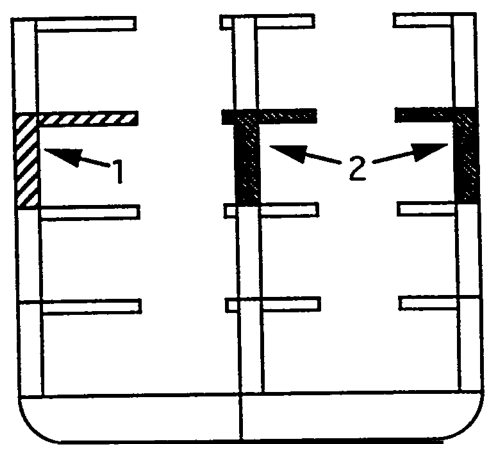
Hatch Position and Number of Erection Units. Careful consideration should be given to the position of hatches as hatch placement might have an effect on the number of erection lifts-required (see Figure 8).

Innerbottom and Adjacent Bulkhead In sections of the ship where there are outboard longitudinal bulkheads and an innerbottom, the innerbottom should be designed with the tank top extending to the side shell, and the longitudinal bulkheads should end at the tank top. This innerbottom configuration will provide a convenient platform onto which vertical structural units can be erected.

Alternative Structural Details. NAVSEA's own process improvement effort has identified that "(the) Navy should get familiar with shipyard standards and standard details" (7). All structural details should be examined for improving ship producibility. As an example, existing vehicle tie-downs are castings that must be welded into the deck from both above and below. These castings are expensive long-lead items, and their installation is labor intensive and requires early access to both sides of each deck. This additional access requires additional repositioning of each deck over and above the repositioning already required for other outfitting. The installation of these castings and their supporting structure make the assembly of the decks much more schedule-critical with the possibility of their effecting overall construction duration. A possible alternative might be that the clover-leaf openings could be automatically (NC)



Hatch Arrangement As Specified, 14 Erection Units Per Section.



Alternative Hatch Arrangement, 10 Erection Units Per Section.

Figure 8. Hatch Arrangement vs. Number of Erection Units.

cut in the deck plate, and pipe caps could be welded from the back side to serve as reinforcement and as watertight seals between decks. Uncoped flat bar could be used to back these caps. The more standard the structural configuration and the positioning of these tie-downs, the more amenable this installation work is to automated/robotic fitting and welding. Another structural detail producibility example is the potential for use of bulb plate rather than angles and T's in some ship structure.

Drive-Through Passageway Arrangement. Main deck drive-through passageways should be positioned so as not to interfere with engine room casing(s)/uptakes, and such that they complement second deck structure. For example, port and starboard main deck passageways could be positioned similarly to passageways on second deck - this would simplify deck structure.

Deck Height and Structural Design Deck heights and/or beam depths should be designed to allow the running of as many distributive and service systems as possible without having to penetrate structural members. This would apply in accommodations and other spaces.

Shipbuilder Involvement In Design Shipbuilders should & involved in conceptual, preliminary, and functional design to help identify and develop the type of ideas discussed above.

Outfitting Product Consideration

PODAC Compatibility of Design The FSS design must be completely compatible with product/zone oriented work breakdown structure to facilitate maximum pre-outfitting, early testing, and aggressive construction schedules. The earlier outfitting work and testing can be completed in the construction process, the less time it will take and the less it will cost (6). There is a substantial increase in the time and cost required for work from one construction stage to the next (on-unit to on-block to on-board) (see Figure 9).

Alternative Engine Room Arrangement NAVSEA should carefully consider the potential benefits of alternative engine room arrangements. Both shipyards agree that an alternative arrangement such as that proposed by Shipyard A could reduce construction duration and cost. The development of a producible machinery arrangement would be greatly facilitated by the development of physical and/or CAD design models.

Major Equipment Decisions. Both shipyards expressed significant concern over seemingly premature and/or ill-considered NAVSEA decisions on major propulsion equipment for the FSS BLOa design variant. Both shipyards feel that these type of decisions can jeopardize any attempt to improve the efficiency of construction and operation of any ship. This is particularly true when unproved major equipment has been specified.

In the case of the BLOa, only one of the 18 PC4.2V Colt-Pielstick engines specified has ever been built. In addition, there are no build/test beds in this country capable of accommodating these engines. This makes the delivery of these engines to support aggressive construction schedules of the mid-term sealift ships a potentially serious problem, even at this early date. The reduction gears will also cause problems with regard to their development and delivery. To the shipyards' knowledge, no single-reduction gear has ever been built to accommodate two 22,000 kilowatt inputs and an almost 45,000 kilowatt output. Double reduction gears with this capability have been built, but have not yet been designed for a reduction from a 400 RPM input to a 120 RPM output.

Additionally, even if the specified equipment were available to support an aggressive multi-ship procurement schedule, sealift ships with these machinery specifications would be very complex and expensive to operate and maintain. This expense would remove such ships from the category of "commercially viable."

NAVSEA should be absolutely certain that equipment specified for these ships will be proven and available to support aggressive multi-ship build schedules. NAVSEA should also consider the impact that equipment decisions will have on operations complexity and expense, and on the resulting commercial viability of these ships.

Modularized Accommodations. NAVSEA should consider the use of modularized accommodations spaces similar to those used on cruise ships. These are pre-fabricated cabins which are installed and attached to the hotel services with flexible couplings.

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5 Data provided in Figure 10 was confirmed by two shipyards on the team based upon their own experience.

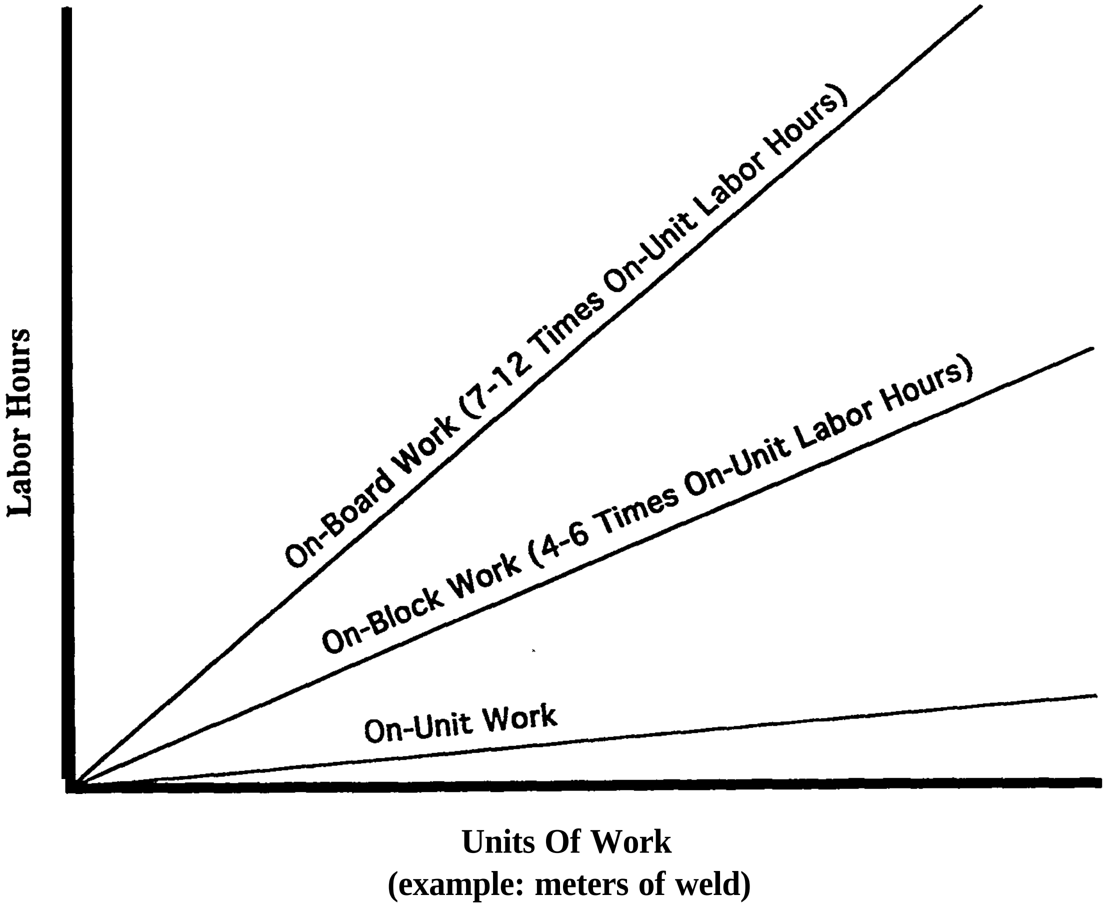

Figure 9. Productivity Versus Stage of Construction.

System Joining Technology. NAVSEA should consider the development and use of alternative systems joining technologies such as electrical splices, different couplings for pipe, etc. Present specifications related to system continuity and joining methods sometimes directly limit the amount of pre-outfitting and testing that can be completed on-unit and on-block.

Shipbuilder Involvement In Design. Shipbuilders should be involved in conceptual and preliminary design to help identify and develop the type of ideas discussed above.

Other Product Considerations

Commercial Standards. Navy auxiliary ship designs should be based on globally accepted commercial product and process standards to the greatest extent possible. Using commercial standards would allow both the Navy and the shipyards much greater flexibility in procurement, and would significantly reduce integrated logistics support (ILS) and contract data requirements list (CDRL) requirements, and the inspection, testing, approval, and reporting requirements associated with the construction and maintenance of these ships. The shipyards identified that using commercial standard equipment, materials, and procedures could help reduce the time from launch to delivery, which averages 8-10 months on present Navy auxiliaries, by up to 3 months.

Metrification. Metrification is inevitable if U.S. shipbuilders wish to compete in the global shipbuilding market. in fact, both shipyards on the team are already using some metric-based material and equipment in their commercial work. Both shipyards feel that in spite of the considerable initial cost, the sooner the Navy supports the conversion to metric, the less costly and more beneficial the conversion will be in the longer term for the Navy, U.S. shipbuilders, and the supporting industrial base. In the short term, it is recommended that NAVSEA initiate cost/benefit analyses to determine the effects of implementing metrification over time.

Standardized Interim Product The development and use standard interim products, such as the fan room package produced by Avondale Industries for the LSD 41 and LSD 41 (CV) classes, could significantly reduce the duration and cost of follow-ship design, material identification and procurement, and construction, even for new and different classes of ships. The standardization of interim products would also reduce the cost of ship maintenance through reductions of spare-part inventories and custom-made components and systems. Standard outfitting units, such as chill water machinery units of various sizes/capacities, SSDG units of various sizes/capacities, fire pump units, etc. could be developed to globally accepted commercial specifications. This ties in directly with NAVSEA's "Affordability Through Commonality" initiative. NAVSEA should actively involve shipbuilders and the shipbuilding-related industrial base when developing standard interim products.

Existing Alternative Materials Existing alternative materials should be identified and evaluated for potential savings in construction duration and cost. NAVSEA's own process improvement effort has identified that the Navy should". ..allow use of alternative materials, especially better ones" (7). Some of these materials are poured epoxy chocks, composites (piping, joiner bulkheads, etc.), spiral ducting, U-bolt pipe mounts, and bulb plate stiffeners.

POLICY-RELATED RECOMMENDATIONS

Following are procurement policy issues that would have to be addressed to support a construction contract cycle of 24 months.

Product Development Policy

Navy ship design-related and construction-related policies should be re-defined to clearly describe the various product development stages and the extent of shipyard involvement in each of the following:

- conceptual, preliminary, and functional design;
- material, equipment, and **VFI** procurement;
- transition design;
- detailed design and construction.

NAVSEA's own process improvement efforts have identified that "ship acquisition rules frequently inhibit incorporation of design changes by shipbuilders which could enhance producibility" (7). Both shipyards on the producibility team strongly recommend that the Navy redefine its shipbuilding related contracting procedures to accommodate shipyard involvement throughout the procurement cycle, from conceptual and preliminary design through delivery. The Navy should obtain shipyard input to help define the product development process and associated contracts.

Commercial Standards Policy

Existing globally accepted commercial standards should be approved for incorporation into sealift design to the greatest extent possible.

Design Change Policy

A policy to eliminate, or at least significantly limit design changes after construction contract award must be established. NAVSEA's own process improvement efforts have identified that there are significant unnecessary costs associated with excessive design changes (7).

Vendor Approval Policy

A streamlined Navy approval process for vendors proposed by shipbuilders must be created, and/or vendor pre-selection should be supported.

Multiple Ship Procurement Policy

The Navy should consider using multi-ship procurements so that shipbuilders can take advantage of design and planning standards developed on earlier hulls and keep process lanes going continuously. Multi-ship procurement would also encourage investment in re-tooling and automation for repetitive work. Multi-ship procurement would have a significant positive impact on procurement duration and cost per ship.

PROCESS-RELATED RECOMMENDATIONS

All improvements in the product development process identified below are dependent upon satisfactory resolution of many policy issues identified above.

The Design Process Prior To Construction Contract Award

As identified in the "policy" section above, shipbuilders feel that they must be involved in every stage of product development to assure the producibility of the ship design. NAVSEA's own process improvement efforts have identified that "potential cost savings (are) not being realized (with) producibility not part of early design stages. . . . NAVSEA ship designers are not sufficiently knowledgeable of the latest advances in ship construction technology to incorporate producibility features in the design. . . . NAVSEA design policies, procedures, and standards do not routinely address design trade-offs relative to ship production efficiency. . . . There is a lack of concurrent product and process design and an inconsistent approach to addressing producibility among ship designs" (7).

The ship design/product development process should focus upon the development of a generic build strategy for the ship, meeting the specified functional requirements, and incorporating producible characteristics into the design. The generic build strategy would support the incorporation of design-for-production attributes and globally accepted commercial standards to the greatest extent possible, and would facilitate the organization of production work by a variety of individual U.S. shipyards to suit their mutual and individual needs. The GBS would be used to guide product development and production planning.

In support of the GBS, all functional and much of transition design would be completed prior to construction contract award. Transition design is defined to include the development of all multi-system composites and the ship's product structure. Also, as part of the design process all material, components, and VFI would be identified prior to construction contract award, and all schedule-critical material, components, and VFI would be ordered prior to construction contract award to support design and construction schedules. All important testing requirements would be identified and some supporting documentation prepared prior to the construction contract award. The normally inactive period of time between submittal of shipyard quotations and construction contract award (6-18 months[6]) could be used by shipyards, perhaps working with NAVSEA, to complete some of the work identified above.

Cost Estimating Processes and Tools

The development of a GBS that is based on PODAC concepts would require the support of cost estimating methods and tools that accurately reflect the costs of building a product-oriented ship design in a modem ship construction environment. Some current NAVSEA cost estimating algorithms may not accurately reflect the benefits that can accrue from the utilization of product-oriented design and construction methods, and from the incorporation of producibility-related characteristics into a design. Many existing NAVSEA algorithms are known to be system- and weight-based which sometimes drive reductions in steel weight at the expense of internal ship volume. These reductions in internal volume necessarily increase outfitting density and, in turn, drive up the cost of construction outfitting, maintenance, and overhaul, and may adversely impact the effective unitization of outfitting. NAVSEA's own process improvement efforts have identified that "the NAVSEA ship acquisition cost estimating process used in assessing the cost impacts of different design options is not adequately sensitive to producibility considerations in a ship design. . . -High cost drivers (are) not well understood; (there is a) lack of quantitative measures of producibility" (7). Current cost estimating algorithms should be critically examined and modified/replaced as necessary (perhaps with time- and/or density-based methods) to assure that they accurately reflect the costs/benefits of modem ship design and construction.

Material and VFI Procurement Processes

Procurement responsibility for material, equipment, and required VFI should be more clearly defined for each stage of product development. This would help streamline the procurement process by eliminating redundant administration and inspection requirements.

Detailed Design Process

Detailed design (which is defined to include the development of work instruction, construction drawing, and detailed/working schedule) should continue to be conducted by the shipbuilders after construction contract award as part of the construction contract.

Cost and Schedule Reporting Process

Cost and schedule reporting requirements outlined in the Department of Defense instruction DOD1 7000.10 should be used for these ships (or something even less burdensome), rather than the full cost and schedule contro1 requirements of DODI 7000.2.

6 Source: Shipyard experience with recent Naval auxiliary contracts.

Naval Auxiliary Ship Acquisition Process Model

A Navy auxiliary ship acquisition process model should be developed. It is important that all parties to the Navy auxiliary acquisition process clearly understand the process and agree where the greatest acquisition time reductions and savings could be gained for a given investment of resources. It is also important to have a tool that can be used to measure the effects of changes as they are implemented (4).

Shipyard Capabilities Survey and IMIP Information

A survey should be conducted to identify the facilities capabilities and construction philosophies of the different U.S. shipbuilders as related to Naval auxiliaries, and to use in determining the minimum level of facility and methods required to support future Navy auxiliary ship acquisition. This information would serve as a key starting element for the generic build strategy development process. It is also recommended that NAVSEA ensure that shipbuilders are made aware of these minimum requirements and that they are also made aware of the Industrial Modernization Incentives Program (IMIP).

Navy/Vendor "Tiger Teams," Complex Component Installation Processes

Technicians and specialists who are familiar with specific complex components and systems are expensive personnel for individual shipyards to keep on payroll full time so that they are available for relatively intermittent installation, testing and inspection work. The Navy, along with appropriate vendors, could maintain "tiger teams" for the installation, inspection, and testing of specific complex components and systems. These teams would rotate from shipyard to shipyard as needed, and thus would be kept busy on a full-time basis. This method of installation, inspection, and testing of complex outfitting would be worth investigating for potential savings.

SUPSHIP Construction Evaluation and Inspection Processes

As standards are developed and adopted more and more within the shipbuilding industry, the Navy's Supervisor of Shipbuilding (SUPSHIP) organizations at different shipyards should be trained to evaluate construction consistently according to these standards.

Circular of Requirements Process

A potentially more cost-effective method by which the Navy could procure fast sealift ships might be through a commercial-type procurement using a Circular Of Requirements. Both shipyards on the producibility team agree that the most cost-effective method by which they could produce these ships would be through the use of a commercial-type COR. Using a commercial-type procurement, shipyards would be responsible for all product development work including all design work, material procurement, VFI procurement, and construction. This type of procurement would help shipyards orient their operations more toward the commercial market. The potential cost savings associated with a commercial-type procurement can be demonstrated by comparing the NAVSEA-estimated $385M price and the NSWC-estimated $304M price to an estimated commercial market price of $220-230M per ship.7 Container ships of similar size and with significantly less complex machinery arrangements are presently being built in Japan and Germany for about $l25M per ship (12). Adequate consideration should be given to commercial-type procurement methods which might reduce costs and result in ships which are more desirable for chartered commercial service.

TECHNOLOGY-RELATED RECOMMENDATIONS

Following are some technologies that could directly reduce, or facilitate the reduction of, the construction contract cycle if developed and implemented.

Modeling Tools

Physical and/or CAD design modeling capability could be developed for ship design and construction planning. Physical and CAD models of outfit-intensive areas within a ship, such as the

7 UMTRI estimate based on vessel complexity and current world market prices, and on information from a shipyard stating that a COR-type procurement for the BLOa ship would result in 20-25% cost and schedule savings at their facility over a traditional-type procurement. 75% of $385M is $289M; if the world's most productive shipyards are presently at least 20% more cost effective than any U.S. shipyard (an estimate that UMTRI feels is reasonable), then the current world market price would be less than $231 M.

engine room, can be tremendously useful for identifying interferences and restricted accesses. Models can also be used to compare various product structure alternatives and associated erection plans for production and maintenance efficiency.

New Materials

Materials research should be conducted to identify and evaluate alternative materials or material applications which have not yet been used on ships of this type.

Producibility Guide For Design

A producibility guide for design could be developed to assure that designers and engineers (Navy, shipyard, design agent) have access to information that will support the incorporation of producible characteristics into ship designs. This producibility guide could be developed so that it could be accessed within the CAD environment. The guide would contain information from the numerous producibility studies that the Navy has funded over the last twenty years, as well as other information developed through the NSRP and by foreign shipbuilders. The available information would be maintained to represent the state of the art in naval ship construction.

Standard Materials Guide For Design

With increased use of standard interim products and components, a standard material guide could be developed for use by designers (Navy, shipyard, design agent). This guide could be developed so that it could be accessed within the CAD environment.

Automation in Production

With increased use of standard interim products, and, possibly, multiple-ship procurements, many production processes would be standardized and some could be automated. The assembly of structural panels is one example area where the associated production processes could potentially be automated, greatly reducing process variation and production cost.

Real-time Production Monitoring and Control

Improving shipbuilders' ability to monitor production in a realistic way and on a real-time basis could significantly improve their ability to identify and improve costly interim products and construction processes.

Electronic Data Transfer

Electronic data transfer could greatly enhance the efficiency of the ship acquisition process if the ship is being developed or built by multiple parties. Data requirements could be developed for in accordance with NIDDESC (Navy Industry Digital Data Exchange Standards Committee) guidelines.

Scaffolding Technology

Foreign shipbuilders use significantly more modular, moveable scaffolding than U.S. shipbuilders. Many U.S. shipbuilders continue to use old-fashioned pipe-and-plank scaffolding. The development of new scaffolding technology to coincide with the development of standard interim products would help reduce the difficulty of work on large units and on-board ship, improve safety, and reduce non-value-added labor hours associated with scaffolding set-up and tear down.

Jigs and Fixtures

The government and shipbuilders could work together to develop, build, and share jigs and fixtures for the fast sealift ships.

Test Equipment

The government and shipbuilders could work together to develop, build, and share test equipment for the fast sealift ships.

Welding and Heat-Forming Technology

Research should continue to be pursued in these areas to develop intelligent and automated systems for this work.

CONCLUSIONS

In determining what Mid-Term FSS research and development areas to support, the Navy must recognize that because the Ship Construction Navy (SCN) budget will not be capable of supporting the shipbuilding industrial base as it had during the 198Os, the survival of the industrial base is dependent upon becoming competitive in the world shipbuilding market. The Navy can support this objective by attempting to acquire auxiliaries that are as commercial in nature as possible. A determined effort must be made to increase the level of common types of hull, machinery, and electrical (HM&E) components that reside in commercial and defense-related ships. The Navy could also modify its procurement practices to be more like commercial procurement practices. Failing to address these issues will result in a severely weakened and inefficient mobilization base by the end of this decade, as U.S. shipbuilders either go out of business or choose to compete only in the world market in order to maintain their commercial competitiveness.

In determining where to focus production-related RDT&E resources, it is also important to realize that a significant portion of the production technology needed to boost the industry's competitiveness already exists. Many U.S. shipbuilders have not implemented significant portions of this existing technology. For example, there are four prime components to product-oriented design and construction that have been documented within National Shipbuilding Research Program literature. These four components are the Hull Block Construction Method (HBCM) (6), Zone Outfitting Method (ZOFM) (6, 13,14), Zone Painting Method (ZPTM) (15), and Integrated Hull, Outfitting and Painting Method (IHOP) (16). To date, the Hull Block Construction Method is the only component that has been widely implemented by the U.S. shipbuilding industry. Some of the other components have been applied with varying degrees of success by some U.S. shipbuilders. The piece-meal application of PODAC concepts by most U.S. shipbuilders has not allowed them to realize the full potential of implementing all four components in an integrated fashion.

A major contributing factor to this lack of implementation has been the lack of incentives in past and existing Navy contracts. NAVSEA has already identified this as a problem through their process improvement efforts (7). A serious effort should be made to encourage and facilitate the implementation of existing fundamental ship production methods and technologies prior to Developing new technologies. The pursuit of contractual vehicles which can provide the incentive for full implementation of PODAC within the industrial base should be a top priority. The producibility team has identified the generic build strategy as a potential tool which. if properly executed, could provide the necessary focus for the Navy and the industrial base in this regard.

Recommendations which would support the successful implementation of a GBS and PODAC have been identified above. Most items requiring immediate action are associated with refining/changing existing design and procurement policies and processes, as these items are most critical to supporting GBS development and reducing procurement duration and cost. Items requiring action in the longer term are primarily associated with the development of new shipbuilding technology as these items by themselves will have significantly less impact on reducing construction duration and cost.

It is impossible for the project team to estimate the cost of making the policy and process changes that will facilitate the development of a generic build strategy and the PODAC-based construction of the Mid-Term Fast Sealift ships. It is the team's belief, however, that the benefits that will result from such changes would far outweigh the associated Costs.

The Naval Surface Warfare Center, Carderock Division, has made some COST estimates for the development of a generic build strategy and for the development of some supporting product, policy, process, and technology areas. The project team is also analyzing many of the other product, policy, process, and technology areas identified in this paper to determine for each the time to develop, time to implement, cost to develop, cost to implement, potential time savings, and potential cost savings.

NSWC estimates that an investment of less than $30M in the most critical producibility-related areas identified in this paper, if supported by necessary policy and process changes, will lead Mid-Term Fast Sealift development in a direction, as manifest in the development of a generic build strategy, that will result in significant savings over the NAVSEA estimated cost of $385M per ship. The total estimated cost savings for a 24-month construction contract cycle are $49M or 13 percent per ship. The total estimated cost savings resulting from an 18-month construction contract cycle are **$81M** or 21 percent of the NAVSEA estimated initial acquisition cost for the BLOa design.

NAVSEA should continue its efforts related to improving product development and procurement policies and processes to create a more streamlined environment for the development and procurement of the Mid-Term Fast Sealift ships and all future Navy ships. The Navy should also begin to invest in the critical producibility research and development areas identified in this paper.

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Evaluating the Producibility of Ship Design Alternatives

No. 7B-2

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ABSTRACT

This paper presents the results of a project that has been carried out under the sponsorship of Panel SP-4, Design/ Production Engineering, of the Ship-Production Committee of the National Shipbuilding Research Program. Two methods for evaluating the producibility of ship designs and/or ship design alternatives have been developed, one of which provides quantitative results in manhours or dollars. The other method provides relative results based on weighting factors developed for specific ship projects and the design phase during which the alternatives are being considered. The second, relative, method also can be used for evaluating all of the other parameters which must be considered in making a decision to proceed with any design change, including total cost, performance, schedule and risk. The two methods are described in some detail and examples of application of each of these two methods to specific design alternatives are presented.

INTRODUCTION

In March 1991, SP-4 authorized a project to develop Producibility Evaluation Criteria for U.S. Navy Ship Designs. The objective of this project was to develop a technique for use by project managers and ship design managers to evaluate the construction cost difference of different design variants. The particular objective was to develop a technique that was based on the actual work content of the design rather than being based on the weight of the resulting design. This distinction is made because most existing cost-estimating techniques utilize weight based factors which are derived from prior designs and are applied to the weight of the design being considered. One consequence of this is that most of the design studies which have been labeled "producibility" studies have concentrated on methods for reducing weight. Many examples can be cited to demonstrate that weight reductions may actually result in increased construction cost. The most extreme result of assuming that cost is a direct function of weight has been the imposition of displacement limitations on some shin types during the design process in the misguided expectation that such limitations would control costs! While recognizing that, in the gross sense, the cost of a product is weight related, the authors were convinced that other techniques could be developed to relate cost more directly with the actual work content of a design.

An additional goal of the project was to provide a method that could be applied at any stage of the design process. It was hoped that the technique developed could be used equally well during early feasibility studies, when few details of a ship design have been developed, as during the construction period, when the design details would be available.

EVALUATION OF PAST PRACTICES

The first three tasks of the project. involved analyzing the content and effectiveness of producibility evaluation methods that had been used on prior programs or that were currently in use for ongoing programs. In carrying out these tasks, team members met with personnel from NavSea project management and design management offices, Supervisor of Shipbuilding Offices, private and public shipyards and private design agents. A listing of various attributes that had been used in the programs carried out under the direction of these organizations was compiled. The results of these meetings were somewhat disappointing, in that the criteria that were being used for evaluating producibility included relatively few items that related to the magnitude of the construction effort. The criteria in use were primarily weight-related factors or performance related factors. Further, it was noted that shipyards do not necessarily make a detailed calculation of cost savings if it is obvious that a change in production practice will reduce manhour5 and cost. Thus, the team was not able to find, in any organization, a method already in use that would accomplish the goals of the project.

DEFINITION OF PRODUCIBILITY

One of the findings from the review of existing methods for evaluating producibility was the recognition that "producibility" usually was being interpreted so broadly that any cost reduction study was labeled as a producibility study. People inherently understand that by improving the "producibility" of a project, the cost of the product will be decreased. However, the converse - that all cost reductions result from having made producibility improvements - is patently invalid. In effect, Producibility was being equated with Productivity. In order to focus the effort of the study team, the following statement was developed:

> Improved producibility involves reduction in the recurring expenditure of resources for constructing a product. Recurring cost is the measure of producibility. There is an inverse relationship between recurring cost and producibility.

This definition identifies the relationship between producibility and cost, but differentiates producibility cost from all other cost items, particularly the non-recurring cost. This distinction is necessary because the non-recurring cost may be prorated over the number of units of the product to be produced, and thus is a variable, while the recurring cost is essentially nonvariant. Producibility cost should include labor cost, material cost and operational cost of the facilities used directly in the production of an item. However, of the operational cost of facilities, only the cost of consumable items has been addressed in the techniques presented herein.

METHODS AND APPLICATIONS

During discussions with personnel of shipyards involved in ship construction, team members obtained lists of design attributes that contribute to reducing construction cost. Most of these had not been used explicitly in any of the existing producibility evaluation methods that were studied. The attributes that were identified were precisely the type of criteria that could be used for evaluating the producibility of a design. This led the team to consider a method for identifying and evaluating criteria known as the Analytical Hierarchy Process (AHP). This method does not require hard data in order to select the preferred choice. However, its results are relative, rather than absolute, and are based upon the subjective opinions of a group of participants with expertise in the field under consideration. The numerical evaluations which it provides do not relate directly to dollars. The potential power of the AHP method is so great that the team decided to apply it to evaluating producibility. However, in addition, the team proceeded to develop a more conventional method, which would provide cost data directly. Consequently, two distinctly different approaches for evaluating the producibility of designs have been developed, each of which has specific advantages.

The techniques discussed above would be considered important and useful if they provided only the cost of producing one specific design compared to the cost of another. *However* the team realized that the AHP method also was suitable for use in evaluating those elements that enter into a design selection decision, which are schedule, risk, performance and other cost elements. There must be a net positive balance to the consideration of these elements in order to justify a choice between competing designs. Application of the AHP process to the evaluation of these elements, I.e., to the total design decision making process, was the final effort accomplished by the team. Each method was applied to several theoretical and actual producibility issues for validation of the values and techniques used.

THE COST ESTIMATING COMPUTER PROGRAMS

This section describes a technique for determining the cost, in manhours and dollars, to construct a product. The technique is based upon a bottom up, production engineering approach to estimating costs in ship construction and repair.- It is particularly applicable to the analysis of the Producibility of alternate designs and can be applied to small subassemblies as well as to the total ship. Although the complexity of a total ship design might require the expenditure of excessive effort, discrete changes in a total ship design can be evaluated by using the differential method. The technique lends itself equally well to obtaining the total cost of the work or to the differential cost of alternative designs. For producibility questions, the differential cost normally is all that is required.

The work required to prepare a cost estimate of even a simple design can be daunting if performed manually. Further, comparing estimates prepared by different organizations can be extremely difficult, since each organization *may* use different assumptions, approaches and factors for analysis. In order to simplify and standardize the calculation of cost estimates in producibility issues, cost estimating computer programs (CECOPs) for ship construction and repair costs have been developed for those types of shipyard work which are normally the major drivers of construction costs. The CECOPs have been prepared for the high impact trades involved in structural, piping and electrical, as well as for heating, ventilation and air conditioning (HVAC) work. However, this initial group of programs is not all-inclusive. Programs have been prepared only for the major materials utilized in the work in these categories. For example, the structural program has been prepared only for mild steel. aluminum. HY80 and HTS, while the HVAC program is-limited to sheetmetal ducting.

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

The CECOPs are in spreadsheet format and are designed for use with Lotus 123 Release 2.0 or later. Translation of the programs to and from other spreadsheet application programs has been accomplished without difficulty. The cost factors used are based upon data and engineering standards obtained from various sources. The contributions to this effort by the U.S. Naval Shipbuilding Scheduling Office and Philadelphia Naval Shipyard are particularly appreciated. It is fully recognized, however, that the data contained in the current version of the programs provide only a reasonable starting point and that extensive revisions and expansions can be expected after other organizations review and apply the programs.

Basic Concept

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

The steps in the process follow.

1. Select the design feature to be analyzed.

2. Identify the shipyard work processes which would be used in the production of the design feature.

3. Identify the trades required to perform the work.

4. Determine and apply the engineered standards for each work process.

5. Apply a factor to reflect the increased difficulty of performing the work at a stage other than the ideal stage, on which the engineered standard is based.

6. Apply a factor for the support man-hours required.

7. Convert manhours to dollars.

a. Estimate material costs from the bill of material.

9. Total the cost for constructing the design.

10. Compare the cost with alternate design construction costs.

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

Spreadsheet Format

Table I illustrates the elements of the CECOP forms, each of which is in a similar format. The details of all of the forms developed are provided in Reference (1).

The heading of each form defines the type of system being covered and provides fields for the entering the size of the material to be used. When the material size is entered into the field at the top of the form, all of the values in the process factor column are automatically entered, from a cost estimating data table in which the engineered standards for each material size have been provided. Table II provides the data used for the mild steel piping form. Data for the other

SP-4 COST ESTIMATING FORM FOR PIPING (P2)

FILEPIP2CFE PROJECT : EXAMPLE #l -FITTINGS PIPE MATERIAL : CARBON STEEL
2/20/92 FILE : EXAMPLE1 DIAMETER: 2 IPS
SCHEDULE : 40

WORK PROCESS	WORK UNITS	PROCESS FACTOR (MNHRS/WK UNIT)	UNIT AMOUNT	ACTUAL STAGE	STANDARD STAGE	ACTUAL FACTOR	STANDARD FACTOR	MANHOURS REQUIRED
1 OBTAIN MATERIAL								
RECEIPT & PREP	PIECE	1.00	4	1	1	1.0	1.0	4.0
2 CUTTING								
MACHINE	COT	.05	14	1	1	1.0	1.0	.7
MANUAL	COT	.50	0	2	2	1.5	1.5	.0
3 BENDING								
MACHINE	BEND	.39	0	1	1	1.0	1.0	.O
MANUAL	BEND	5.00	0	2	2	1.5	1.5	.0
4 MARKING	PIECE	.10	15	2	2	1.5	1.5	1.5
5 HANDLING (KITTING)								
STORAGE	PIECE	.10	15	2	2	1.5	1.5	1.5
TRANSPORTING	PIECE	3.00	0	2	2	1.5	1.5	.0
LIFTING	PIECE	5.00	0	2	2	1.5	1.5	.0
6 WELDED JOINTS								
WELDING, BUTT	JOINT	1.70	0	2	2	1.5	1.5	.0
WELDING, SOCKET	JOINT	1.20	14	2	2	1.5	1.5	16.8
7 FIT UP, ASSEMBLE 6 INSTALL								
BUTT	JOINT	1.70	0	2	2	1.5	1.5	.0
SOCKET	JOINT	1.40	14	2	2	1.5	1.5	19.6
FLANGED	JOINT	.80	0	2	2	1.5	1.5	.0
THREADED	JOINT	.50	0	2	2	1.5	1.5	.0
SILBRAZED	JOINT	.32	0	2	2	1.5	1.5	.0
THERMOFIT	JOINT	1.00	0	2	2	1.5	1.5	.0
CRYOFIT	JOINT	1.50	0	2	2	1.5	1.5	.0
MAF	JOINT							
8 SURFACE PREP								
EXTERIOR	SQ FT	.10	0	3	3	2.0	2.0	.0
INTERIOR	SQ FT	.20	0	2	2	1.5	1.5	.0
9 COATING	SQ FT	.20	0	2	2	1.5	1.5	.0
10 INSTALLATION								
PIPE BANGER5	BANGER	.50	0	2	2	1.5	1.5	.0
INSULATION	LN FT	1.14	0	4	4	4.0	4.0	.0
11 TESTING								
AIR	OPENING	.10	0	6	6	7.0	7.0	.0
HYDRO	OPENING	.96	0	6	6	7.0	7.0	.0
AUDIOGRAM	LIN FT	.05	0	1	1	1.0	1.0	.0
x RAYS	LIN FT	.10	0	1	1	1.0	1.0	.0

TOTAL TRADE HANHOURS		44.1
TRADE SUPPORT MANHOURS (35% *OF* TRADE MANHOURS)		15.4
TOTAL PRODUCTION MANHOURS		59.5
LABOR COST (MNHRS X HRLY RATE)	20.00	1190.70
MATERIAL COST (FROM MATERIAL SCHEDULE)		67.10
TOTAL COST		1257.80

DIFFERENTIAL MATERIAL SCHEDULE

ELBOWS, SOCKET WELD, 90 DEG	4 *ea.*	10.76	43.04
ELBOWS, SOCKET WELD, 45 DEG	2 *ea.*	12.03	24.06
TOTAL			67.10

TABLE I - COST ESTIMATING FORM

COST ESTIMATING PROCESS FACTORS MATERIAL: CARBON STEEL
SCHEDULE 40

PIPE SIZE IPS	1 CUT PIPE	2 BEND PIPE	3 (FIT BUTT	4 UP SOCKET	5 ASSEMBLE FLANGE	6 AND THREAD	7 INSTALL) SILBRAZE	8 PIPE INSUL'N	9 HYDRO TEST
.25	.02	.25	.8	.6	.5	.3	.22	.91	.27
.50	.02	.25	1.0	.7	.6	.3	.23	.91	.41
.75	.03	.25	1.1	.8	.6	.4	.24	.91	.55
1.00	.03	.25	1.2	.9	.6	.4	.27	.9l	.68
1.25	.04	.25	1.2	1.1	.7	.4	.28	1.14	.75
1.50	.05	.25	1.5	1.2	.7	.4	.30	1.14	.82
2.00	.05	.39	1.7	1.4	.8	.5	.32	1.14	.96
2.50	.06	.39	1.9	1.6	.8	.5		1.14	1.09
3.00	.06	.39	2.2	1.9	.9			1.23	1.23
3.50	.07	.39	2.5	2.2	1.0			1.33	1.23
4.00	.08	.39	2.7	2.4	1.0			1.41	1.36
5.00	.O8	.39	3.1	2.7	1.0			1.49	1.50
6.00	.09	.39	3.6	3.2	1.1			1.71	1.64
8.00	.15	.72	4.5	4.0	1.1			2.30	1.77
10.00	.21	1.61	5.5	4.9	1.2			2.58	
12.00	.26	4.33	6.4	5.9	1.3			2.84	
14.00	.32	4.33	7.4	6.8	1.4				
16.00	.38	4.33							

SCHEDULE PIPE SIZE IPS	40 HELD BUTT	80 HELD BUTT	160 WELD BUTT	40 HELD SOCKET	80 WELD SOCKET	160 WELD SOCKET
-25	1.1	1.2	1.4	.7	.8	1.0
.50	1.1	1.2	1.4	.7	.8	1.0
-75	1.1	1.2	1.4	.7	.8	1.0
1.00	1.1	1.2	1.4	.7	.8	1.0
1.25	1.1	1.2	1.4	.8	.8	1.2
1.50	1.1	1.2	1.4	.8	.9	1.2
2.00	1.7	1.8	2.9	1.2	1.3	1.6
2.50	1.7	1.8	2.9			
3.00	1.7	1.8	2.9			
3.50	2.1	2.4	4.2			
4.00	2.1	2.4	4.2			
5.00	2.6	3.0	5.3			
6.00	3.2	3.7	6.5			
8.00	3.9	4.5	7.9			
10.00	4.7	5.4	9.5			
12.00	5.1	6.0	11.0			
14.00	5.9	6.7	12.0			
16.00	6.6	7.8	16.0			

TABLE II - COST ESTIMATING DATA FOR PIPING (P2)

forms is given in Reference (1).

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

Stages. Modern ship construction is based upon modular construction, with each module (or unit, or block, depending upon the nomenclature chosen by a shipyard), passing through a series of stages, each of which is normally associated with specific work sites. While different shipyards may use differing designations and vary the number of stages that they identify, the stages shown in Table III have been selected for use in the CECOP forms. 1 Tab1e 111, the normal location of the work is also shown, to clarify the stage definition and to facilitate the application of this technique to repair work as well as new construction. The column headed Standard Stage identifies the stage at which each work process is most efficiently accomplished, and the stage to which the Process Factors **apply**.

	Stage	Location	Difficulty Factor
1.	Fabrication	In Shop	1.0
2.	Preoutfitting Hot	On Platten- Hot work	1.5
3.	Paint	Paint Shop/Stage	2.0
4.	Preoutfitting Cold	On Platten- Cold Work	3.0
5.	Erection	Erection Site	4.5
6.	Outfitting	Erection Site	
7.	Waterborne	Pierside after Launch	10.0
8.	Tests and Trials	Pierside & Underway	15.0

Table III - Construction Stages and Difficulty Factors

Stage Difficulty Factors. At each stage, a given task becomes progressively more difficult to accomplish than at an earlier stage. Consequently, tasks accomplished later than the standard stage require a greater expenditure of resources. The difficulty factor between stages has been estimated at 1.5 to 2 times the effort required in the prior stage. The work stage difficulty Factors provided in Table III reflect an amalgam of the work stage difficulty data obtained from various sources. Revisions to the work stage factors, based on later and expanded measurements, are anticipated.

When a stage later than the standard stage is entered into the Actual Stage column for a process, the applicable stage difficulty factor is obtained automatically from a lookup table and appears in the Actual Factor column.

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

Data Entry

Filling in the form for any CECOP form, then involves only the following steps.

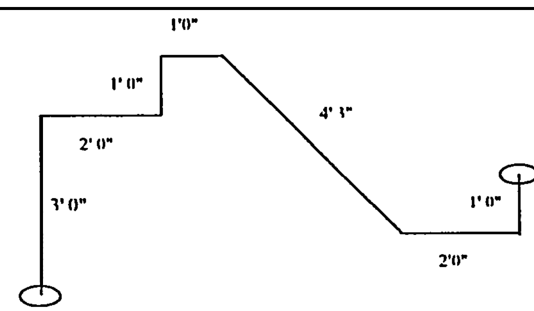
1. Identifying each Work Process which will be involved in the construction of the design alternative being considered and entering, in the Unit Amount column, the number of work units required for that alternative,

2. Entering, in the Actual Stage column, the work stage during which the work is expected to be accomplished. The form already includes the Standard Stage value in this column, making it unnecessary to make any-entry in this column unless the work will be accomplished at some other stage. This column normally will not need to be filled in except after ship construction has started, i.e., for analyses made during the detail design phase.

3. Entering material cost information.

Examples

Pipe fittings vs bending. As an example, the piping cost estimating computer program was applied to two alternative approaches to producing the simple section of piping shown in Figure 1. The differential cost of manufacturing the piping detail by the use of fittings for each change in direction versus by bending the pipe with a pipe bending machine was estimated. The costs of identical material and work processes were ignored and only the costs of the different material and work processes were considered. Table I illustrates the application to the Fittings alternative. The cost differential between the two alternatives was calculated to be $955 in savings for the bending approach.



MATERIAL LIST

		Fittings	Bends
1.	Pipe		
2.	Socket Fig	2	2
3.	Elbow, 90	4	0
4.	Elbow, 45	2	0

Figure 1 - Pipe Example

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

Validation

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

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

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

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

Validation example 1. A producibility item applicable to handholes and manholes was used. The original method of fabricating handholes, as illustrated by "Current Design" in Figure 2, consisted of welding a 20 mm flat ring to the inside of a 10 mm circular flat bat which was welded into the opening in the deck. Round bar stack with a diameter of 32 mm was cut to 38 mm lengths to form studs. These studs were welded to the underside of the flat ring, drilled and tapped to accept 19 mm (3/4 inch) hold down bolts. The proposed producibility improvement, substituted a 30 mm flat ring for the 10 mm ring. The bolt holes were therefore drilled and tapped into the ring without the installation of the studs.

The shipyard estimated that the old method required 28 manhours per manhole and that the new method would result in a 40% saving in manhours, or 11 manhours. Data was not available to support either the estimate of current manhours or the percentage of savings.

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

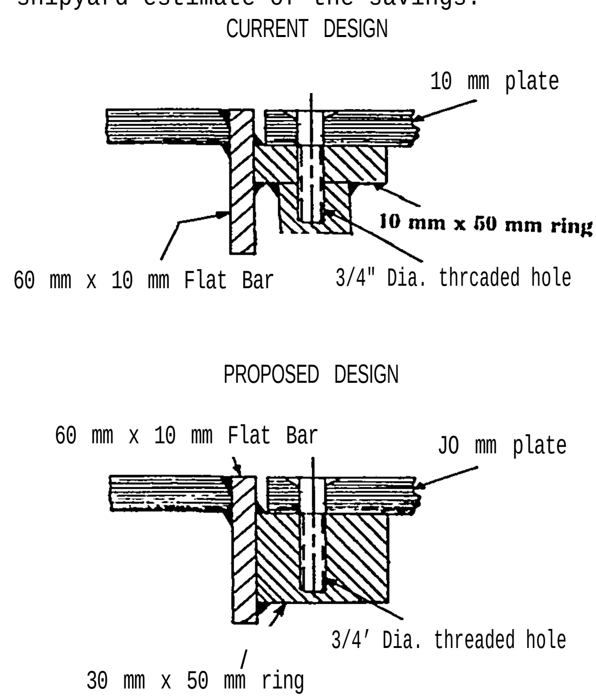


Figure 2 - Manhole Design Alternatives

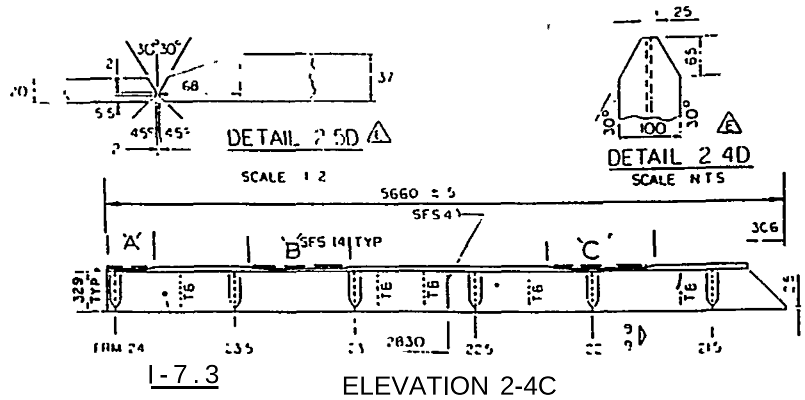


Figure 3 - Generator Seat Configuration

Validation example 2. A producibility proposal applicable to fabricating Diesel Generator Seats also was used. The original method of fabricating the seats consisted of fitting and welding six sections of plating, alternating in thickness between 20 and 37 mm. The plates were welded together by double sided butt welds, as shown in Figure 3. Each joint required edge preparation with two bevels for each plate. further, the 37 mm thick plate required a longer bevel to reduce the thickness to 20mm at the joint. Overall, each seat was 390 mm wide and 5660 mm long when completed.. The proposed producibility improvement was to use a single 37 mm thick plate and machine the thinner areas to the required 20 mm thickness. The length of the three areas to be machined to 20 mm were 336 mm, 719 mm and 719 mm.

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

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

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

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

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

Findings

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

RELATIVE PRODUCIBILITY EVALUATION

General

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

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

This second method is an application of the Analytic Hierarchy Process (AHP) developed by Prof. Thomas L. Saaty of the University of Pittsburgh (2). The AHP allows effective decisions to be made concerning complex issues by following several discrete steps.

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

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

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

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

AHP Advantages

There are several very important advantages to the use of the AHP method. One is that this technique has a rigorous methodological basis. Reference (2) provides further information on this matter. This reference also provides a detailed description of the AHP process as a framework for application to many different areas, including areas not explored by Professor Saaty. However, the examples in the book demonstrate that application of the method to different types of problem requires at least some minimal system engineering effort to structure the problem appropriately.

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

Shipbuilding Application

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

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

Top Level Producibility Criteria

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

- Arrangements
- Simplicity
- Material
- Standardization
- Fabrication/assembly requirements

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

Underlying Subcriteria

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

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

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

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

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

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

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

- Component standardization
    - Structural
        - Plate thickness
        - Shapes
        - Sizes
    - Outfitting
    - Equipment
- Process standardization.

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

- Welding considerations
  - Process required
    - Automation achievable
    - Position optimization
    - Heat treatment
  - Configuration
    - Weld length
    - Weld type
    - Fillet configuration
      - Plate bevel angles
      - Number of passes

- Sheetmetal considerations
  - Configuration
  - Process required

- Machinery considerations
  - Use of common foundations
  - Mounting details
  - Installation

- Pipefitting considerations
  - Pipe size
  - Length
  - Material type
  - Piping support needs
  - Process
    - Use of bends vs. fittings
    - Connection type

- Electrical/Electronic considerations
  - Wireways
  - Connections/hookups
  - Cable
    - Length
    - Size

- HVAC considerations
  - Ducting
    - Size
    - Length
    - Material
    - Configuration changes
  - Equipment installation
  - Insulation

Weighting Factors

The weighting factors to be used for each of the criteria identified above are obtained by a method of pairwise comparison of each element of a higher level of the hierarchy. Thus, for instance, each of the three first level parameters listed under HVAC (Ducting, Equipment installation, Insulation) would be compared with the other two, and each of the four under "Ducting" would be compared with the other three. In doing each pairwise comparison, a scale of 1 to 9 is used, where a 1 means both parameters are equally important and a 9 means that the corresponding parameter is very much more important than (actually, 9 times as important as) the other. A questionnaire format has been prepared for accomplishing these comparisons. The format of one element of the questionnaire is shown in Figure 4.

Persons familiar with the influence of the factors identified are asked to circle the numerical value which indicates their considered opinion. A copy of the questionnaire used for developing the data presented in this report is provided in Reference (1). A computer program has been developed to capture the data presented in each questionnaire. The same program can be used for direct entry individual responses to the questions contained in the questionnaire. A second computer program has been developed to combine the results of each individual response into a single weighting factor for each of the parameters of the entire hierarchy. Table IV presents the weighting factors derived from the responses received from those who answered the questionnaire. The values for each series of elements from each level of the hierarchy will add up to 1.0, as can be demonstrated by adding all of the values in Level 1, all of the values for the Arrangement subcriteria of Level 2, etc. The composite figures listed in the last column are obtained from multiplying the factor for each individual subcriterion by the values for each element located above it in the hierarchy. Only those elements of the hierarchy whose composite factors are shown in the column headed "Use" arc used when comparing the producibility Of design alternatives. Again, it is emphasized that this process need be accomplished only once for a specific ship project and design phase. Once the criteria to be evaluated have been determined, and their weighting values calculated, as in the Use column, they are used for evaluating each set of design alternatives.

Evaluating Design Alternatives

In order to determine the relative producibility of two or more competing design proposals, a process similar to that used to determine the performance criteria weighting factors is followed. The difference is that each alternative ship design proposal is compared with each of the other competing design alternatives for each of the lowest tier producibility parameters, again using the 9 to 1 to 9 rating scale. The comparison of the alternative designs can be carried out quite quickly, using questionnaire forms prepared for this purpose. The general format of the questionnaire is as shown in Figure 5.

Several knowledgeable persons should evaluate the same design alternatives. The data from each person's evaluation will be entered into computer programs which will generate a combined *score* for each design for each criterion. The sum of the values for each design is provided by the program. Since these amounts represent relative values and the more producible design is given the

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

Ducting size　　　　　　　　　　　　　　　　　　　　　　　　Ducting Length
9...8....7....6....5....4....3....2....1....2....3....4....5....6....7....8....9

Figure 4 - Pairwise weighting questionnaire element

Which of the two design alternatives has the smaller HVAC DUCTING SIZE, and what is the dogree of difference? A 9 indicates Very much smaller, 7 much smaller, 5 moderately smaller, 3 somewhat smaller, 1 equal:

Alternative A　　　　　　　　　　　　　　　　　　　　　　　　Alternative B
9....8....7.... 6................. ..5....4....3....2....1...2......3....4....5....6....7....8....9

Figure 5 - Comparison of Design Alternatives for One Criterion

higher score for each criterion, the largest sum will identify the most producible (least costly) design alternative. In order to determine the dollar value of cost savings to be expected, one would then proceed to the "absolute" evaluation described previously.

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

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

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

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

THE DECISION RARING PROCESS

General

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

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

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

	USE	1	2	3	4	5	COMP
RECURRING PRS-DELIVERY CONSTRUCTION COST							
Arrangement		.2419					.24190
Enhanced Packaging of Components	.06451		.2667				.06451
Direct Routing of Distributive Systems	.04115		.1701				.04115
Interference Avoidance	.08769		.3625				.08769
Volumetric Density	.04855		.2007				.04855
simplicity		.2239					.22390
Shape of Pieces			.2402				.05378
Flat Plate	.02705			.5030			.02705
simple curvature	.00952			.1770			.00952
Rectangular Configurations	.01721			.3200			.01721
Accessibility	.10714		.4785				.10714
Number Of Pieces	.06298		.2813				.06298
Material	.08000	.0800					.08000
standardization		.2220					.22200
component standardization			.6380				.14164
Structural				.2067			.02928
Plate Thickness	.00709				.2421		.00709
Shapes	.01385				.4732		.01385
Sizes	.00833				.2847		.00833
outfitting	.05106			.3605			.05106
equipment	.06131			.4329			.06131
Process Standardization	.08036		.3620				.08036
Fabrication/Assembly Requirements		.2323					.23230
Welding Considerations			.1271				.02953
Process Required				.5825			.01720
Automation Achieved	.00877				.5099		.00877
Position optimization	.00375				.2179		.00375
Heat Treatment	.00468				.2722		.00468
configuration				.4175			.01233
Fillet Configuration					.3345		.00412
Plate Bevel Angles	.00175					.4243	.00175
Number of Passes	.00237					.5757	.00237
Weld Length	.00326				.2648		.00326
weld Type	.00494				.4007		.00494
Sheetmetal Considerations			.0609				.01415
configuration	.00626			.4427			.00626
Process Required	.00788			.5573			.00788
Machining Considerations			.2118				.04920
use of Common Foundations	.01503			.3054			.01503
Mounting Details	.01440			.2926			.01440
Installation	.01978			.4020			.01978
Pipefitting Considerations			.2057				.04770
Process				.3404			.01627
Use of Bends Vice Fittings	.00902				.5544		.00902
Connection Type	.00725				.4456		.00725
Pipe size	.00627			.1312			.00627
Length	.00615			.1286			.00615
Material Type	.00811			.1698			.00811
Piping Support Needs	.01099			.2300			.01099
Electrical/Electronics Considerations			.2176				.05055
Cable				.2560			.01294
Length	.00641				.4955		.00641
Size	.00653				.5045		.00653
connections/Hookups	.02100			.4154			.02100
Wireways	.01661			.3286			.01661
HVAC Considerations			.1769				.04109
Ducting				.4013			.01649
Size	.00320				.1943		.00320
Length	.00324				.1962		.00324
Material Type	.00291				.1765		.00291
Configuration Changes	.00714				.4330		.00714
Equipment Installation	.01439			.3501			.01439
Insulation	.01022			.2486			.01022
sun of weighting Factors	1.00001	1.0001	4.0000	8.0001	6.0000	1.0000	

TABLE IV - SURVEY WEIGHTING FACTORS FOR PRODUCIBILITY EVALUATION

	REL. MERIT FITTINGS	REL. MERIT BENDS	EVALUATION FACTOR	VALUE FITTINGS	VALUE BENDS
RECURRING PRE-DELIVERY CONSTRUCTION COST					
Arrangement					
Enhanced Packaging of Components	1	1	.06451	.03225	.03225
Direct Routing of Distributive Systems	1	1	.04115	.02007	.02007
Interference Avoidance	1	1	.08769	.04384	.04384
Volumetric Density	1	1	.04855	.02427	.02427
Simplicity					
Shape of Pieces					
Flat Plate	1	1	.02705	.01353	.01353
Simple Curvature	1	1	.00952	.00476	.00476
Rectangular Configurations	1	1	.01721	.00860	.00860
Accessibility	1	1	.10714	.05357	.05357
Number of Pieces	3	14	.06298	.0llll	.05187
Material	1	1	.08000	.04000	.04000
Standardization					
Component Standardization					
Structural					
Plate Thickness	1	1	.00709	.00354	.00354
Shapes	1	1	.01385	.00693	.00693
Sizes	1	1	.00833	.00417	.00417
Outfitting	1	1	.05106	.02553	.02553
Equipment	1	1	.0613X	.03066	.03066
process Standardization	1	1	.08036	.04018	.04018
Fabrication/Assembly Requirements					
Welding Considerations					
Process Required					
Automation Achieved	1	1	.00877	.00438	.00438
Position Optimization	1	1	.00375	.00187	.00187
Heat Treatment	1	1	.00468	.00234	.00234
Configuration					
Fillet Configuration					
Plate Bevel Augles	1	1	.00175	.00087	.00087
Number of Passes	1	1	.00237	.00119	.00119
Weld Length	1	1	.00326	.00163	.00163
Weld Type	1	1	.00494	.00247	.00247
Sheetmetal Considerations					
Configuration	1	1	.00626	.00313	.00313
Process Required	1	1	.00788	.00394	.00394
Machining Considerations					
Use of Common Foundations	1	1	.01503	.00751	.00751
Mounting Details	1	1	.01440	.00720	.00720
Installation	1	1	.01978	.00989	.O0989
Pipefitting Considerations					
Process					
Use of Bends vice Fittings	1	3	.00902	.00226	.00676
Connection Type	1	1	.00725	.00362	.00362
Pipe Size	1	1	.00621	.00313	.00313
Length	1	1	.00615	.00307	.00307
Material Type	1	1	.00811	.00406	.00406
Piping Support Needs	1	1	.01099	.00550	.00550
Electrical/Electronics Considerations					
Cable					
Length	1	1	.00641	.00321	.00321
Size	1	1	.00653	.00326	.00326
Connections/Hookups	1	1	.02100	.0l0S0	.01050
Wireways	1	1	.01661	.00831	.00831
HNAC Considerations					
Ducting					
Size	1	1	.00320	.G0160	.00160
Length	1	1	.00324	.00162	.00162
Material Type	1	1	.00291	.00146	.00146
Configuration Changes	1	1	.00714	.00357	.00357
Equipment Installation	1	1	.01439	.00719	.00719
Insulation	1	1	.01022	.00511	.OOSll
		suns:	1.00000	.47740	.52260

TABLE V - PRODUCIBILITY EVALUATION SHEET: TWO DESIGN ALTERNATIVES

Identification of Criteria

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

Cost Criteria. The cost criteria related to shipbuilding programs are listed below.

- Recurring Predelivery Costs
  - (Producibility)
  - See Table II.

- Nonrecurring Predelivery Costs
  - Program management
  - Design and engineering
  - Production planning
  - Production aids
  - Disruption
  - Delay

- Postdelivery costs
  - Operational costs
  - Consumables
  - Personnel
  - Maintenance
  - Growth/upgrade costs

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

- Design/Engineering Schedule
- Procurement Schedule
- Construction Schedule

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

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

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

- 'Operational capability
  - Payload carrying capacity
  - Payload effectiveness
  - Mobility
    - Speed
    - Endurance
    - Maneuverability
  - Availability
    - Reliability
    - Maintainability
    - Ability to operate in extreme environments
  - Survivability
    - Ability to avoid detection
    - Ability to operate after damage

- Operational efficiency
  - Manning
  - Habitability
  - Safety

- Future growth margin
  - Weight margin
  - KG margin
  - Volume margin (Density)
  - Modularity

Criteria Weighting

Cost, Schedule and Risk. Having established the hierarchy, the next stew in the process was to determine weighting factors for each of the elements in each tier. The cost, schedule and risk criteria were included in a questionnaire similar to that represented by Figure 4, in order to obtain the factors. The results from the questionnaires were fed into computer programs that were developed to analyze the data. Since not all of the individuals who received the questionnaire were asked to identify the ship type or design phase to which their answers referred, the figures provided in Table VI represent an overall weighting for ships in general. The value of 0.0000 is shown for the weighting of test and trials schedule because that criterion was not included in the questionnaires, but was later recognized as a one that should have been included. A copy of the questionnaire used is contained in (1). Copies of the programs used to analyze the data can be obtained from the authors.

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

	USE	<-----LEVEL-----> 1	2	3	COMB
1. COST		.I731			.I7310
1.1 Recurring Predelivery Construction Cost			.3334		.05771
1.2 Non-Recurring costs; predelivez			.3333		.05769
1.2.1 Design and Engineering	.04327			.7500	.04327
1.2.2 Production Planning	.00577			.1000	.00577
1.2.3 Production Aids/ Tooling	.00288			. OS00	.00288
1.2.4 Disruption	.00288			.0500	.00288
1.2.5 Delay	.00288			.0500	.00288
1.3 Postdelivery Costs			.3333		.05769
1.3.1 Operational Costs	.01442			.2500	.01442
1.3.2 Coneumables	.01442			.2500	.01442
1.3.3 Personnel	.01442			.2500	.01442
1.3.4 Maintenance	.01442			.2500	.01442
2. SCHEDULE CRITERIA		.1076			.10760
2.1 Design/ Engineering Schedule	.03159		.2936		.03159
2.2 Equipment/Material Procurement Schedule	.02369		.2202		.02369
2.3 Construction Schedule	.05232		.4862		.05232
2.4 Test and Trials Schedule	.00000		.0000		.00000
3. RISK CRITERIA		.3200			.32000
3.1 Naturity of Technology	.12867		.4021		.12867
3.2 Yard Experience	.09539		.2981		.09539
3.3 Confidence in Cost Estimate	.5114		.1598		.05114
5.4 confiqence in schedule Estimat	.04400		.1400		.4480
1 PERFORMANCE CRITER1A	.39940	.3994			.35940

Table VI SURVEY WEIGHTING FACTORS

ship design process, (when performance variation tradeoffs may still be made) the results are most representative of those phases. Table VII provides the results of this effort. Values were obtained for aircraft carriers (CVN), Destroyer/Cruisers (DD), Frigates (FFG), Small Combatants and Amphibious ships. Some of the respondents considered their response as being good for any ship. Their responses, plus the responses in which no specific ship class was identified, are included in the listing for "Any" ship. The column headed NGM5 contains the. normalized geometric mean of the values given in the first 5 columns. The column headed NGM6 includes the values in the "Any" column as well.

Application

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

Despite the fact that it is preferable to have more than two alternatives to evaluate simultaneously, it is most likely that only two will exist. Simple spreadsheet forms have been developed for comparing two or three alternative designs (1). It would be simple to generate similar forms for evaluating additional alternatives simultaneously. Table VIII illustrates the use of the form for evaluating two alternatives, as applied to the decision to use pipe fittings or to bend the pipe shown in Figure 1.

Although the pipe bending approach was identified as the more producible, the other criteria which control the decision making process must be considered. The lactors for recurring cost are taken from the results of the producibility evaluation, Table V.

The non-recurring cost of producing drawings and equipment lists will be somewhat greater for the fittings case. Assuming that the design and engineering effort will be about 50% greater for the fittings case, a superiority factor of 1.5 is assigned to that criterion. Normally this value would have been entered into the separate computer program that has been prepared for this purpose. The program would have generated a value of

SHIP PERFORMANCE CRITERIA	CVN	DD	FFG	SHALL COMBATANT	AMPHIB	NGM5	ANY	NGM6
operational capability	.7009	.5971	.4947	.3326	.2326	.5205	.6074	.5399
Operational Efficiency	.2020	.2106	.3808	.5278	.0543	.2564	.3033	.2665
future Growth Margin	.0971	.1924	.1246	.1396	.7131	.2231	.0893	.1936
Operational Capability								
Payload Carrying Capacity	.0666	.1293	.0971	.2093	.0563	.1057	.1252	.1095
Payload EffectiVeness	.3252	.3030	.3090	.2474	.3021	.3138	.3509	.3222
mobility	.0362	.1194	.1178	.1629	.0373	.0838	.0766	.0832
Availability	.1814	.2516	.3483	.2460	.3021	.2752	.3404	.287;
survivability	.3907	.1967	.1279	.1344	.3021	.2215	.1069	.1977
Mobility								
speed	.4444	.3174	.2444	.4891	.2326	.3468	.2120	.3216
Endurance	.4444	.5110	.5070	.3296	.7131	.5103	.6280	.5318
Maneuverability	.1111	.1716	.2486	.1813	.0543	.1429	.1600	.1466
Availability								
Reliability	.6047	.5508	.5677	.3041	.5589	.5570	.5082	.5495
Maintainability	.1047	.1393	.2377	.1206	.3829	.1929	.2583	.2029
Ability/Environm Extremes	.2906	.3099	.1946	.5753	.0582	.2501	.2334	.2477
Survivability								
Ability/Avoid Detection	.2743	.7306	.6667	.7388	.5000	.5870	.4654	.5671
Ability/Operats Damaged	.7257	.2694	.3333	.2612	.5000	.4130	.5346	.4329
Operational Efficiency								
manning	.7142	.3768	.4396	.6042	.4040	.5220	.3479	.4929
Rabitability	.1429	.2066	.1118	.0729	.0687	.1173	.1083	.1169
Safety	.1429	.4166	.4486	.3229	.5273	.3607	.5439	.3902
Future Growth Margin								
Weight Margin	.3214	.2460	.1824	.2557	.0763	.2184	.1852	.2151
KG Margin	.3214	.1582	.4206	.2733	.6097	.3628	.2995	.3558
volume Margin (Density)	.3214	.2060	.2157	.2292	.1294	.2370	.1501	.2223
Modularity	.0357	.3898	.1813	.2417	.1846	.1818	.3652	.2068

A

TABLE VII - PERFORMANCE CRITERIA WEIGHTING FACTORS BY SHIP TYPE

.4000 for fittings and .6000 for bends. The results for the final weight columns would have been identical. The information *is* presented as it *is in* Table VIII to demonstrate the flexibility of the technique which has been developed.

Because the production engineering effort would be slightly greater for the fittings case, a superiority factor of 1.1 has been entered in the pipe bending column.

These values for non-recurring costs have been based on the assumption of a one time application. In a real situation, the non-recurring cost for each alternative may be increased by the number of applications per ship, resulting in a greater total non-recurring cost differential. The non-recurring costs may be applied over more than one ship, in which case the relative superiority of one design alternative to another would need to be reduced accordingly.

Under service life costs, since more joints exist in the fitting method, it is more likely that a maintenance problem will occur during the operational life of the ship. On the assumption that maintenance costs for fittings will be twice those for the bent pipe, a superiority factor of 2 was assigned to the latter.

It should be noted that if cost estimates had been prepared for any of the cost-related criteria, those "hard" numbers could have been substituted in place of the relative values that have been used.

The choice of either bends or fittings is not likely to have any notable effect upon schedule, risk or performance, no changes were made to the table, thus, in effect, treating the two design approaches as being equal with respect to these criteria.

With these data entered into the form, the overall values for Fittings and Bending, shown at the bottom of the Final Weights columns *on* the form in Table VIII, become .4914 and .5086, respectively. This result demonstrates that the bending choice is the preferred alternative from the overall perspective as well as from the standpoint of producibility alone.

CRITERIA	WEIGHTING FACTOR	SUPERIORITY FACTORS PIPE FITTINGS	PIPE BENDING	FINAL WEIGHTS PIPE FITTINGS	PIPE BENDING
COST					
Recurring Cost (Producibility)	.0577	.4774	.5226	.0275	.0301
Non-Recurring Pre-Delivery Cost					
Design and Eugineering	.0293	1.0000	1.5000	.0117	.0176
Production Planning	.0163	1.0000	1.1000	.0078	.0085
Production Aids/Tooling	.002.,	.5000	.5000	.0012	.0012
Disruption	.0042	.5000	.5000	.0021	.0021
Delay	.0055	.5000	.5000	.0028	.0028
Service Life Cost					
Personnel	.0150	.5000	.5000	.0075	.0075
Consumables	.0189	.5000	.5000	.0094	.0094
Maintenance	.0238	1.0000	2.0000	.0079	.0159
SCHEDULE					
Design/Engineering Schedule	.02?7	.5000	.5000	.0149	.0149
Rquipment/Material Procurement Sched	.0218	.5000	.5000	.0109	.0109
construction Schedule	.0504	.5000	.5000	.0252	.0252
Test and Trials Schedule	.0056	.5000	.5000	.0028	.0028
RISK					
Maturity of Technology	.1287	.5000	.5000	.0643	.0643
Yard Experience	.0954	.5000	.5000	.0477	.0477
cost Estimate Confidence	.0511	.5000	.5000	.0256	.0256
Schedule Estimate Confidence	.0448	.5000	.5000	.0224	.0224
PERFORMANCE	.3994	.5000	.5000	.1997	.1997
	1.0000			.4914	.5086

TABLE VIII - DESIGN SELECTION CALCULATION SHEET

CONCLUSIONS

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

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

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

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

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Shipbuilding Performance Measurement in Unstable Conditions

No. 7B-3

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ABSTRACT

A number of descriptions of systems of performance measurement have been published, and more work has been carried out recently to develop their use for estimating purposes. One of the key problems is that most of the systems described rely on a systematic database which is built up from analysis of a stable production system. Currently such stability is the exception rather than the rule for most shipbuilding companies.

The paper reviews the problem, focussing on global measures which can allow overall performance to be assessed, and also on work station performance. It considers the relationship between the global and local measures and proposes a method which would allow performance to be established readily. A method of planning for an improved performance in the future, but during the life of existing contracts is also proposed.

PERFORMANCE MEASUREMENT

Measuring performance is important to all organizations (1). At the level of the total organization, it. provides a measure of the ability of the organization to make profits, anad ultimately to remain viable (2). At different levels of the organization, and in terms of different external or internal constraints on parts of the organization, the performance can be measured in numerous ways. In simple terms it is always the output achieved for the inputs used.

This paper looks specifically at. measures for the shipbuilding industry. Considering both the overall shipyard, and its different functions, there dLe numerous measures available. These range from overall measures such as Compensated Gross Tonnes (CGT) per manyear (3) to local measures such as manhours per foot of weld. Not only labor productivity, but facilities productivity, such as tons per square foot of' workshop, can be measured. So also can utilisation of consumables, for example pounds of welding wire per ton of assembled steel. Measures can be devised to meet all needs, including for example the need to control waste material.

The measurement of performance has two main functions. The first is to monitor trends in performance, in which case consistency is of prime importance. The second is to set absolute levels of performance, in which case the accuracy of the recorded data is of prime importance in monitoring.

The role of performance measurement can be seen in the standard feedback loop (Figure 1). Both the target setting and monitoring aspects can be identified. What should also be clear is that the performance achieved is an output of the production system, that is, the result of some managerial action. Therefore in relating the actual performance to the target which has been set, the measuring system is only reporting history. To make any necessary corrections, which link target and outcome, to the production system requires distinct management action. (4)

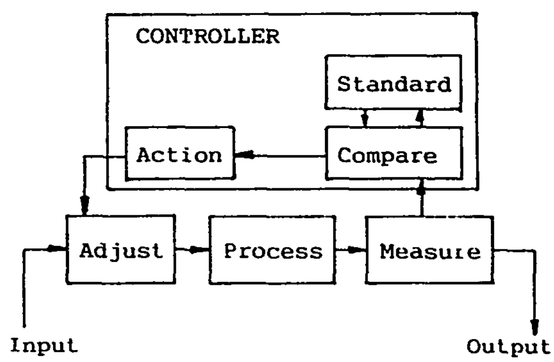


FIGURE 1

UNSTABLE CONDITIONS

Most shipyards are now operating in a very unstable environment. This is due to structural problems in the world-wide industry, including over-capacity, and the necessity to make product changes in many cases because of changes in the defense climate.

If performance is measured in unstable conditions, problems can occur. Some of these also occur in stable conditions. The two main sources of problems are;

1) The feedback of data from the production functions may not be accurate. In that case the value of the measurement is diminished, although, if consistent, it may still be of some use.

2) The data may not be consistent, because of variable errors or changes in recording practice. The inconsistency may also be function of changes in the production system, such as new processes.

Most organizations which have had d long term stable run of production have accumulated a database of performance information which is used as a basis for estimating, planning and monitoring new contracts. This data may be detailed, or sparse, and may suffer from some of the inaccuracies outlined above. It is nevertheless the basis on which a company is prepared, Or constrained, to operate. It can be seen that it should be a major consideration, because of its impact on the ultimate viability of the organization.

A particular problem occurs when an organization has to make a radical product change, or in a situation where a significant productivity increase is needed to ensure survival. In either of these cases, the required performance is sufficiently different from that previously achieved to make the previous data of dubious value.

The rest of this paper reviews the problems which shipbuilders face when trying to reconcile past data with future intentions, and proposes an approach to measurement which should allow change to be made, in a largely predictable and controlled manner.

GLOBAL PERFORMANCE

As a starting point, consider the global performance of a shipyard It is relatively simple to determine an appropriate level of performance which will permit a shipyard to produce vessels competitively. In the commercial field, the simplest measure to apply is CGT per manyear. This is a relatively coarse measure, but serves to provide an order of magnitude level of performance and, importantly, can readily be calculated.

CGT per manyear can be calculated from published data for a wide variety of shipyards. It can be calculated precisely for the shipyard which is interested in making the comparison. It is necessary to make allowances for subcontracting, and to Correct the output and resource figures to permit the comparison to be made.

So as to make useable comparisons of performance, it is necessary to consider productivity data alongside relative cost. Therefore the value for CGT per manyear must be combined with a figure for labor plus employment cost. This allows the relative variations in labor cost and productivity to be combined in graphical form. Figure 2 shows how the information can then be utilized to determine by how much a shipyard must change in order to become competitive, and also how potential changes in relative cost may affect competitive performance in the future.

The curve shown in the figure plots Man-years per CGT against Man-year cost. The cost is for fully-burdened man time. The curve links points which have equal total cost - in terms of labor, materials not being considered - and which represent the status of the most competitive ship producers. Low labor cost producers can have lower productivity, and generally do so, partly through lower labor skills and partly through lower capital investment.

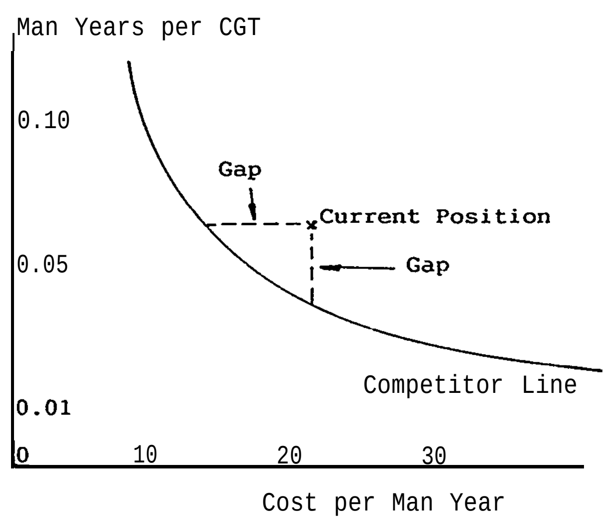


FIGURE 2

The curve can be used to review the required target productivity for a shipbuilder, by identifying the position of the shipbuilder on the cost axis. The actual productivity can then be plotted, and this will indicate the size of the productivity gap. In overall terms, the need to reduce costs, increase productivity or achieve a combination of the two can be determined. The global target in terms of performance can then be utilised to set targets throughout the shipbuilding company.

LOCAL PERFORMANCE

Once a global level of performance has been determined, it is necessary to develop local targets via both the work breakdown structure of the ships and the organisation structure of the company. The target will be an input to the production system, and the outputs of that system will include the actual recorded performance. This will be compared with the target, and deviations will trigger management action to reestablish the required performance.

At the level of the individual work station, the historic recorded performance may be used as a basis for the target setting. However, using this basis creates two problems, which are:

1) The actual past performance may not correspond to the requirements from the global target setting, particularly where an improvement is sought.

2) The past performance includes all the inefficiencies associated with the workstation, and in particular its relationships with upstream and downstream stations. This aspect can be examined by considering the potential performance, predicted by work study, with the actual performance.

Dealing with the above is the key to developing a consistent system of performance setting and monitoring which will permit an improvement to be planned and achieved. Another problem occurs when an improvement target is imposed from the senior management level, as an output to be achieved, without due consideration of the inputs needed to achieve the target. As a result local targets derived from the global target are simply perceived by local supervision as impossible, because they are beyond past achievements.

MATCHING LOCAL AND GLOBAL PERFORMANCE

It is necessary to build up a system which allows the global performance target to be achieved, through the achievement of local performance targets throughout the company. The first step is a carefully considered strategy for construction of a vessel. This will take the global target, not only in terms of manhours, but also in terms of the reduced timescale for the project that is implied. This immediately leads to the crucial consideration that all. activities must be programmed to support the target. Otherwise the target becomes no more than a pious hope, which will not be achieved, for example because some critical item will not be delivered when required.

It is also necessary to assume that the target can and will be achieved, so that all the planning and scheduling does support it. To do so requires some courage on the part of the management responsible, since a failure will be laid at their door. On the other hand, to try to achieve a significant change, and to partly fail, is a better outcome than accepting the status quo or merely exhorting all personnel to greater efforts. It is necessary to set the target, and the acceptable intermediate goal (or partial failure), so that all contractual obligations are still met.

A number of steps must be taken to ensure that the required performance at global level and the performance at local level are matched. The steps are as follows:

1) Determine the global target to achieve corporate objectives. This will be a performance level which allows the company to remain viable, in the environment in which it has to operate, and will generally be expressed as a manhour productivity figure.

2) Determine the master schedule needed to meet the target. In order to achieve this there will be some interaction between the time and resource targets. It can be expected that a reduction in time to complete a vessel will be an important part of reducing manhours and the overhead burden.

3) As far as possible, identify at local level past performances for similar classes of work. (In principle. it is expected that many individual work stations, for example a steel cutting machine, will be relatively unaffected by a change of product). It is most important to recall that the past performance represents the output that has

been achieved, within a set of constraints. It must not be regarded, necessarily, as a determinant of what can be achieved in future, if some or all of those constraints are removed.

3) Estimate the resources needed to achieve the target production for each part of the company, using the levels of performance which have previously been achieved. This represents the "normal" performance of the shipyard, which is unacceptable, but which represents a baseline form which improvements can be targeted.

5) Also at local level, determine the performance which should be achieveable, if it is assumed that the constraints because of other work stations are removed. There will be a large difference between this and the previous item, which will contain more than enough scope for the improvement which is sought. A simple example of the variation which can be found is in semi-automatic welding, where the potential performance, even allowing for rest and other non-productive time, is several times what is actually achieved.

6) Prepare a revised estimate for the resources using achievable rather than past performance. The resulting resource levels will be significantly lower than the historic levels. Productivity comparisons between shipyards have shown that some require two or three times the hours of others, for similar work and using similar technology.

Following the above steps results in two performance targets, one bottom up and the other top down. The task is then to build a series of intermediate targets, for each level of operation, which reflect the overall target and build a bridge between that and the work station performance. In other words, while any individual work station could achieve its theoretical performance, given a steady supply of accurate data and correct materials, it is accepted that some problems will occur in production. An overall performance level which makes allowance for problems, but which does not include slack to cover for what may be historically poor performance, should be targeted.

MODELLING THE PRODUCTION SYSTEM

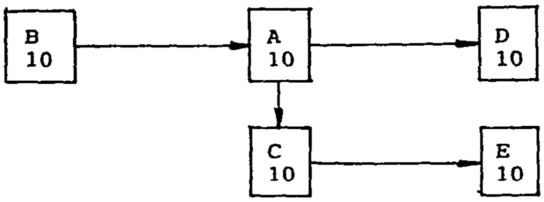
It is essential to model the complete production system to achieve the result required. In a simple form, this requires a plan of the facilities, on which the location and function of all work groups can be identified. This can then be linked to the tactical level of planning, which will allow the volume of production through each area to be determined and thus the performance level predicted from the planned throughput and the Iesources available.

If the performance improvement which is sought is large, then a relatively simple model of the production system, as described, may be sufficient. If the shipyard is already operating at a performance level which is good, measured in terms of a comparison of the global performance level with other, comparable shipyards, then a more sophisticated model will be needed. A discrete event simulation package may be required to provide the necessary detail and ability to fine tune the model (5).

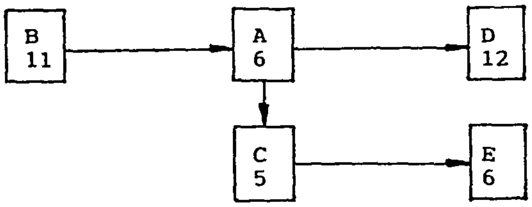
The main function of the model, at whatever level of sophistication, will be to identify the numbers and functions of all the personnel in the production system. Therefore, any planned change in performance can be resolved into a re-distribution of the resources of the shipyard. Similarly, changes in process can be modelled, not only in terms of the effect on their immediate work stations, but also of the downstream workstations. The beneficial effects of a new process on workstations other than the one . immediately affected are frequently written off as "unquantifiable" (6).

Figure 3 shows, in a simplified form, how such a model may be utilised. It represents part of the production system of a shipbuilding company. The first diagram shows the existing system and the second shows a proposed change to the system. The introduction of a new process is intended to improve local productivity. However, in order for the process to deliver the required productivity, a change is also needed to the input reaching the workstation at which the process is to be located.

If the process achieves greater productivity, then there will be greater output, which must be used in the downstream workstations to realise an overall gain. These workstations may need more labor, if productivity remains constant. Tne new process may improve quality, so that in another downstream workstation an additional productivity increase is possible. This will only be realised if some of the labor is redeployed, possibly to the workstation where the ddditional labor is needed.



EXISTING PRODUCTION SYSTEM



REVISED PRODUCTION SYSTEM

A - New process, requiring fewer people for a greater throughput

B - Input to new process, extra person

C - Rework station, fewer people due to improved quality of new process at A

D - Downstream, more people for extra throughput from new process at A

E - Downstream, fewer people due to improved quality from A

FIGURE 3

The requirements for quality inspection and rework may be reduced, and this also has implications for the resources which are needed. By making a detailed analysis of each part of the production system, a specific value can be determined for all of the benefits which are often described as "unquantifiable". More importantly, revised performance levels can be determined for each part of the system, which greatly increases the probability of achieving the overall improvement which is sought (7)

The same basic principle will be adopted, whatever the cause of the instability in the production system. It may be a simple requirement to improve performance, to meet the viability criterion for the company, or a new product, or a change in some of the processes in use.

There may be an argument that the method described is unworkable in a given situation, typically because there is insufficient historical data to even attempt to build a model. In such a situation, it is difficult. to visualize how any change can be planned. Data is available in most cases, but it may not have been collected systematically. However, performance data for equipment is available, local productivity can be measured in a short time, and estimates can be used if all else fails.

The counter argument Lo the one above is that even a poor attempt at a systematic approach is an improvement on pure guesswork.

TARGET SETTING

Once an acceptable model of the production system has been produced, it can be utilized in the process of setting targets for different parts of the organization. These must include *an* overall performance which meets corporate requirements, a local performance which is close(r) to the best available and must include a recognition that interaction between work-stations and external events may prevent the targets being achieved.

Figure 4 shows how the process of target setting, monitoring and making planned changes is built into a formal manufacturing strategy. This is an important component of the whole process which ensures that the changes really are planned, and that their intended beneficial effect is realised (8).

The overall target should show an improvement in performance. This may be relatively modest, compared to work stations which could produce two 0f three times as much as has been the case.

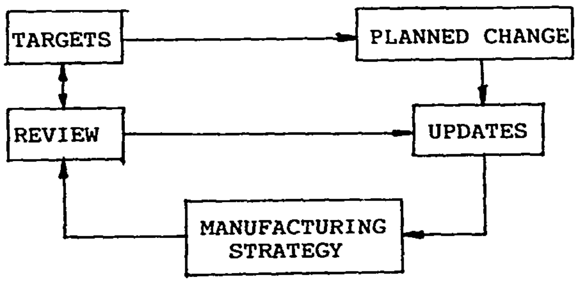


FIGURE 4

The differences which exist between the performance level at individual work stations and that at departmental or shipyard level are recognized. Local targets can be sel which reflect a performance near to the work station potential, but an allowance given which is intended to cater for problems and delays which are external to the work station. The allowance is available to the department manager, and can be applied at his discretion. The local supervisor should also have a discretionary allowance fox internal problems.

At the corporate level, there should be an overall allowance to manage supplier and other disturbances external to the company. Any other areas which are known to contribute to manhour growth and time overruns can also be be given allowances.

To take a simple example, consider a shipyard planning a new project which historical data indicates will require 170,000 manhours. BY reviewing the competitive position, it has been established that a figure of 150,000 hours is the target needed to achieve a competitive result. It is in no way sufficient to impose a 12% cut in all budgets, and impractical to consider a capital investment to achieve the improvement.

If the performance at local level is reviewed, and compared to work study data, it is typical to find that most of the work stations are performing below their theoretical capacity. If only this aspect is considered, a target of 100,000 hours may be possible. This would be in theory supported by the potential performances, but would not be acceptable to supervisors and managers, and would not he achieved in practice.

It is therefore necessary to arrive at a compromise which sets targets which are achievable if there are no problems, and which allows hours to increase in a controlled manner if problems do occur.

The resulting manhours could be spread as follows:

Target Hours for Contract	150,000
Less Reserve for Customer-related problems	15,000
Departmental Budgets	135,000
Less Reserve for Material-related problems	15,000
Less Reserve for Design-related problems	10,000
Work Station Budgets	110,000
Less Reserve for Quality and local problems	10,000
Budget if problems are eliminated	100,000

Approaching the target setting from this direction identifies, and quantifies as far as possible, reasons for not reaching high performance levels. In the process, many of the underlying causes of poor performance should he exposed and action taken to eliminate them. The resource levels in each part of the shipyard should also he set so that the targets are supported.

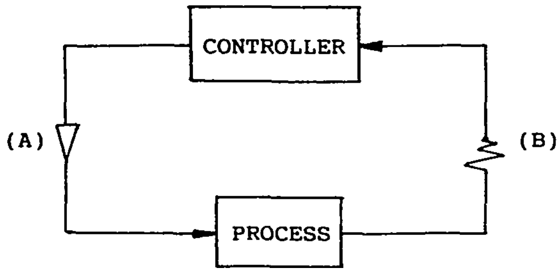
At every level in the company, the supervisors would have targets that are achievable if there are no external disturbances. They are thus protected from unfair criticism, hut remain accountable for their performance. The attention of each management level should be focussed on aspects of production which lead to constraints on performance, rather than attempts to force improvements which are rendered impossible by those constraints.

The process also has to be supported by an effective planning process, and by material control which can deliver items to the shop floor as required. The provision of engineering information also has to he adequate, and the control of quality is also important. All of these are universally recognized as critical to good performance. One of the objectives of the system described is to make the effects of these aspects of ship production explicit. It is not adequate to introduce a quality assurance system, in the expectation that an improvement in performance will naturally flow from it. The same applies to new processes, and to any other change.

The change must be introduced in the context of:

- a target for the improvement in performance
- a model of the affected areas of the production system, before and after the planned change. which identifies how the improvement will be achieved
- an overall plan which builds the performance improvement into schedules and delivery dates
- a system for collecting and analysing actual Performance data, so that-the improvement can be monitored

Much benefit can also be gained by a careful examination of the actual function of each work group. Unnecessary activity can be eliminated prior to project start. However, this should be the province of the local supervisor. It is important that the senior management takes an interest in each work station, hut equally important that it does not attempt to manage all aspects of the shipyard remotely. This is a danger which can be made worse by the existence of a comprehensive computerized data collection system. which gives management the ability to examine details in any area of production. In terms of the feedback loop in Figure 5, it is critical that the amplifier is on the correct side.



(*) - Amplifier to increase the effectiveness of control

(B) - Attenuator to filter out data which is irrelevant

FIGURE 5

CONCLUSIONS

The potential shortcomings of a database of past performance information have been pointed out. Nevertheless, any planned beneficial change to a production system, or response to instability in a company environment, should be based on a systematic analysis of how the changes will affect performance. This must be done at both corporate and local levels. Even relatively sparse, or uncertain data can be utilized for the purpose, but it is essential that both a too-down and bottom up approach are used.- To be of value, the performance data must be used to provide an updated model of the production system, as it would be after a planned change. It is also absolutely essential to monitor the actual results and to take effective corrective action when it is needed.

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Aluminum Steel Construction in a New 36M (120 Ft) Patrol Boat

No. 7C-1

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ABSTRACT

Construction of the U.S. Coast Guard Cutter Leopold, the lead ship of the 36 m (120 ft) Heritage Class, is discussed. A new Structural Critical Aluminum-Steel Transition (SCAST) product, Duratemp II" was selected for the welding transitions between the aluminum deck house and steel deck. The explosion bonded material's higher strength and toughness permitted use of lighter, narrower transition joints (1 cm (0.375") wide x 2 cm (0.75") thick) than are permissible with traditional materials. The unique heat resistance of the material permitted cutting and welding of the small section joints without overheating. The need for corner butt joints was reduced due to the product's reliable bendability. Welding procedures and Quality Assurance procedures are discussed in detail.

INTRODUCTION

The U.S. Coast Guard in conjunction with its ship repair facility in Curtis Bay, Baltimore, Maryland, was tasked with building the USCG Leopold WPB 1900, a 36 m (120 ft) "Heritage Class" patrol boat. The Leopold was to be used primarily as an offshore platform for the interdiction of drugs, search and rescue, and law enforcement. Lightweight construction and minimal maintenance were critical factors in design and selection of material of construction. Construction Ot the Leopold was placed on hold subsequent to the work discussed here.

DESIGN AND FABRICATION

The Leopold, due to its critical weight and high speed demands, required the use of light gauge 5086 aluminum for the pilot and deck-house structure. The aluminum was to be joined to the steel deck by using an explosive bonded transition joint material. A newly developed product, Duratemp II", was chosen over more traditional Aluminum/Steel transition joint materials due to its higher strength, superior fabricability, and proven corrosion resistance. This was the first shipboard installation to use this material.

The USCG, in cooperation with the manufacturer, chose a 1 cm (0.375") wide x 2 cm (0.75") thick transition joint for use in joining the pilot and deck-house to the steel deck. Fabrication of traditional Aluminum/Steel transition joint materials using bars of this small of a cross-section is generally considered unreliable. Traditional aluminum/steel transition joint products can be significantly degraded if the bond zone is heated above 260 degrees C (500 degrees F) during welding. Maintaining the transition joint bond zone below this temperature becomes increasingly difficult as the width and thickness are reduced. There are no nondestructive testing methods to verify that overheating, and resultant strength deterioration, have not occurred. The new transition joint material discussed in this paper employs additional interlayer metals which increase the maximum permissible welding temperature to over 540 degrees C (1,000 degrees F).

The new product was also used to join watertight aluminum deck panels to steel web frames and stiffeners in the armory space. This required the material to be formed in tight radii of 5 cm (2"). Traditional aluminum/steel materials cannot be bent in this manner without cracking and must be saw cut from plate to produce the desired contours.

JOINT DESIGN

The selection of a butt joint design that would minimize areas susceptible to corrosion was a concern for design and construction personnel. Due to the unpreventable formation of brittle intermetallics during full butt welding, aluminum/steel transition joint products are butt welded using partial penetration procedures. The effects of corrosion on dissimilar metals in a marine environment requires unwelded portions of the joint to be sealed tight by hand peening or the use of such products as silicone caulking or epoxy patching compound. Additionally, external surfaces should then be painted to seal areas not filled by peening or caulking. After evaluating various joint designs, the Coast Guard selected the joint design outlined in Figure 1. This design provided a structurally sound, repeatable, impact resistant and cost efficient butt weld.

PRE-SELECTION DESTRUCTIVE AND NONDESTRUCTIVE TESTING

Three aluminum to steel transition test plates were submitted to a commercial lab for destructive testing. ASTM A607 steel, 5 mm (0.188") thick, was welded to one side, and 5086 H116 aluminum, 3.2 mm (0.125") thick was welded to the other side using the Gas Metal "Short Arc" (GMAW) welding process in accordance with the requirements of

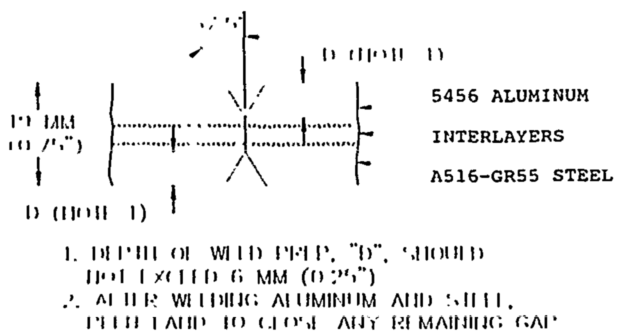

FIGURE 1: Design of butt joints between ends of transition joint strips.

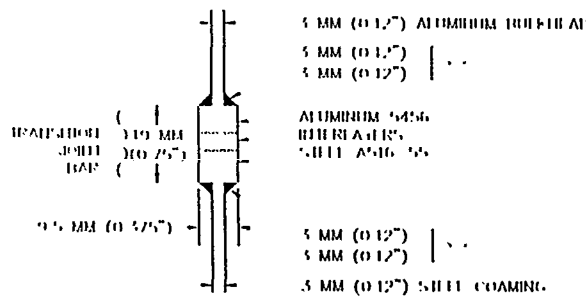

FIGURE 2: Design of welds between aluminum and steel plates using transition joint material.

Table I: Welded Tensile Tests Using Specimen Design Shown in Figure 2

Test I.D.	Dimensions mm (in)	Area mm-Sq (in-sq)	Failure Load kg (lb)	Ultimate Strength kg/cm-so (lb/in-sq)
Specimen #1				
Aluminum Web	3.0 x 13.4 (0.121 x 0.526)	40.2 (0.064)	1,218 (2,680)	3,030 (41,875)
Transition Joint	12.3 x 13.4 (0.484 x 0.526)	165 (0.256)	NO Failure	738 (10,469)*
Specimen #2				
Aluminum Web	3.1 x 8.7 (0.123 x 0.343)	27 (0.042)	927 (2.040)	3,430 (48,571)
Transition Joint	10.4 x 8.7 (0.410 x 0.343)	90.5 (0.140)	NO Failure	1,020 (14,571)*
Specimen #3				
Aluminum Web	3.1 x 13.6 (0.123 x 0.534)	42.2 (0.066)	1,255 (2,760)	2,970 (41,818)
Transition Joint	9.9 x 13.6 (0.389 x 0.534)	135 (0.209)	No Failure	930 (13,205)*

* Stress on bond zone at time of Aluminum failure.

Table I of MIL-STD 248C. Four macrotech specimens were evaluated showing no defects in the bond zone after welding. Three transverse tensile specimens were also evaluated. (Specimen design is shown in Figure 2, except width and length! per Table I.) All three tensile specimens broke in the aluminum base material outside the heat effected zone, thus proving the overall effectiveness of the joint. Values are given in Table I for each test; the aluminum data reflects the ultimate tensile strength of the aluminum only. The test data shows the maximum stress successfully sustained by the coupon before the aluminum failed.

Test butt welds were made using the design presented in Figure 1. Initial welds were made using aluminum alloy 5356 filler metal. Dye penetrant examination revealed cracking in the aluminum portion of the weld. A change to alloy 1100 filler metal eliminated this problem.

WELDING PROCEDURES

Welding the bulkhead panels to the transition joint was accomplished using Gas Metal Arc (GMAW) and Shield Metal Arc (SMAW) for the steel welds and Gas Tungsten Arc Welding (GTAW) for the aluminum. The welding parameters listed in Table II were conducted and qualified in accordance with MIL-STD 248C. The information provided does not reflect the entire welding procedure specification and is presented for information only.

Table II: Welding Procedures

Welding Procedure Specification for GMAW: ASTM A607 Grade 50 or A572 Grade 50 Steel

Base Material	Filler Material	Shielding Gas	Amps	Volts
1.5 - 15 mm (0.058 - 0.560")	E70S-6	100% Argon at 0.6-0.7CMH : (20-25CFH)	40-260	10-18

Note: The welding power source was constant voltage DC type-with the torch on reverse polarity (DCEP). Maximum weave was l cm (3/8") in width. Vertical welds were in the uphill progression. minimum preheat was maintained at 10 degrees C (50 degrees F). No postweld heat was specified. Gas cup size was between 6 and 16 mm (l/4" and 5/8"). A

Welding Procedure Specification for GTAW: 5086 H116 Aluminum

Base Material	Filler Metal	Shielding Gas	Amps	Volts
1.5 - 15 mm (0.058 -0.560")	AWS EWTH - 2 or EWZr	100% Argon at 0.56 CMH (11.3 CFH) or Higher	40-260	10-18

Note: The welding power source was constant voltage AC type with high frequency arc stabilization. Maximum weave was 1 cm (3/8") in width. Minimum preheat was maintained at 10 degrees C (50 degrees F). No postweld heat was specified. Can cup size was between 1 and 2.2 cm (3/8" and 7/8").

Welding Procedure Specification For SMAW: ASTM A607 Grade 50 or A572 Grade 50 Steel

Base Material	Filler Metal	AMPS	Volts
1.5 - 15 mm (0.058 - 0.560")	2.2 mm (3/32") E7018 or as per Table II MIL-STD 248C	65-100	18-22
	3.2 mm (1/8") Electrode	90-150	21-23
	4 mm (5/32") Electrode	110-230	21-25

Note: The welding power source was constant amperage DC type on reverse (DCEP) or straight polarity (DCEN). Maximum weave was three times the electrode diameter. Minimum preheat was maintained at 10 degrees C (50 degrees F). No postweld heat was specified. Gas cup size was between 1 and 2.2 cm (3/8" and 7/8").

INSTALLATION

The installation of the aluminum deck house and the armory space required over 150 m (500 ft) of transition joint material. Aluminum and steel attachment welds were made along the full length using the design in Figure 2 and the weld procedures in Table II. The construction included over 50 butt welds of the design shown in Figure 1. Figure 3 shows a section of the transition joint bar to which both aluminum bulkhead plates and steel combing have been tack welded in preparation for final welding. A butt weld between two transition joint bars can be seen near the left side of Figure 3. In Figure 4 the aluminum welding has been completed and the steel weld is being made. Figure 5 shows the welded sections of prebent transition joint bars in the armory space. Figure 6 shows a pad of the transition joint product which has been fillet welded on the vertical steel edges.

INSPECTION OF INSTALLATION

Nondestructive evaluation of the welded sections was conducted in accordance with MIL-STD 271, Nondestructive Testing Requirements for Metals and NAVSHIPS 0900-003-8000, Surface Inspection Acceptance Standards for Metals. The installation was dye penetrant inspected on both sides over 100% of the length. There was no evidence of bond separation over the complete length of the installation, including the armory space corners, and the fillet welded pads.

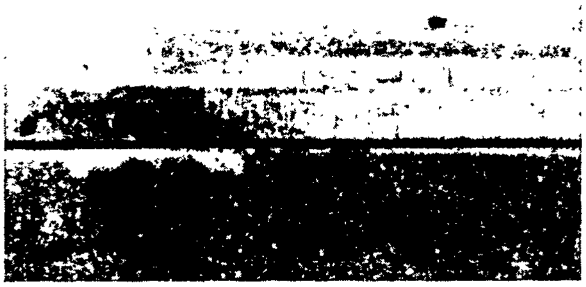

FIGURE 3: Transition joint strip tack welded to aluminum and steel plates fixtured for final welding. A butt joint between bars is located approximately 3 cm (1.2") from left edge of picture.

FIGURE 4: Welding steel combing to bottom of transition joint strip.

FIGURE 5: Corner weld in armory space. Transition joint is bent at 5 cm (2") radius.

FIGURE 6: Stanchion support transition joint steel fillet weld is made to vertical edge of pad.

TRANSITION JOINT MATERIAL EVALUATION

The transition joint material was manufactured in accordance with the requirements of MIL-J-24445A. The product used in the Leopold installation was manufactured as explosion bonded plates, then saw cut into 1 cm (3/8") wide x 3 m (10 ft) long strips. The job required materials from two plates 1.2 m *(48")* wide x 3 m (120") long. Both plates were fully tested for compliance with MIL-J-24445A, including all First Article Tests. First Article Test results are presented in Table III.

The new transition joint material was developed in response to requests by shipbuilders for a "fabrication friendly," higher strength aluminum/steel transition joint material. Extensive data on the development of the product and a comparison to properties of other transition joint materials were presented at the 1990 and 1991 SNAME Ship Production Symposiums [1,2].

The new transition joint material is an engineered product designed to provide superior performance while being highly resistent to deterioration during

Table III: Transition Joint Material Test Data IAW MIL-J-24445A, First Article Testing

Test	Type	Simulated Weld Cycle (Note 1)	Test Results (Note 2)
A.	*Ram Tensile Test*	As delivered	2,087 kg/cm-sq (29,680 lb/in sq)
		As delivered	2,134 kg/cm-sq (30,357 lb/in sq)
		315°C (600°F)	1,738 kg/cm-sq (24,719 lb/in sq)
		315°C (600°F)	1,833 kg/cm-sq (26,067 lb/in sq)
		538°C (l,000°F)	1,359 kg/cm-sq (19,326 lb/in sq)
		538°C (l,000°F)	1,359 kg/cm-sq (19,326 lb/in sq)
B.	shear *Strength Test (Note 3)*		
Bl.	*Aluminum/* Titanium *Bond*	As delivered	1,032 kg/cm-sq (14,682 lb/in sq)
		As delivered	989 kg/cm-sq (14,064 lb/in-eq)
		315°C (600°F)	871 kg/cm-sq (12,386 lb/in sq)
		315°c (600°F)	891 kg/cm-sq (12,676 lb/in sq)
		538°C (l,000°F)	895 kg/cm-sq (12,733 lb/in sq)
		538°C (l,000°F)	823 kg/cm-sq (11,702 lb/in sq)
B2.	Titanium/ *Copper-Nickel Bond*	As delivered	3,921 kg/cm-sq (55,749 lb/in sq)
		As delivered	3,982 kg/cm-sq (56,627 lb/in-sq)
		315°l.T (600°F)	4,007 kg/cm-sq (56,984 lb/in sq)
		315°c (600°F)	3,928 kg/cm-sq (55,866 lb/in sq)
		538°C (l,000°F)	3,926 kg/cm-sq (55,831 lb/in sq)
		538°C (l,000°F)	3,260 kg/cm-sq (56,355 lb/in sq)
B3.	*Copper-Nickel/ Steel Bond*	As delivered	3,252 kg/cm-sq (46,250 lb/in sq)
		As delivered	3,564 kg/cm-sq (50,680 lb/in-sq)
		315°c (600°F)	3,155 kg/cm-sq (44,864 lb/in sq)
		315°c (6OO°F)	3,654 kg/cm-sq (51,954 lb/in sq)
		538°C (l,000°F)	3,291 kg/cm-sq (46,794 lb/in sq)
		538°C (l,000°F)	3,348 kg/cm-sq (47,615 lb/in sq)
C.	*Side Bend Test*	As delivered	90° bend, no failure
		315°c (600°F)	90° bend, no failure
		538°C (l,000°F)	90° bend, no failure
D.	*Chisel Test*	As delivered	Acceptable
		315°c (600°F)	Acceptable
		538°C (l,000°F)	Acceptable
E.	*Fatigue Test*	As welded	Acceptable per specification

NOTES:

1) Specimens were heated to temperature indicated and held 15 minutes at that temperature.

2) Results are shown for two sets of specimens selected from diagonally opposite corners of plate.

3) Shear strength values are average of three tests each.

cutting, bending, and welding. The improved properties are achieved through the use of two interlayer materials between the aluminum and steel. A titanium interlayer adjacent to the aluminum eliminates problems of deterioration due to overheating during welding. A copper-nickel interlayer between the titanium and steel considerably improves fracture toughness and strength.

In comparison to traditional aluminum/steel transition joint materials, the new material exhibits:

over twice the tensile strength,
over twice the fracture toughness,
equivalent corrosion resistance, and
bendability at l/10 the radius.

With the older material, the bar widths are limited to 2 cm (0.75") minimum for reliable fabrication; as demonstrated at Curtis Bay, the new material can be reliably fabricated at 1 cm (0.375") width.

When using the old material, welding temperatures must be maintained below 260 degrees C (500 degrees F) during cutting and welding to avoid bond strength and toughness deterioration. As shown in Table III, the new product maintains properties after heating to 482 degrees C (900 degrees F). During welding the welder can concentrate on making a strong, sound weld, not on minimizing heat to the bimetallic transition joint.

CONCLUSION

The joining of the aluminum pilothouse and armory decking to the steel deck using the 1 cm (3/8") x 2 cm (3/4") transition joint bar has been successful. There were no indications of defects in material or workmanship indicated by nondestructive testing. The new transition joint material appears to be suitable for making structural shipboard welds between aluminum and steel using bars of half the width and half the weight of traditional transition joint materials.

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Strip Cladding of Main Propeller Shafting with Ni Alloy 625 by Electroslap Surfacing

No. 7C-2

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ABSTRACT

A comprehensive comparison between electroslag surfacing (ESS) and submerged arc surfacing (SAS) using 30 mm (1.2 inch) wide x 0.5 mm (0.020 inch) thick Ni Alloy 625 strip was conducted in both the as-deposited and stress relieved (at 604°C, 1120°F) conditions. In most cases, exactly duplicate cladding conditions were used to best compare ESS with SAS. Ni Alloy 625 strip was deposited on 10 cm (4 inch) thick flat plates and 64 cm (25 inch) diameter shafting (both MIL-S-23284 Class 1 steel) using optimized ESS and SAS processes. Tensile, CVN toughness, and face and side bend tests were performed on as-welded and stress-relieved cladding at room temperature. Microstructural analyses of the clad specimens were performed using optical and electron microscopy.

Cladding parameters were found to affect the dilution, deposition rate, and penetration. Although ESS and SAS cladding possessed similar strength levels, the cladding deposited by ESS was shown to have greater ductility than that by SAS. Also, the resistance to solidification cracking of cladding by ESS was superior to SAS because of the reduced Si, C, 0, and impurity levels which promote interdendritic Laves phase, Nb-rich MC carbides and inclusions. Compared to SAS, the ESS method proved to be not only more metallurgically favorable but also cost-effective.

The mechanical properties, solidification cracking resistance and microstructure of electroslag cladding deposited with (1) Ni Alloy 625, (2) modified Ni Alloy 625 with low iron and (3) Ni Alloy 59 were compared. These Ni alloy strips produced cladding deposited on Class 1 steel with nearly similar mechanical properties. Cladding deposited with Ni Alloy 59 strip developed the best resistance to solidification cracking due to its very low Nb content which was found to reduce the level of detrimental Laves phase in the cladding microstructure.

Due to the high carbon content and high hardenability of the shafting steel, an appropriate preheating had to be determined. Y-groove testing, diffusible hydrogen testing and microstructural analysis was used to establish a safe preheating temperature.

INTRODUCTION

Electroslag surfacing (ESS) with strip electrodes is a new cladding technology in the USA. Until recently, high deposition rate cladding was performed exclusively by the submerged arc surfacing (SAS) process. But previous work has shown that ESS could produce about twice the deposition rate with half the dilution and less than half the impurity inclusion content compared to SAS. As a result, a program sponsored by the Navy ManTech-Office was initiated in 1990 to clad Ni Alloy 625 on-to main propulsion shafting.

In 1971, Seidel and Hess (1) reported a new adaptation of electroslag processing for cladding in the flat position using strip electrodes and called it electroslag surfacing. Ten years later, this concept was also utilized by Nakano et al(2) in Japan to develop Kawasaki's electroslag surfacing techniaue called "Maqlay." Since that time, many technical-papers have been published on electroslag surfacing in the flat position (3-12).

The great advantage of electroslag surfacing is high deposition rate, low dilution and cost-effectiveness. The electroslag surfacing process with strip electrodes has been shown to generate a substantially greater deposition rate with much less-dilution compared to its nearest competitor. submeraed arc strip surfacing (6). Because of-the high CaF content in the flux, cladding deposited' by electroslag surfacing contains about one third the oxygen content compared to submerged arc surfacing.

The objective of this research was to compare the cladding characteristics and capabilities of the electroslag surfacing and the conventional submerged arc surfacing of MIL-S-23284, Class 1 steel with Ni Alloy 625 strip. These characteristics included deposition rate, penetration, dilution, cladding composition, microstructure and mechanical properties. A second objective was to compare the properties and microstructure of electroslag cladding deposited with three strip compositions: (1) conventional Ni Alloy 625, (2) Ni Alloy 625 with low iron and (3) Ni Alloy 59. The third objective was to determine the safe preheating temperature for this new ESS process.

EXPERIMENTAL PROCEDURE

The materials in this study included 100 mm (4 inch) thick plate of MIL-S-23284, Class 1 steel. The filler strip electrodes were 30 mm (1.2 inch) by 0.5 mm (0.020 inch) thick and consisted of Ni Alloy 625, modified Ni Alloy 625 with low Fe and Alloy 59. Compositions of materials are given in Table I. The flux compositions for both ESS and SAS are

TABLE I. Composition of Shafting Steel (MIL-S-23284, Class 1) and 30 X 0.5 mm Strip Electrodes

		Strip Electrodes		
	Shaft	Alloy 625	Alloy 625 (LOW Fe)	Alloy 59
C	0.25	0.03	0.005	0.007
Fe	BAL	4.25	0.95	0.34
Si	0.22	0.09	0.04	0.04
MO	0.44	9.00	9.30	15.5
Nb		3.45	3.70	0.30
Cr	0.42	21.50	22.50	22.50
Mn	0.34	0.00	0.03	0.15
Ni	3.25	BAL	BAL	BAL
Ti			0.2	

presented in Table II. Cladding to compare ESS with SAS involved duplicate welding conditions using the same constant voltage DCep power supply. The flux was baked to at least 94°C (200°F) before cladding.

TABLE II. Major Ingredients in the Flux Used for ESS and SAS

	ESS	SAS
CaF_2	80	16
CaO		24
SiO_2	5	25
Al_2O_3	8	29

Microscopic examination of cladding included optical microscopy, scanning electron microscopy and scanning-transmission electron microscopy (STEM).

The etchant used for optical microscopy of the cladding was electrolytic oxalic acid. The steel base metal was etched in 1% nital. The dilution measurements and profile of the bead and HAZ were calculated by an image analyzer. The dilution is defined as:

$$\%Dilution=\frac{B}{B+A}$$

where A is the transverse cross sectional area of the cladding reinforcement above the base metal surface and B is the cross sectional area of the melted base metal below the base metal surface.

Mechanical testing of the cladding included tensile testing and bend testing. In all cases, tensile specimens were machined so that the longitudinal direction of the tensile specimens was always perpendicular to the direction of cladding. For single 0layer cladding approximately 6 mm (l/4 inch) thick, flat all-cladding tensile specimens were used and tested in accordance with ASTM E8. For the multilayer cladding approxi- mately 25 mm (1 inch) thick, 12.7 mm (1/2 inch) diameter all-cladding round tensile specimens were used. In bend testing, only single layer tests were conducted in accordance with the guided bend test procedure in AWS B4.0. Both side and face bend specimens were machined so that the longitudinal axes of the bend specimens were always perpendicular to the cladding direction.

A new solidification cracking was designed particularly for cladding with strip electrodes as illustrated in Figure 1. In this test, a non-symmetrical slit 1.75 mm (0.07 inch) was placed in the center of a 25 mm thick plate of the MIL-S-23284, Class 1 steel. In Figure 1, "L", is the total crack length measured across the width of the strip cladding bead and "W" is the bead width.

RESULTS & DISCUSSION

Cladding Variables

In comparing electroslag surfacing (ESS) with submerged arc surfacing (SAS) the welding variables such-as current, voltage and travel speed affected deposition and dilution. Raising current (Figure 2) increased deposition rate significantly but only slightly decreased dilution. Increasing travel speed (Figure 3) had little effect on deposition rate while greatly increasing dilution. Since voltage changes (Figure 4) had little effect on deposition rate and dilution, voltage was used to control the bead shape of

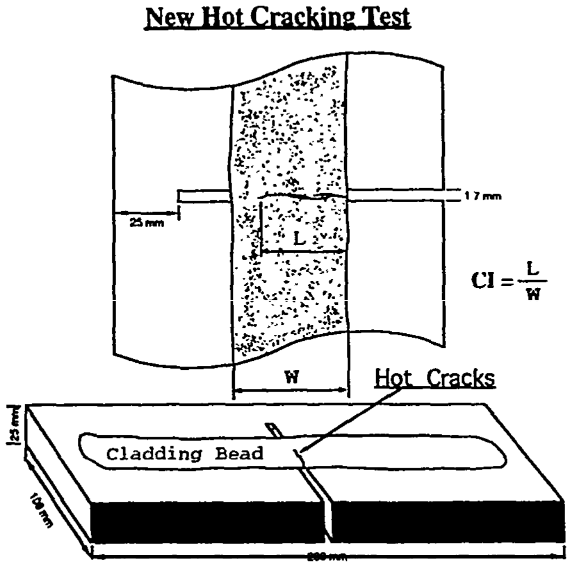

FIGURE 1. Solidification Cracking Test for Strip Cladding Developed by Oregon Graduate Institute.

the cladding. When comparing similar cladding deposited by ESS versus SAS (for reference) using the same welding variables, the ESS process developed a greater deposition rate and lower dilution than similar cladding deposited by SAS. After analyzing the effects of cladding variables, the optimized parameters for ESS were develop to provide excellent cladding integrity with minimal (6% - 8%) dilution for Ni Alloy 625 strip deposited on steel as shown in Table III.

<u>Tensile Testing</u>

ESS and SAS cladding layers were deposited on the MIL-S-23284, Class 1 steel for mechanical testing. The tensile tests were carried out on single layers of the Ni alloy 625 cladding approximately 6 mm (0.23 inch) thick in both the as-clad and stress-relieved conditions using the parameters shown in Table III. The yield strengths of both ESS and SAS cladding were similar but the cladding deposited by ESS possessed substantially higher ductility than did comparable cladding deposited by SAS as shown in Table IV. Also, the ductility in the as-welded condition was generally higher than the stress relieved cladding for both ESS and SAS.

A similar comparison of the tensile properties of multiple layers of cladding approximately 25 mm (1 inch) thick deposited by ESS was conducted. Cladding deposited by ESS using Ni Alloy 625, low-Fe Ni Alloy 625 and Ni Alloy 59, and cladding by SAS with Ni Alloy 625 (for reference) in both the as-clad and stress-relieved conditions are

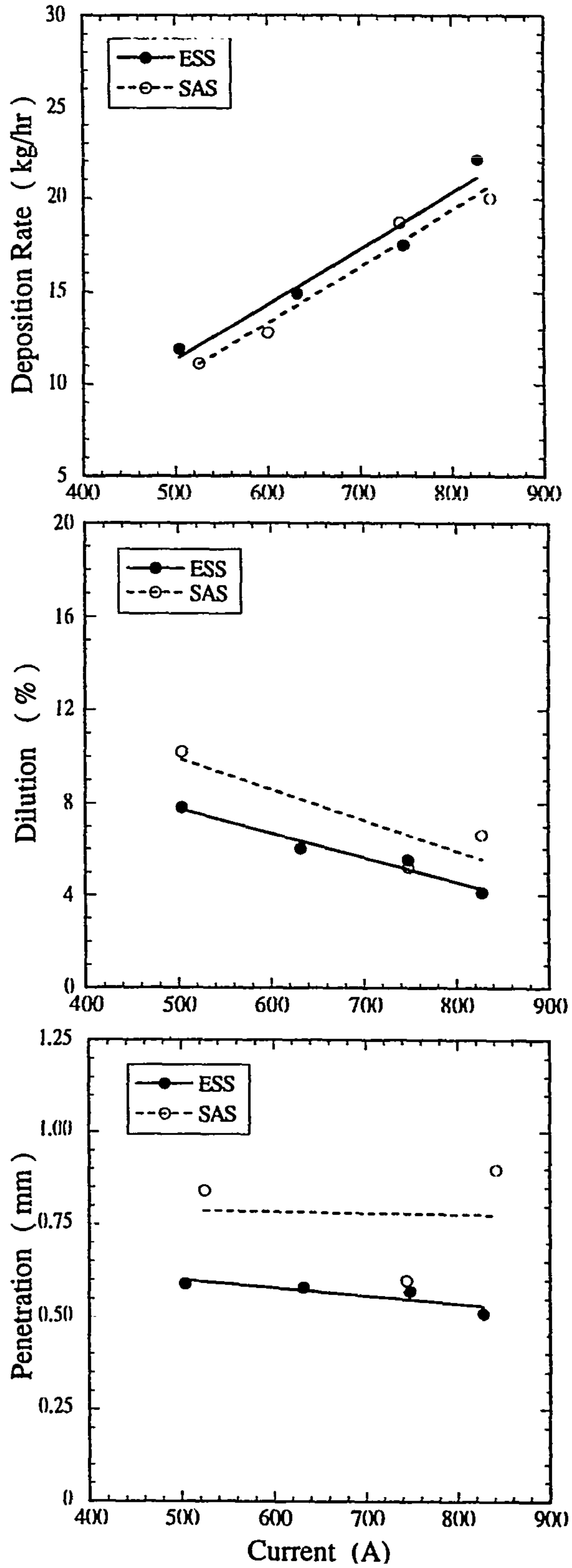

FIGURE 2. The Effect of Current on the Deposition Rate, Dilution and Penetration of Cladding Deposited on MIL-S-23284 Class 1 Steel Using 30 by 0.5 mm Strip of Ni Alloy 625.

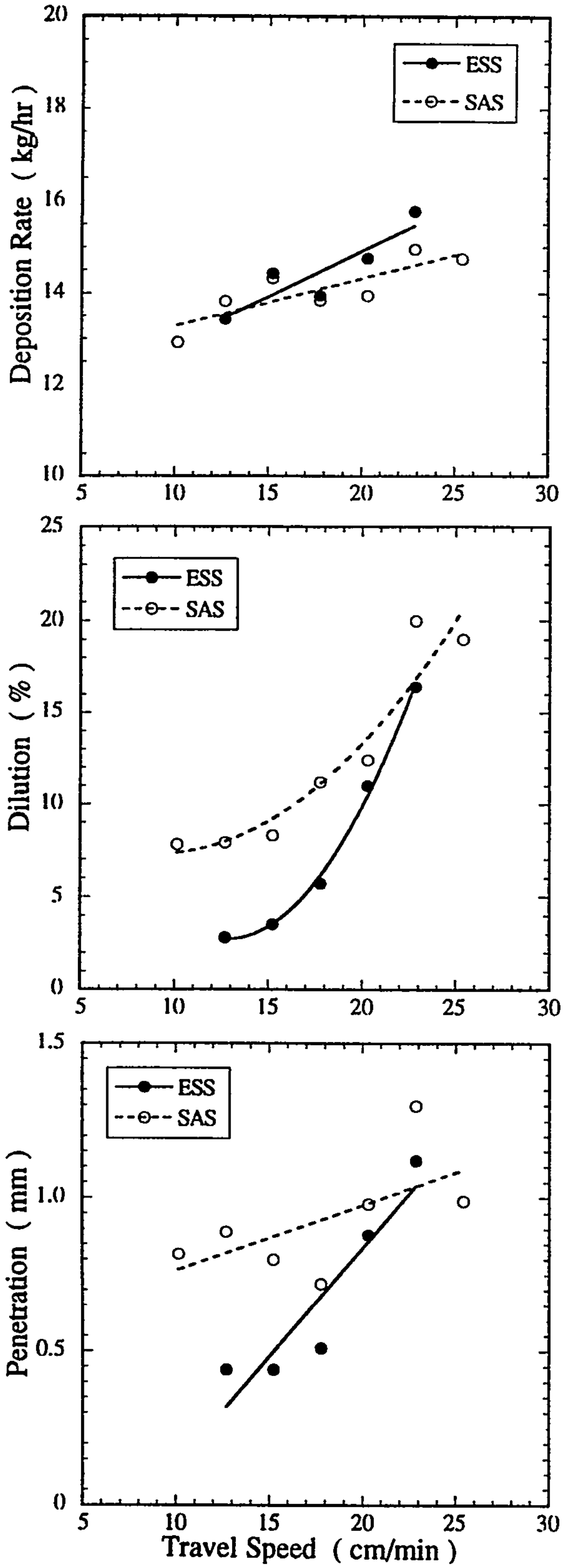

FIGURE 3. The Effect of Travel speed on the Deposition Rate, Dilution and Penetration of Cladding Deposited on MIL-S-23284 Class 1 Steel Using 30 by 0.5 mm Strip of Ni Alloy 625.

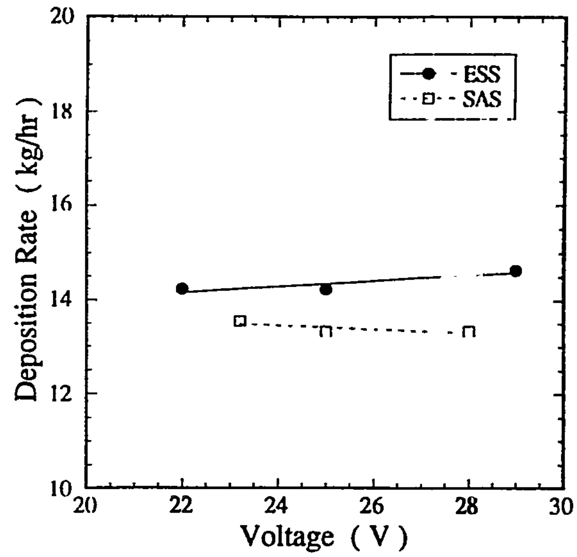

FIGURE 4. The Effect of Voltage on the Deposition Rate, Dilution and Penetration of Cladding Deposited on MIL-S-23284 Class 1 Steel Using 30 by 0.5 mm Strip of Ni Alloy 625.

compared in Figure 5. Generally, the strength and ductility of cladding deposited with Ni Alloy 625, low-Fe Ni Alloy 625 and Ni Alloy 59 strips were similar. The ductility values were all superior to that of the parent shafting steel. Stress relief heat treatment of the cladding at 604OC (1120°F) produced no observable change in mechanical properties.

Rend Testing

The side and face bend tests were carried out on single layers of the Ni alloy 625 cladding approximately 6 mm (0.23 inch) thick (deposited on MIL-S-23284 Class 1 steel) in both the as-clad and stress-relieved conditions as shown in Table V. All face bend and side bend specimens containing both the cladding deposited by ESS and SAS passed the 22% strain level of MIL-S-23284 Class 1 base metal. Also in Table V, the face and side bend tests results of ESS cladding deposited with Ni Alloy 625, low-Fe Ni Alloy 625 and Ni Alloy 59 are presented. In all cases, each type of Ni alloy strip produced ductile cladding which passed the 22% elongation face and side bend tests without any sign of surface cracking or defects.

TABLE III. Variables for Electroslag Cladding MIL-S-23284. Classes 1 Steel Shafting Using 30 X 0.5 mm Ni Alloy 625 Strip

STRIP FEED SPEED	185 CM/MIN 73 IN/MIN	+/- 13 +/- 5
CURRENT	650 A (TYPICAL*)	
VOLTAGE	27 V	+/- 1
MACHINE TYPE	DCep CONSTANT VOLTAGE	
TRAVEL SPEED	178 MM/MIN 7 IPM	160/190 6.5/7.5
TIE-IN OVERLAP	4MM 0.160 IN	3.5-5.0 .140/.200
WELD HEAD POSITION	7° DOWNHILL	+/- 1
STRIP FEED ANGLE	7°	+/- 1
FLUX	59s (SANDVIK OR SOUDOMETAL)	
WELDING HEAD	HEAVY DUTY; WATER-COOLED	
PREHEATING TEMPERATURE	200°C (400°F) MIN	
INTERPASS TEMPERATURE	315°c (600°F) MAX	
POST SURFACING STRESS RELIEF	650°C 1200°F	+/- 15 +/- 25

* Only typical values of current are given because current is dependent upon strip feed speed.

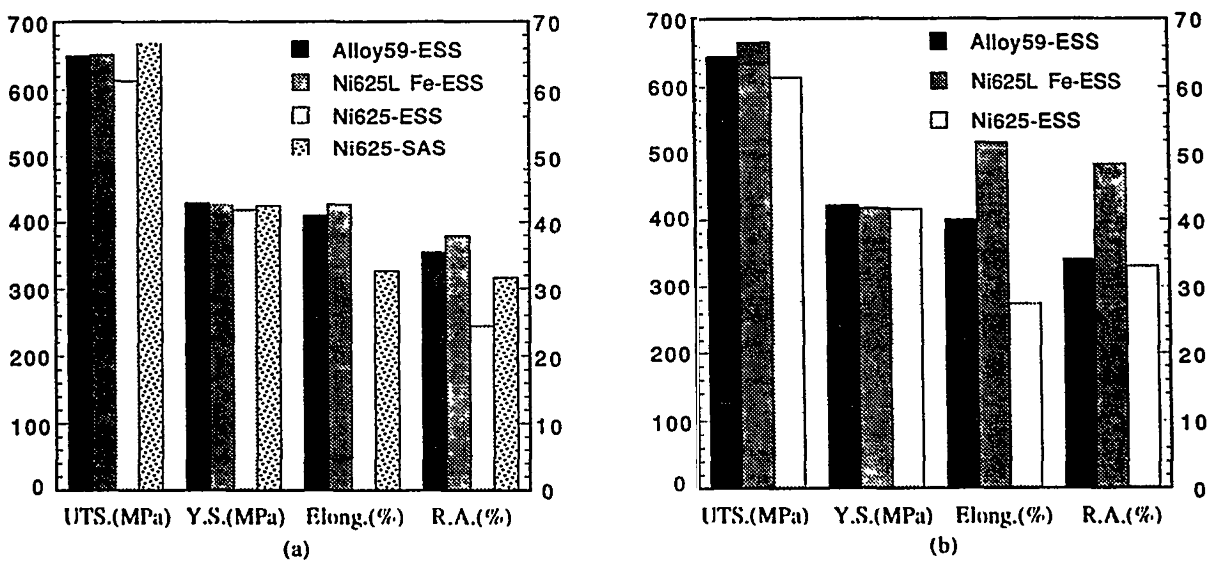

FIGURE 5. Tensile Properties of 25 mm (1 inch) Thick Cladding Deposited in Five Layers with Ni Alloy Strips on MIL-S-23294, Class 1 Steel Using ESS; (a) As-welded and (b) Post-weld Stress Relieved.

TABLE IV. Tensile Properties of NI Alloy 625 Cladding Deposited in a Single Layer on MIL-S-23294, Class 1 Steel Using ESS and SAS

	YS. MPa	UTS. MPa	%ELONG	%RA
Base Metal	617	754	21	62.5
Ni 625 Strip	490	855	50	
AS-CLAD CONDITION				
ESS	393	676	50	38.5
SAS	386	669	39	38.5
STRESS RELIEVED AT 604°C (1120°F)				
ESS	407	696	42	38
SAS	379	676	32	31

TABLE V. Face and Side Bend Test of Cladded Plate per AWS B4.0 to Pass 22% Strain Required by MIL-S-23284 Class 1

	E S S	S A S
Ni Alloy 625	pass	pass
625 with Low Fe	pass	N/A
Ni Alloy 59	pass	N/A

Solidification Crackina Susceptibility

Although many solidification cracking tests have been developed for weld metal deposits, none were found acceptable for testing of strip cladding. The new Oregon Graduate Institute design for a solidification cracking test for strip cladding is shown in Figure 1. This test was applied to both ESS and SAS cladding using different strip electrode compositions including 309L stainless steel containing 9% ferrite and 7O%Cu-300Ni for reference. The 309L is known to be crack resistant whereas the 7O%Cu-30%Ni strip deposited on steel is known to be extremely susceptible to solidification cracking and should always fail the OGI cracking test. The results of this strip cladding test are given in Table VI.

From Table VI, the Ni alloys appear to be more susceptible to solidification cracking than the 309L austenitic stainless steel as expected. However, the cladding deposited by SAS was more sensitive to solidification cracking than similar cladding deposited by ESS. The reason for the increased cracking susceptibility in cladding by SAS may be due to two factors: (1) the slag reaction that raises the Si content of cladding to enhance formation of the low melting interdendritic Laves phase, and (2) the high level of dilution from the steel base metal that is characteristic of SAS. The differences in solidification cracking susceptibility for cladding deposited by ESS using Ni Alloy 625, modified low Fe 625 and Ni Alloy 59 were small. Table VI, shows that Ni Alloy 59 probably possessed the best resistance to solidification cracking.

Composition Profile of Cladding

The composition of the cladding was found to be dependent upon (1) dilution from the MIL-S-23284, Class 1 steel base metal, (2) slag reactions, and (3) distance from the base metal interface. In Figure 6, the chemical compositions of the lst, 2nd, 3rd and 4th layers of cladding are given for both ESS and SAS deposits. In Figure 6a, the carbon content was lower than that in either the strip or base metal due to a slag reaction. Because of the lower dilution from ESS compared to SAS, Fe contents of the first layer of the electroslag deposits using Ni Alloy 625, modified low Fe 625 and Ni Alloy 59 were well below the 9% limit specified by NAVSEA 0900-LP-014-1010. The cladding deposited by SAS, however, exceeded the 9% limit in the first layer. The extra low Fe contents of the Ni Alloy 59 strip and Ni Alloy 625 with low Fe strir, tended to also reduce the iron content of the first layer cladding deposited on steel shafting. The Fe contents in the 2nd, 3rd, and 4th layers of both ESS and SAS cladding were below 9% as shown in Figure 6b. In Figure 6c, the Si content of cladding deposited by SAS was nearly 4 times greater than that in the ESS cladding. This is due to the high SiO content in the SAS flux. High Si leve1s may have increased solidification crack sensitivity in the SAS cladding as shown in Table VI.

TABLE VI. Oregon Graduate Institute Solidification Cracking Test of Strip Cladding Deposited on MIL-S-23284 Class 1 Steel

	309L ss	Ni Alloy 625	Ni Alloy 625 (LOW Iron)	Ni Alloy 59	70Cu-Ni
ESS	0	l/3	l/4	1/8	1
SAS	0	1	1	213	1

0 = No Cracking
1 = Cracking Across Entire Width of Cladding

Reactions between the strip electrode and the slag produced small but beneficial reductions in carbon and iron contents in the cladding (Figure 6). However, the Si content of the cladding was always greater than that of the strip electrode particularly for the SAS process. Within each cladding layer, the chemical composition was uniformly distributed except at the interface between the Ni alloy cladding and the Class 1 steel base metal. A transition zone of 140 microns (0.006 inch) was needed for the composition to adjust from that of the base metal to that of the bulk cladding.

Oxygen Content of Cladding

The oxygen content of the cladding was found to be dependent upon the oxygen potential of the flux. Since the ESS flux contained approximately 80% calcium fluoride, its oxygen potential was very low compared to the SiO_2-rich flux used for SAS (Table II). As a result, the inclusion concentration and oxygen content of the cladding deposited by SAS was approximately three times that of the cladding deposited by ESS. Typical oxygen content of the ESS cladding of Ni Alloy 625 was 280 ppm while similar SAS cladding contained over 700 ppm.

Microstructure of Cladding

The cladding microstructures deposited by both ESS and SAS consisted of primary gamma matrix dendrites and interdendritic precipitates, which were mainly Nb-rich MC carbides and Laves phase, as shown in Figure 7a. In the cladding microstructure deposited by ESS, the post-weld stress relieving treatment at 604°C (1120°F) for two hours caused some precipitates to grow into a coarse irregularly-shaped morphology as shown in Figure 7b. In contrast to the relatively inclusion-free cladding deposited by ESS, the cladding deposited by SAS contained many inclusions introduced by slag reactions in addition to the large MC carbides and Laves phase precipitates, as shown in Figure 7(c) and (d) for as-welded and stress relieved conditions, respectively.

Related to the microstructures shown in Figure 7, the reduction of ductility was understandable due to the excessive inclusion content and coarseness of the interdendritic precipitates in cladding deposited by SAS. Examination of the tensile fracture surfaces of cladding deposited by SAS showed that the cracks preferred to propagate along the interdendritic spaces. However, for similar cladding deposited by ESS, the fracture exhibited a homogeneously distributed dimple structure. Therefore, the reduction of ductility in SAS was attributed to the excess quantities of oxide inclusions, Laves phase and MC carbides in the interdendritic areas. Nevertheless, cladding produced by both ESS and SAS passed the 22% ductility requirement (MIL-S-23284, Class 1 shafting) for side bend tests at room temperature in Table V.

In comparing the microstructures of ESS cladding deposited by Ni Alloy 625, Ni Alloy 625 with low Fe and Alloy 59, Ni Alloy 59 contained less than one third of the Laves phase observed in the other Ni cladding alloys as shown in Table VII. This may account for the superior solidification cracking resistance of Alloy 59.

Preheating Temperature Determination

Because of its high hardenability and carbon content, the shaft material must be preheated to avoid hydrogen-induced cold cracking. Although the preheating temperature of MIL-S-23284, Class 1 steel is specified in NAVSEA 0900-LP-o14-1010 for conventional welding operations (but not ESS), the effect of preheating temperature was investigated for the new ESS process using Ni-Alloy 625 filler metal. The microstructures of heat-affected zone of the Class 1 base metal (obtained by optical and transmission electron microscopy) has been summarized as a function of preheating temperature in Table VIII. From these results, totally safe welding conditions occur when the preheating temperature was equal to or greater than 204°C (400°F) since all of the martensite was in the tempered condition. However, preheating at 150°C

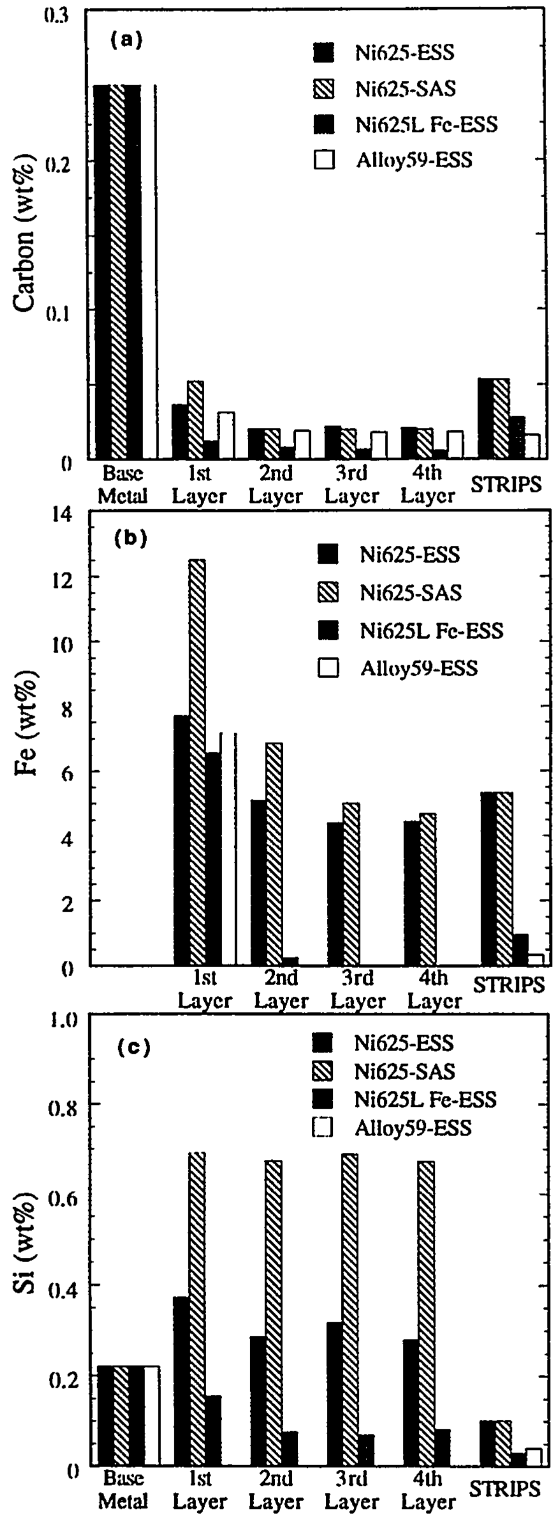

FIGURE 6. Composition of 1st Through 4th Layers of Cladding Deposited by ESS and SAS Using 30 X 0.5 mm Strip Electrodes: (a) Carbon, (b) Iron, and (C) Si.

TABLE VII. Relative Amounts of Leaves Phase in the Microstructure of Cladding Deposited by Electroslage Surfacing on MIL-S-23284, Class 1 Steel Using Ni Alloy strips

Strip Material	Relative Amount of Laves Phase (counts/ field)	Confidence (%)
ESS - Ni Alloy 625	477	98
ESS - Ni Alloy 625 Low Fe	162	99
ESS - Ni Alloy 59	54	98
GMAW Cladding* - Ni Alloy 625	512	97

* For comparison with conventional cladding by GMAW with wire electrodes.

(300°F) produced a microstructure that was predominately tempered martensite and bainite.

The Japanese Industrial Standard (JIS z 3158) known as the Y-Groove Cracking Test was also used to quatify preheating temperatures for the ESS process. Since the Y-Groove Cracking Test has been developed for wire welding systems, the Ni Alloy 625 wire and ESS flux were used (in the Y-Groove Cracking Test) to evaluate the cracking resistance of the cladding material. Y-Groove tests were conducted on 25 mm (1 inch) thick MIL-S-23284, Class 1 steel base metal using Ni Alloy 625 filler wire as well as MIL-loos-1 steel filler wire (matching the base metal strength), for reference. Y-Groove Cracking Tests were performed in the electroslag mode at different preheating temperatures including: room temperature, 94°C (200°F), 150°C (300°F), and 204°C (400°F).

Results showed that one out of three Y-Groove specimens welded with matching steel filler wire preheated to 94°C (200F) cracked in the HAZ. The Y-Groove test specimens welded at 300°F were crack-free. Cold cracks have been observed in the HAZ of test specimens of the Y-Groove Cracking restraint test of preheated at 94°C (200°F) but have never been detected on cladded shaft material at this preheating temperature. When Y-Groove Cracking Tests were conducted with Ni Alloy 625 wire, no cracking was observed at 94°C (200°F). It is

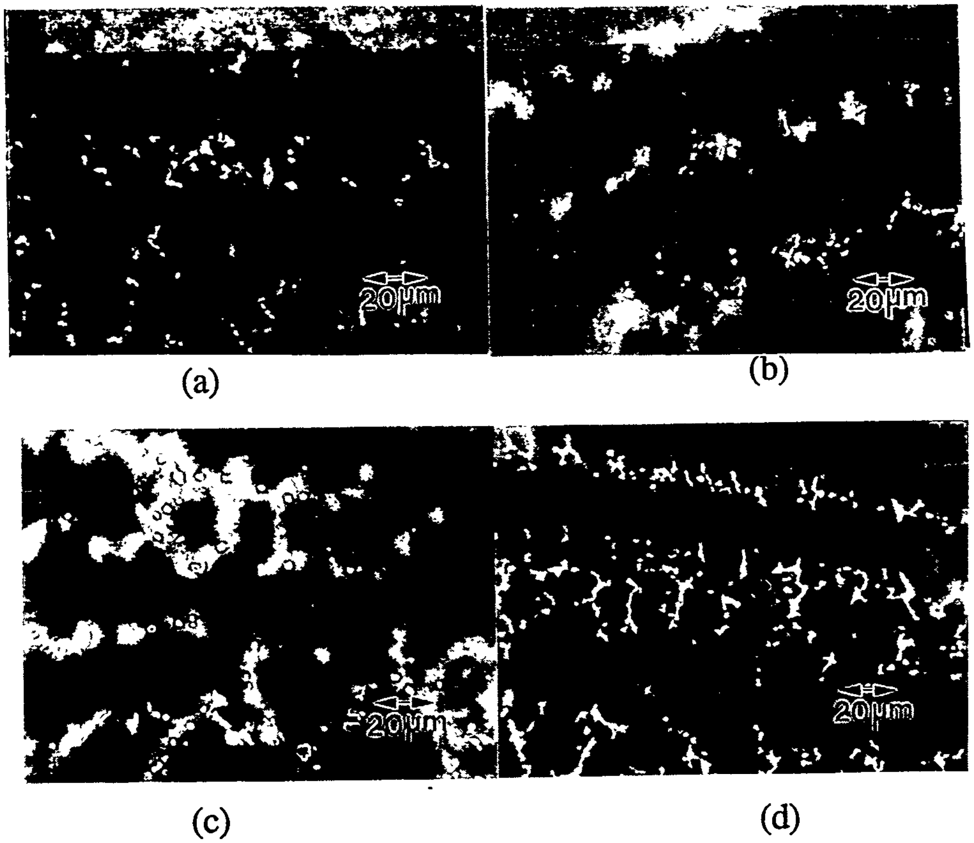

FIGURE 7. Microstructures of Cladding Deposited with Ni Alloy 625 by ESS and SAS: (a) ESS, As-welded, (b) ESS, after Stress Relief at 604°C (1120°F), (c) SAZ, As-weided, and (d) SAS, after Stress Relief at 604 C (1120°F). Precipitates are Laves and Nb-rich (MC Type) Carbides.

TABLE VIII. TEM Analyses of the Heat-Affected Zone of Cladded MIL-S-23284 Class 1 Steel

	Microstructure	
Preheat Temperature	ESS	SAS
As-cladded		
93°C (200°F)	Martensite + Bainite	Martensite + Bainite
150°C (300°F)	Martensite + Tempered Martensite + Bainite	
204°C (400°F)	Tempered Martensite + Bainite	
Post Weld Stress Relief at 604°C (1120°F)		
93°C (200°F)	Tempered Martensite + Bainite	Tempered Martensite + Bainite

believed that the high solubility of hydrogen in nickel and reduction in hydrogen diffusivity in nickel cladding significantly reduced solidification - cracking susceptibility. Thus, the required preheating temperature of 204°C (400°F) appears to be very safe.

In determining the amount of diffusible hydrogen in the cladding, Ni Alloy 625 was deposited in the electroslag mode on Class 1 steel plate per AWS B4.0 using the ESS flux. From Figure 8, the variable having the greatest effect on the amount of diffusible hydrogen was the flux baking temperature prior to cladding. A minimum baking or holding temperature of 93°C (200°F)is required to maintain control of diffusible hydrogen content. The heat input had no appreciable effect on the amount of diffusible hydrogen in the cladding (Figure 8). The use of Ni Alloy 625 filler metal significantly reduced the amount of diffusible hydrogen in the weld metal because of hydrogen's high solubility in Ni and the order of magnitude slower diffusion rate of hydrogen in face-centered cubic Ni. As a result, cladding with Ni alloys presents a diminished threat of hydrogen induced cold cracking particularly after post-weld stress relieving at 604°C (1120°F).

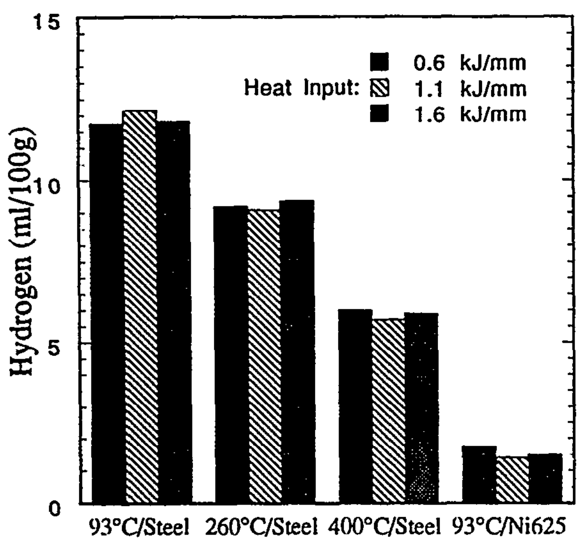

FIGURE 8. Diffusible Hydrogen Content of Steel and Ni Alloy 625 Cladding for Different Flux Baking Temperatures.

CONCLUSIONS

An investigation was conducted to determine the characteristics, properties and microstructure of cladding deposited on steel by ESS and SAS processes using Ni alloy strip electrodes. The following can be concluded:

1. ESS provides lower dilution, lower and more uniform penetration, and higher deposition rate than does SAS under the similar cladding conditions.
2. Cladding deposited with Ni Alloy 625 strip by ESS is less sensitive to solidification cracking than similar cladding deposited by SAS.
3. Oxygen content of cladding deposited by ESS is less than l/3 that of similar SAS cladding.
4. Microstructures of cladding deposited by ESS and SAS contain both MC carbides and Laves phase.
5. Cladding deposited with SAS is substantially higher in Si content compared to similar cladding by ESS.
6. In comparing ESS cladding deposited with Ni Alloy 625, Ni Alloy 625 low-Fe, and Ni Alloy 59, all strip electrodes produce nearly similar mechanical properties. Alloy 59 appears to be least sensitive to solidification cracking. Alloy 59 cladding contains the least amount of detrimental Laves phase due to its low Nb content.
7. Because Ni alloy cladding is deposited over MIL-S-23284, Class 1 steel, preheating temperatures as low as 150°C (300°F) are effective in preventing HAZ cracking.

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Evaluation of the Hitachi Zosen Welding Robots for Shipbuilding

No. 8A-1

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ABSTRACT

The application of robotics provides good potential to increase welding productivity, reduce dependence on skilled labor and improve the competitive position of U.S. shipyards. However, shipyard applications have generally been limited to small part sizes and repetitive batch lots.

Hitachi Zosen of Japan has made considerable progress in developing and applying portable robotic welding equipment for welding primary ship's structure. These robots are not the conventional teach-playback variety, but rather a numerically-controlled (NC) robot that utilizes off-line programming making it particularly adaptable to high volume, non-repetitious welding tasks. The robot system was designed for ease of handling, minimal set-up time and operator intervention, and for use in smaller confined spaces. Unskilled operators rather than experienced welders can be used because of the robots off-line programming feature and computer control of the welding operation.

An initial technical evaluation, including a trip to Japan to observe the portable welding robots in operation, was completed under funding 'from the National Shipbuilding Research Program (NSRP) The evaluation concluded that the portable welding robot offers excellent potential in U.S. shipyards to reduce structural welding costs and improve overall productivity for commercial and naval ship construction.

INTRODUCTION

The NSRP SP-7 Welding Panel has continually monitored Japanese shipbuilding robotic welding applications. During a visit to Japan in 1982, SP-7 members became aware of the planned development of the programmable portable welding robot. At that time, the design concept was under way but hardware development had not yet started.

In 1990, successful operation of the portable welding robot was observed at the Lindoe Shipyard in Denmark. The robots were impressive in their ease of set-up, operation, and programming. Productivity gains were evident since one operator was simultaneously running three robots with minimal intervention. As far as can be determined, this Danish shipyard is the only yard outside of Japan that is using these portable welding robots.

Because of potential value to the U.S. shipbuilding industry, a proposal for an evaluation of the portable welding robot was submitted to the SP-7 Welding Panel for consideration. The project concept was approved and a contract to complete an initial technical evaluation was subsequently awarded. The primary technical objectives of this evaluation were:

- observe the operational capabilities of the portable welding robot in a shipbuilding production environment;
- determine potential benefits in fabrication, productivity, quality and welding performance utilizing the portable welding robots; and
- evaluate the interface between the Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) systems and the ability of the robots to interface with shipyard computer design systems.

TRIP TO JAPAN

A team travelled to Japan in December, 1991 to visit shipyards that use the Hitachi Zosen portable welding robot. The authors, from Newport News Shipbuilding and Drydock Company, were joined on the trip by SP-7 Pane1 members from Peterson Builders, Inc., Ingalls Shipbuilding, Puget Sound Naval Shipyard, and the David Taylor Research Center.

The trip was beneficial in gaining an appreciation of Japanese advancements in robotics. For example, because of a shortage of workers, Japan has established a goal to replace one-third of its work force with robots. Through the use of robots and other automated processes, Japan has increased the yearly electrode consumption per welder per year from 907kg (1 ton) in 1980 to 5,262kg (5.8 tons) in 1990.

The following summarizes the highlights of the companies visited.

Hitachi Zosen Ariake Works

This yard, built in 1973, is Hitachi's largest and most modem with a capacity of six very large crude carriers (VLCC's) per year. Because of government-imposed constraints on capacity, the yard is only building four VLCC's per year. The yard employs approximately 1,200 people of which 400 are subcontractors.

Typical construction duration for a 240,000 - 300,000 DWT VLCC is about 9 months (3 months from start fabrication to keel, 3 months in the dry dock, and 3 months post launch).

The visit included a tour of their structural fabrication and assembly shops, final assembly areas, and dry docks. The portable welding robots were observed under actual production conditions. The team was provided technical presentations on the development, design, programming and operation of the robot as well as presentations on their robotic welding plans for the future.

Robotic welding currently accounts for 20% of their welding and their short-term goal is to achieve 50%. Their long-term goal is that 80% of all structural welding will be accomplished with robots and 95% of all welding will be accomplished in the flat or horizontal position.

Eighty-five percent of all structural welding and all robotic welding uses a specially formulated seamless flux-cored electrode.

Robots are predominately used for straight-line welding. Three-dimensional accuracy control is considered absolutely critical for robotic welding. Component parts are expected to be located within plus or minus lmm (.039 inches) for welding.

Portable programmable robots and twin-torch, gantry-mounted robots are used for fillet welding stiffeners. When stiffener heights do not interfere, welds are made on both sides of a stiffener at the same time.

By the end of 1992, their panel line is expected to make extensive use of robotics and will be operated completely by unskilled labor.

Robots were observed welding fillets through a pre-construction primer (20 ± 2 microns thickness). The primer is intended to last only one month. It was noted that slower welding speeds and a weaving technique were required for welding through the primer.

Hitachi Zosen Maizuru Works

This yard has 70 years of experience constructing commercial ships and surface vessels for the Japanese Navy. Maizuru also manufactures and sells automated systems for welding structural beam and column connection assemblies for the construction of buildings.

The yard runs both commercial and naval work through their shops at the same time. Ironically, they admitted that this was a real problem and were curious how U.S. shipyards were going to tackle the same problem.

The visit included a tour of the shops where the structural robotic welding systems are assembled. The twin torch gantry system and the extended reach robot system used by the Ariake Works are assembled at Maizuru Works.

The team also toured the dry dock area where construction of a double-hull VLCC using the recently developed unidirectional hull design was observed.

Sumitomo Heavy Industries (SHI) Oppama Shipyard

This yard was built in 1971 and has a capacity of six VLCC's per year. The yard is currently building 95,000 DWT tankers and 140,000 DWT bulk carriers.

Typical construction duration for a VLCC is about 12 months (3 months from start fab to keel, 5 months in the dock, and 4 months post launch).

The visit included an extensive tour of their structural fabrication and assembly shops and their dry dock area. Robotic welding applications include:

- robotic equipment for setting and fitting stiffeners to plate;
- single and double torch gantry systems for welding stiffeners to plate;
- a track-mounted articulated robot for welding stiffeners on small assemblies;
- eight Hitachi Zosen portable robots for welding primary hull structure;
- ten track-mounted robots for welding longitudinal stiffeners to transverse bulkheads; and
- four fixed-position robots for welding small and medium sized pipe flanges.

Overall, SHI utilizes 25 robots at this plant with plans to install an additional 25 robots. SHI estimates that their total investment in robotics is about 4 million U.S. dollars.

Daihen Corporation

The team visited Daihen Corporation, formerly known as Osaka Transformer Company. This plant manufactures robots, laser welding and cutting systems and operates a welding school to train and certify welders for other Japancse companies.

The plant was impressive in that 200 robots per month are assembled and tested by 14 people. Their streamlined production operation makes extensive use of Statistical Process Control (SPC) and Just-In-Time (JIT) techniques. Daihen Corporation received the Deming Award in 1987.

OVERVIEW OF HITACHI ZOSEN PORTABLE WELDING ROBOT

The Hitachi Zosen portable welding robot, is a flexible, automated robotic welding system developed specifically for welding the primary (egg-box) structure at the assembly stage of unit construction. Physical attributes of the robot, including size, work envelope, load capacity and number of axes were chosen based on current and future ship designs.

The robot was designed for ease of handling, minimal set-up time and operator intervention, and for use in smaller confined spaces where a robot would be beneficial. The robot can be combined with a robot origin (self travelling) transfer unit (Figure 1) that expands the operating range of the robot to include travelling the full length of a structural bay between two longitudinal and transverse stiffeners. Stationary fixtures can be utilized to allow a wider range of robotic welding applications.

The portable welding robot is not a conventional teach-playback robot but rather a NC robot that utilizes off-line programming making it particularly adaptable to high-volume, non-repetitious structural welding tasks. The required machine control code is created by manual entry of design information into menu-driven, personal computer (PC)-based software.

Computer output is downloaded via floppy disc to the robot's controller on the shop floor. After loading the NC data, the robot operator may optionally add, delete, and insert data on the robot's control panel.

Because of its simplicity, one operator can operate three or more robots simultaneously. Each robot achieves an average arc-time of 50-70% and can deposit more than 20 Kg (44 pounds) of filler metal per eight hour shift.

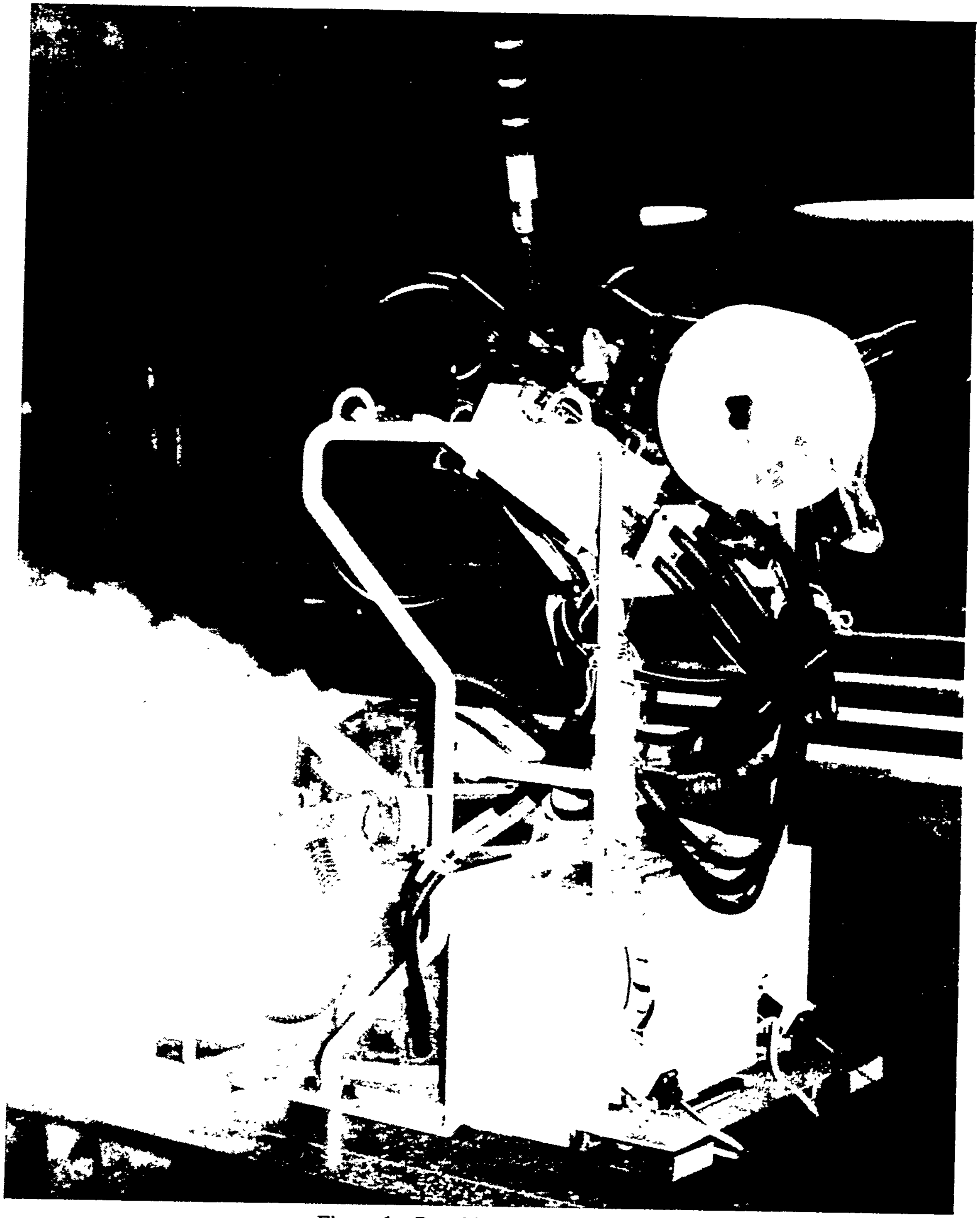

Figure 1. Portable Welding Robot

TECHNICAL EVALUATION

CAM System

The manufacturer has successfully developed a simple CAM system for operating the portable welding robot. Although a link between the portable robot CAM system and their CAD system has not been established, the robot was found to be easy to "program" through menu-driven software.

In addition to the robot and its controller, the system includes: a PC with minimum 1 MB **RAM,** 20 MB hard drive and 3.5" floppy disc drive; a monochrome or color monitor; a 15" printer; and the NC data generation software.

Robot NC Data Generation Software. The robot data generation software provides a menu-driven system for a planner to describe and input the geometry of a section of the ship's structure. Principal features include:

- fundamental hull structure geometry that depicts the basic structural configuration (skin plating with two longitudinal frames and two transverse bulkheads);
- a library of variables for the fundamental hull structure such as type and size of longitudinal stiffeners, frame spacing, types of brackets and collars, etc.;
- a library of welding parameters dependent on single or multi-pass weld and leg lengths and position;
- automatic simulation of trajectories (not displayed) to minimize starts and stops depending on the limitations of the robot movement;
- automatic generation of opposite side weld paths;
- an interference avoidance check between movement of the robot and ships structure; and
- automatic generation of machine language code.

Data Entry/Programming. The team was provided a demonstration of data input for programming a typical portion of a ship's structure. The following summarizes the steps of that operation:

1. A planner uses either a CAD design on a computer terminal or a drawing' that depicts the structural area to be programmed. For purposes of the demonstration, the following sketch (Figure 2) was used:

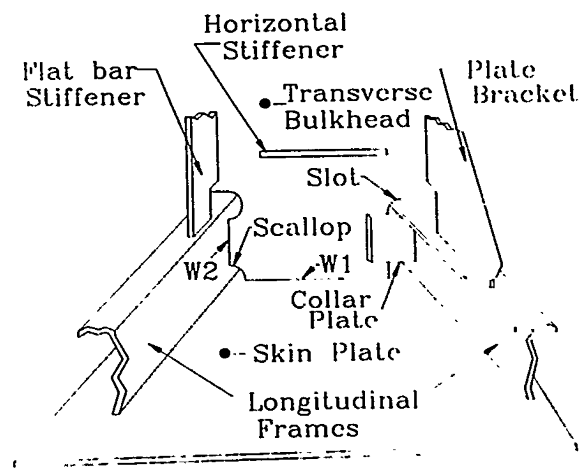

Figure 2. Basic hull structure used for demonstation

2. The planner then accesses the PC software and manually enters the geometric description of the space to be welded. There are 27 variables that define the geometry including types of stiffeners, fitting angles, and overall lengths of the space. Table I provides a sample of the data entered for the demonstration.

   The variables also include the selection of any of 25 slot and 6 collar arrangements. A sample of typical slot and collar arrangements is provided in Figure 3.

Variable	Input data
Long'l floor angle	90°
Long'space	860 cm
Long'l web depth	300 mm
Floor thickness	12.5 mm
Slot type	A712
Weld type	Fillet
Leg length:	
W1	6.0 mm
W2	7.0 mm

Table I. Data entered demonstration

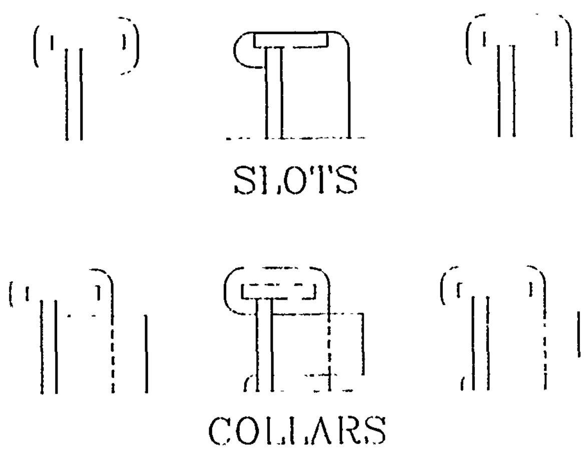

Figure 3. Slot and collar arrangements

3. Upon completion of data entry, the software automatically optimizes weld trajectories by running simulation and interference checks, and then develops the machine language code for the robot's controller.

Structural Data Output. The generated NC data is transferred onto a floppy disc for loading into the robot's controller when the structural welding is to be completed.

An additional unique output is a summary of the projected elapsed times for completing the actual welding of the area.

Assessment of CAM **System.** Based on the demonstration provided, programming the robot appears to be relatively easy and straight-forward. A planner should quickly become proficient at entering the required design input. Because of the repetitive nature of the ship's structure within each block/unit, data entry costs should be minimal.

Direct input from a CAD database would be an enhancement and is technically feasible. However, the lack of this interface is not a significant drawback due to the minimal time required for manual data entry.

The robot's software is designed to work with metric dimensioning while U.S. designs are typically based on feet and inches. This is not a significant problem since most CAD systems can easily convert between the two.

The software can be modified to accommodate design details specific to another shipyards design.

Operating The Robot

To start production welding, the operator lowers the robot onto the structural assembly using a dedicated overhead bridge crane. Because of its relatively small physical size and weight, the operator can easily slide the robot into position. Placement of the robot within the structure is not critical; however, there is a target location near the weld start point for initial alignment.

A job identification number links the CAM generated data to the egg-box structure to be welded. The operator inputs the identification number into the control pendant which downloads all required machine control code to the robot.

When coupled with the robot origin (self-travelling) transfer unit, the robot uses ultrasonic sensors to determine its distance from the transverse frame, and infrared sensors to determine its distance from the longitudinal stiffeners. This feedback is compared to the CAM design data that defined the zone required to complete the welds. The robot then guides itself to the necessary location and begins the welding operation.

After the welds joining the skin plate to the first transverse bulkhead are completed, the robot completes the horizontal fillet welds joining the skin plate to the longitudinal frames. Because of the closeness of the longitudinal frames on the production application the team observed, the robot was unable to turn itself around to complete the welds at the other end of the egg-box structure. In this case, the crane was used to re-orient the robot to complete the welding.

Equipment

Power supply cables, shielding gas lines, and control cables are conveniently supplied by an overhead bridge crane. This crane also is used to move the robot from location to location within the sub-assembly.

The 1.2mm (.047 inch) diameter electrode is supplied in spools weighing approximately 3.6 kg (30 lbs.) One hundred percent carbon dioxide shielding gas is utilized. The electrode drive mechanism is of the single roll type with a wire straightener. To increase accessibility of the torch, the contact tip is extended approximately 19mm (.75 inch) from the gas cup.

Detailed specifications for the robot and origin transfer unit and a summary of the overall capabilities of the portable robot can be obtained in the complete technical evaluation report completed for SP-7.

Weld Tracking

Once positioned inside the structure, touch sensing is used to determine the actual location of the beginning and ends of each weld. Depending ***on the*** weld's accessibility, each start or stop location is found using either two or three search patterns. Prior to each search, approximately 51mm (2.0 inches) of electrode is extended from the contact tip to serve as the touch sensing surface. The wire straightener is used to reduce electrode deflection as it exits the contact tip and to increase the accuracy of the search.

The touch sensing system utilizes a 400 volt charge applied to the welding electrode and was observed sensing through primer-coated steel.

Through-the-arc seam tracking is used to track the joint after welding has started. This tracking method is only applied on longer length welds such as the horizontal fillet weld joining the longitudinal stiffeners to skin plate.

Mechanical contact sensors are utilized to prevent the robot from backing into the transverse bulkhead at the other end of the space.

Weld Sequence and Fillet Weld Sizes

The sequence of welding is established during the CAM movement simulation. This feature optimizes the order in which the welds are completed and reduces both the number of weld starts and stops and the overall distance the robot must travel.

Horizontal fillet welds are made using one pass with a weave. Vertical fillet welds are completed using two passes: a non-weaving, downhand weld is completed first to seal any gap that may exist in the fit-up; an uphand weld is then made using a weave to obtain the desired fillet weld size. When using the downhand technique, root gaps of up to 3mm (. 118 inch) can effectively be sealed. Root gaps in excess of 3mm (.118 inch) result in unacceptable weld quality.

The welds observed were approximately 8mm (-315 inch) vertical and horizontal fillet welds. As illustrated in Tables II and III below, weld schedules containing the welding parameters and weaving conditions for vertical and horizontal fillet welds have been developed.

Fillet size	Position	
	Flat	Vert.
4 mm (.157")	X	
5 mm (.197")	X	X
6 mm (.236")	X	X
7 mm (.276")	X	X
8 mm (.315")	X	X
9 mm (.354")	X	X
10 mm (.394")		X

Table II Fillet weld sizes using a single pass technique

Fillet Size	Number of Passes
9 mm (.354")	2
10 mm (.394")	2
11 mm (.433")	2
12 mm (.472")	3
13 mm (.512")	3
14 mm (.551")	3

Table III Fillet weld sizes using a multi-pass technique

The task of creating this database was simplified by limiting the welding to the Flux Cored Arc Welding (FCAW) process and a single electrode diameter.

Multiple pass welds of up to three passes are possible, however; through-the-arc seam tracking is limited to the first pass. Additional passes are simply offset from the initial pass. The robot operator was observed making slight adjustments to correct the stickout length during a vertical weldment.

Flux Core Electrode Development

In 1981, Ariake Works reviewed the welding processes and consumables they used to determine how they could increase production through process optimization. At that time, 60% of the welding was completed with the shielded metal arc welding process with semi-automatic gas metal arc welding comprising only 20% With the intent to substantially increase the application of automation and robotics, they pursued wide implementation of the FCAW process for several reasons.

- FCAW has the highest deposition rate for a given amperage.
- FCAW has the most consistent feedability of any consumable. This is an important requirement when using robotic seam tracking.
- With the introduction of a seamless FCAW consumable, extremely low diffusible hydrogen values are obtainable.

In a joint venture with Nippon Steel, Ariake Works developed a flux-cored electrode/carbon dioxide shielding gas combination specially formulated to weld through primer-coated surfaces. Work is continuing to improve the consumable to reduce smoke emissions.

Since Nippon Steel is the only producer of that special electrode, arrangements would have to be made either to purchase it from Nippon or request that a United States wire manufacturer develop an alternate electrode. The fillet weld size database may have to be adjusted if an alternate welding consumable or process is used.

Overall, weld quality was considered satisfactory. In some cases, however, the team observed welds that would have been questionable if inspected to U.S. regulatory standards.

Training

Due to the computer's virtual control of the welding process, skilled welders are not required for operating the robot. The strategy at Ariake Works is to train unskilled individuals to be robotic equipment operators and utilize skilled welders in other production areas.

Operator training consists of a one-week safety course, a one-week robot operations course, and one week of on-the-job training. At the end of the three weeks, the operator is fully capable of operating the robot in production.

Safety

As with any automated robotic system, safety to the human operator is a major concern. Many of the safety concerns have been reduced by limiting the power output of the robot and the origin transfer unit motors. The drive motors of the origin transfer unit have a power output of only 80 watts, thus posing minimal danger to the operator.

The robot operator has access to an emergency stop button located on the control pendant. Visual indication of the robot's operational status is provided by a system of four colored lights located on the transfer unit.

Safety issues pertaining to U.S. shipyards must be addressed to identify any requirements that would hinder the system's flexibility.

Maintenance

Ariake Works reported that the robots have been very durable and that only routine maintenance is required.

One robot has been in a production atmosphere since 1985 without any mechanical failure. One reason for this durability record may lie in the use of off-line programming coupled with the collision avoidance feature. The primary source of wear on a conventional teach-playback robotic system results from collisions between the robot and the work piece during programming.

Planned Applications

At the time of the visit to Ariake Works, a system comprised of one robot and a three-axis gantry was being developed for the next step of their subassembly stage. Initial implementation of the system will rely on simple CAM data generated on a PC. Depending on the progress of the application software, a gantry system utilizing four robots on one gantry will be integrated to allow the welding of more complex subassemblies. Tremendous flexibility will be gained when the robotic cell is linked to the CADCAM system allowing the welding of non-repetitious pieces. The CADCAM linkage will also allow one of the four robots to fail and have its work completed by the remaining three.

HITACHI ZOSEN ISSUES

Although the manufacturer **is** clearly interested in selling the robots to U.S. shipyards, two concerns were expressed.

1. The first concern is the issue of third party product liability in the event the robots were used in constructing a ship that failed for any reason.

2. The second concern is patent protection since there may already be patents or patent applications for similar equipment in the United States

PERSPECTIVE ON CONSTRUCTION PHILOSOPHY

While this report provides a technical evaluation of the portable welding robot, an appreciation of its development and how it fits into the overall construction philosophy of the shipyard is important.

There is a hidden danger in selectively "picking and choosing" individual elements of Japanese shipbuilding technology for use in U.S. shipyards. In the case of the portable welding robot, the danger lies in the all-too-typical approach of purchasing automated equipment (islands of automation) but not integrating that equipment with the design, process planning, and construction effort.

The portable welding robot should not be viewed as the end product of years of research and development, but rather as a significant pre-planned and achieved milestone in the design of long-range ship construction improvements. At Ariake Works, these improvements have focused on streamlining production processes and increasing the volume of work completed at the earliest stages of construction. The focus in welding has obviously been in developing assembly processes that complete as much welding indoors in the flat position as possible. Work is designed and grouped according to its shape and joint type to achieve the highest percentage of automatic welding. New ship designs incorporate and take advantage of the full range of robotic capabilities by considering weld size, length, position, space restrictions, etc.

Hitachi Zosen has a company-wide philosophy that strives to reduce costs while eliminating dirty, difficult and dangerous work. It was obvious that the portable welding robots were not developed as islands of automation, but rather as pre-conceived and integral elements of continuous process control and improvement.

Based on the authors' observations at Ariake Works and at SHI Oppama Works, there arc several characteristics of a successful application of robotic welding technology.

- Ship designs are developed with a strong consideration of welding processes and joining techniques.

- Ship designs that incorporate well-defined manufacturing processes and process controls including Just-In-Time techniques, detailed planning, and SPC where appropriate.

- An integrated working relationship exists between design, planning and manufacturing to facilitate process flow and facility utilization.

- All work is planned and standardized to make maximum use of the work force and minimize downtime.

- Long range plans for construction process improvements are developed including the expanded use of CAD/CAM systems; standard designs that facilitate manufacturing automation such as robotic welding, cutting, plate marking, painting; and the advancement of three dimensional accuracy control.

- A strong emphasis on management involvement and commitment to continuous process improvement.

- Automation and related technology applications are simple and not "over-kill" for the particular application;

SUMMARY

Based on observations of the portable welding robots in a production environment and the satisfactory results of the technical review, the portable welding robots offer excellent potential to reduce structural welding costs and increase overall productivity. The relative ease of programming provides a wide variety of potential applications for both commercial and naval shipbuilding in the United States.

The following summarizes the issues that a U. S. shipyard will have to resolve to ensure successful implementation of the portable welding robots.

- Progress in resolving the manufacturer's third person product liability and patent protection rights will have to be monitored.

- Specific design details will have to be reviewed to determine if changes in the robot software are required.

- Metric dimensioning will have to be provided to input the required geometric data.

- The availability of the flux-cored weld wire from Nippon Steel will have to be determined. An alternate source or consumable may require modifications to the weld schedule database.

- Safety issues related to a mobile robot must be addressed.

- Procedure qualifications permitting downhand welding will need to be developed for naval products.
- Process controls will be required for fabrication and fit-up to meet the tolerances of the robot.

- Overall weld quality, particularly vertical welds, will have to be assessed in terms of U.S. regulatory requirements.

- The effectiveness of the touch sensing system on paint and mill scale will have to be determined.

The authors believe the above issues can be successfully resolved, and have recommended that the NSRP fund the purchase of at least one Hitachi Zosen portable welding robot with the robot origin transfer unit for further evaluation by a U.S. shipyard.

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Copies of the SP-7 final report “Evaluation of the Hitiachi Zosen Portable Welding Robot” can be obtained by contacting:

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Cutting of Structural Materials Utilizing High Powered CO2 Laser

No. 8A-2

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ABSTRACT

The method most commonly used for cutting thick 1.90 cm (.75 inch) steel material where edge quality is not of a concern is flame cutting which utilizes an oxyacetylene torch. It provides the energy to heat the steel beyond its melting point and gas pressure forces the molten material (dross) through the thickness of the material. Cutting torches typically remove a kerf of approximately .63 cm (.25 inch) to 1.27 cm (.5 inch). Gas cutting is noisy, generates large quantities of smoke into the environment and forms large pieces of dross which can travel up to 3.04m (10 ft) and cause fires. Typically, when flame cutting shipboard, a fire watch is required. Also, if any type of flammable material exists on the opposite side of the cut, it must be removed for several inches on both sides of the cut line to preclude backside combustion. A search for a better method of cutting thick steel sections. including those with coating materials attached, centered around a high powered CO_2 laser. The CO_2 laser had successfully demonstrated its ability to weld heavy sections of steel with 100% penetration from one side and create a very narrow heat affected zone (HAZ). It was decided to expand this welding process to cutting by introducing high pressure assist gases. The gas would force the molten puddle created by the focused lsoer beam. through the steel material, thereby, creating a cut through the material as opposed to allowing the molten material to fuse back together without the assist gases (creating a welded Joint). It was decided to take advantage of the laser's high powered density to cut/vaporize non-metallic material attached to the steel plate. Also, there was interest in the effects of a laser beam on asbestos material.

LIST OF ACRONYMS

MPa	Mega Pascals
HAZ	Heat Affected Zone
ARL	Applied Research Lab
ICP	Inductively Coupled Plasma Spectrometry
PCB	Polychlorinated Biphenyl
HY	High Yield
HTS	High Tensile Steel
O_2	Oxygen
N_2	Nitrogen
CPM	Centimeter Per Minute
CPS	Centimeter Per Second
CUNI	Copper Nickel
ft	foot
UTIL	United Technologies Industrial Lasers
YAG	Yttrium Aluminum Garnet
mm	millimeter
cm	centimeter
m	meter
in^5	square inch

INTRODUCTION

In order to determine the cutting feasibility of a high powered CO_2 laser through thick steel and non-metallic coatings, a test program was developed to collect data. Mare Island Naval shipyard had been the designated laser welding center of excellence for the Navy. Practical experience existed there for the laser applications. Under funding from the program sponsor, Naval Sea Systems Command, the shipyard entered into a contract with the Applied Research Lab (ARL). Pennsylvania State University which previously performed laser materials processing developing with lasers from 400 watts to 25 Kw. The combined effort also included United Technologies Industrial Lasers (UTIL) who had expertise in gas nozzle design and manufacture of high power (greater than 6 Kw) CO_r lasers. The test program was to evaluate laser cutting parameters such as travel speed. power range. nozzle configurations, gas pressure and gas composition. The cutting was performed inside a chamber so that environmental data could be collected and analyzed. Also. there was interest In temperature gradients at various distances from the cut area. The shipyard was to provide both coated and uncoated material samples of various compositions and thicknesses.

TEST PROGRAM

Test Samples

The shipyard manufactured a series of 30.48 cm (1 ft) by 60.96 cm (2 ft) sample flat plates for testing of various thicknesses and materials as follows.

1. 30.48 cm (12 inches) x 60.96 cm (24 inches) x 1.0 cm (.375 inch) thick HTS Plate (MIL-S-22698 Grade DH) with rubber sound damping on both sides, final painted with approximately .30 mm (12 mils) of epoxy paint. Figure 1 denotes the thickness of the layered materials.

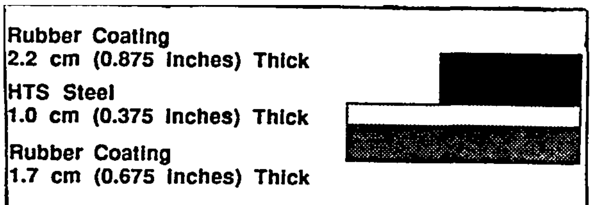


Fig. 1 Material Test Sample

2. 30.48 (12 inches) x 60.96 cm (24 inches) x 3.2 cm (1.25 inches) thick HY-80 plate (MIL-S-16216) with rubber sound damping on one side, foam insulation on opposite side and painted with approximately .30 mm (12 mils) of epoxy paint. Figure 2 denotes the thickness of the layered materials.

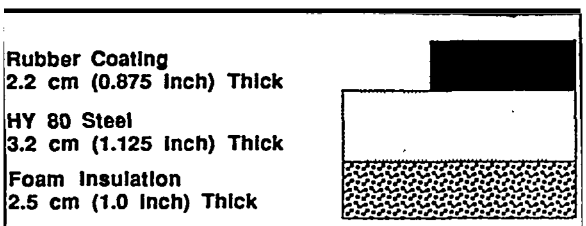


Fig. 2 Material Test Sample

3. 30.48 (12 inches) x 60.96 cm (24 inches) x 5.1 cm (2 inches) thick HY-80 plate (MIL-S-16216) with rubber sound damping on one side, foam insulation on opposite and painted with approximately .30 mm (12 mils) of epoxy paint. Figure 3 denotes the thickness of the layered materials.

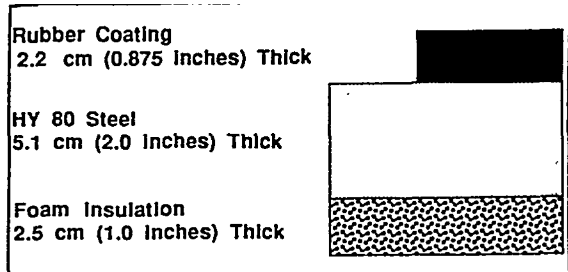


Fig. 3 Material Test Sample

Other HY-80 steel samples for parameter testing were provided in thicknesses from 1.90 cm (.75 inch) to 5.40 cm (2.12 inches). In addition, a 5.08 cm (2 inches) diameter pipe sample coated with 5.08 cm (2 inches) of asbestos was provided and a 6.35 cm (2.50 inches) diameter section of shielded 400 ampere power cable.

Laser Selection

The original development work for the CO_2 laser welding was performed at the ARL Penn State's Research Facility utilizing a 14 Kw CO_2 laser. Laser processing, developed at ARL has been transferred for Navy and private application to Stardyne, Inc., a high powered laser job shop in Johnstown, Pennsylvania. It was in Johnstown where the actual laser cutting testing took place. The CO_3 laser development work centered around the successful welding of medium to heavy steel plate sections. It was this existing welding technology coupled with the inherent ability of the CO_3 laser to produce constant high power 10^{10} watts/cm^3 (10' w watts/in^3) over long periods of time that provided the basis for its selection for this program. It also provided an off-the-shelf power unit capable of making the transition from the lab to field application in shipyards and other industrial facilities.

Testing Work Station

The actual testing was accomplished at A work station approximately 45.72 m (150 feet) from the 25 Kw Co_3 laser location. The laser had eight mirrors from the power source through the various bends in its 45.72 m (150 feet) transmitting tube to the work station. The power loss from the laser's aero-dynamic window to the work station was approximately 12% (1.5% at each mirror). The power levels quoted in this report are the power levels at the laser source. The work station was a 10.97m (36 feet) long sidebeam gantry with focusing optics mounted on the sidebeam carriage. The carriage had a top speed of 4.23 cps (100 inches/minute). A cutting chamber was mounted directly under the laser focus head. The cutting chamber was stationary and supported the sample to be cut. It also featured a sliding cover which moved with the laser beam over the surface area to be cut. The chamber also had a viewing port and exhaust duct to collect environmental samples. The laser focusing optics had a focal length of 44.45 cm (17.5 inches) (F Number=7.6). The laser beam entered the optics box with approximately 7.62 cm (3 inches) diameter coherent light beam and was then focused down to a spot size of .13 cm (.050 inches) in diameter (Figures 4, 5A & 5B).

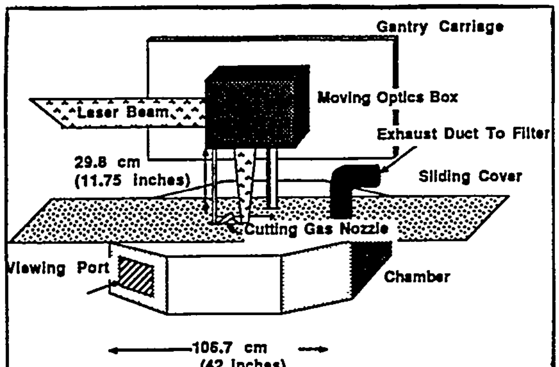


Fig. 4 Diagram of Cutting Chamber Arrangement

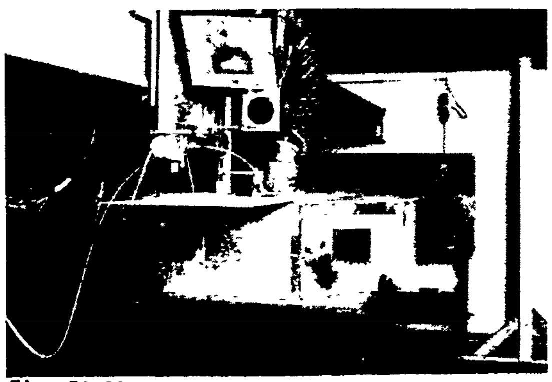


Fig. 5A Side View of Cutting Chamber

Fig. 5B End View of Cutting Chamber

Cutting Nozzles

Three stainless steel hypo tube nozzles were used, 51 mm (.020 Inch), 1.14 mm (.045 inch), and 1.57 mm (.062 inches) in diameter. The nozzle used for most of the testing was a 1.57 mm (.062 inch) diameter hypo tube. The tube was orientated 25 degrees from the vertical axis and positioned to aim the high pressure assist gas at the laser beam Interaction/focus point. (Figure 6 and Figure 7).

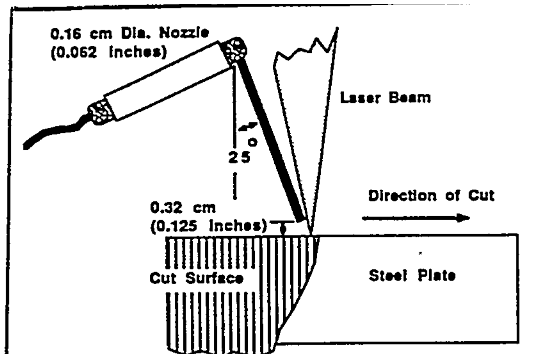


Fig. 6 Cutting Nozzle Orientation with Respect to Laser Beam Interaction Point

Fig. 7 Side View of Cutting Gas Nozzle

High Pressure Assist Gases

With the 25 Kw available energy source, sufficient power was available to accomplish cuts through thick sections. The next most important consideration affecting laser cutting is the gas jet nozzle design and the type and pressure of assist gases. For this cutting program, three types of assist gases were tried separately, pure oxygen (O_2), air, and nitrogen (N_2). Oxygen might directly contribute to oxidation and cutting speed, yet, in other applications where the flammability of backside materials was of primary concern, an inert assist gas such as N_2 might prove more valuable. The gases were stored in standard 'K' size cylinders and were regulated to a maximum pressure of 5.50 MPa (800 psig). A hose connected the cylinders to the gas nozzle via the regulator.

Environmental Procedure

The shipyard environmental

technicians collected airborne samples from selected cuts both inside and outside the chamber utilizing 2.54 cm (1 inch) diameter cassettes and low volume pumps. A syringe was also used to collect air samples inside the chamber. In addition, the exhaust gases from the chamber were collected via a 283 liters/sec (600 cubic foot per minute) pump. across a .3 Micron (.0012 inches) HEPA filter. The filter was changed during the cutting process and weighed before and after its use to determine the amount of material trapped. The filters were then sent to an independent laboratory to determine the existence amount of a possible 24 elements trapped in the filters. The method used for analysis was inductively coupled plasma (ICP) spectrometry.

Thermocouple Procedure

The temperature gradient generated by the CO_2 laser in the material during the cutting operation was of extreme interest. This was especially true for critical heat zones for a future test program involving laser cutting through steel layered with polychlorinated biphenyl (PCB) impregnated materials. Accordingly, thermocouples were mounted on the top surface (same side as laser beam) of selected steel plates in .63 cm (.25 inch) increments to a distance of 2.54 cm (1 inch) from the centerline of the laser cut (i.e..., .63 cm (.25 inch), 1.27 cm (.50 inch), 1.90 cm (.75 inch), and 2.54 cm (1 inch) (Figure 8). Results were then platted as time versus temperature.

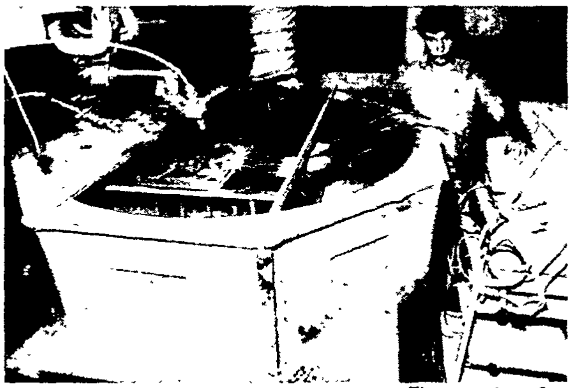


Fig. 8 Top view of Sample Plate w/Thermo Couples

Cutting Parameters

The primary parameters varied during the cutting tests were as follows.

1. Laser Power (5 Kw to 22 Kw).

2. Carriage Speed .21 cps (5 ipm) to 2.96 cps (70 ipm).

3. Gas composition (O_2. Air, N_2).

4. Gas pressure .69 MPa (100 psi) to 4.83 MPa (700 psi).

5. Nozzle orientation.

The parameter setting was first accomplished on uncoated steel plate of 1.90 cm (.75 inch), 3.17 cm (1.25 inches) and 5.40 cm (2.12 inches) thicknesses prior to cutting the plates with coatings. Numerous short cuts and partial cuts were made to establish which parameters were predominant in controlling cutting speed and penetration, especially in the thicker plate 3.17 cm (1.25 inches) & 5.40 cm (2.125 inches).

RESULTS OF TEST PROGRAM

Uncoated 1.90 cm (.75 inch) Thick HY-80 Plate.

Laser cuts were performed with air, O_2 and N_2 as assist gases and 2.76 MPa (400 psig) and 4.14 MPa (600 psig) pressure. The O_2 resulted in the highest cutting speed (Figure 9) at a tradeoff of having the highest surface temperature profile. (See Figure 10 for air and Figure 11 for $O_2$1.

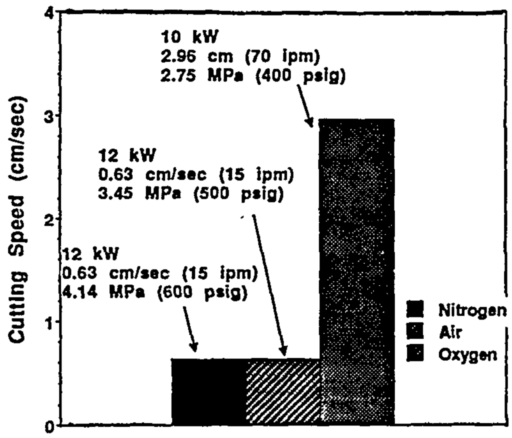


Fig 9. Cutting Gas Composition

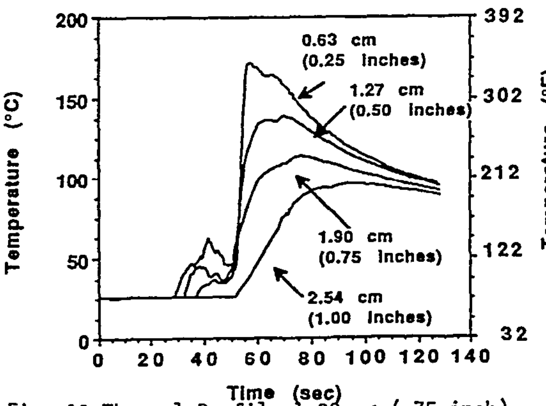


Fig. 10 Thermal Profile 1.90 cm (.75 inch) Plate. Cutting Parameters were 12Kw, 4.14 MPa (600 psig) air

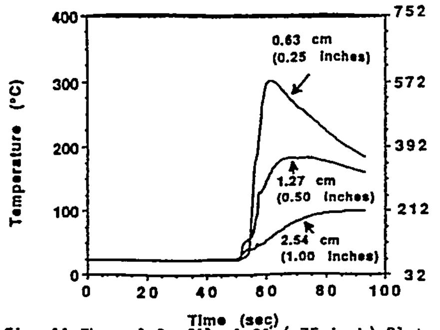


Fig. 11 Thermal Profile 1.90 (.75 inch) Plate. Cutting Parameters were 10Kw, 2.76 MPa, (400 psig), O_2

The higher temperature utilizing O_2 as an assist gas is directly related to an exothermic reaction that occurs between the o_a and the steel. This reaction adds additional heat to the process as witnessed by additional puddling occurring on the cut surface. Since air is 24% oxygen, the same exothermic phenomenon also occurs using air, but not as extensive. When N_2 was used as an assist gas, the striations across the cut surface were more uniform due to the lack of oxidation. Figures 12A, 12B, 13A, 13B, 14A and 14B illustrate the differences in cutting among the assist gases. Also, acid etching of the cross sections of the cut surface revealed greater width for the O_2 HAZ Zone which explains the higher thermal profile for o_2. The slag deposits shown (Figures 12A, 12B, 13A, 13B, 14A & 14B) on the bottom of all three cuts were easily removed from the N_2 sample by tapping lightly with a hammer. The slag removal became increasingly more difficult with the air and O_2 samples. The kerf for the O_2 cut was .63 cm (.250 inch) as opposed to .76 mm (.030 inch) for N_2. The temperature advantage of utilizing N_2 as an assist gas was explored further when cutting coated materials.

Fig. 12_A_Laser Cut Curface (Air)

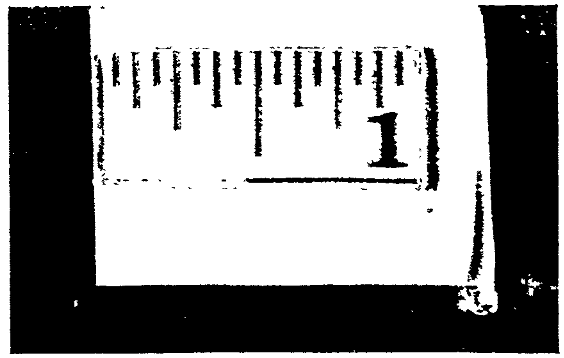


Fig. 12B Laser Cut Cross Section (Air)

Fig. 13A Laser Cut Surface (o_2)

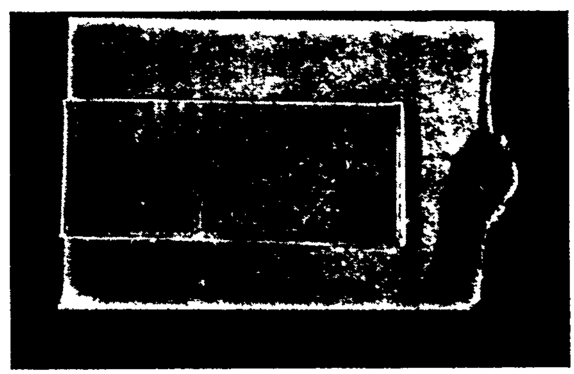


Fig. 13B Laser Cut Cross Section (o_2)

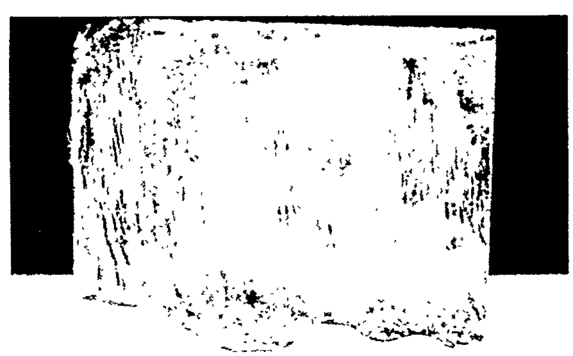
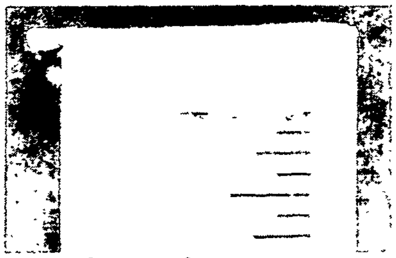


Fig_. 14A Laser Cut Surface (N_2)



Fiq. 14B Laser Cut Cross Section

Uncoated 5.40 cm (2.12 inches) Thick HY-80 Steel Plate.

Successful cuts of this heavy material were achieved at 21 cps (5 lprn) utilizing 4.14 MPa (600 psig) air as the assist gas (Figure 15). Thermocouple data was collected for this sample and plotted (Figure 16).

Fig.15 5.40cm(2.12in)thick, .76mm (.030in) kerf

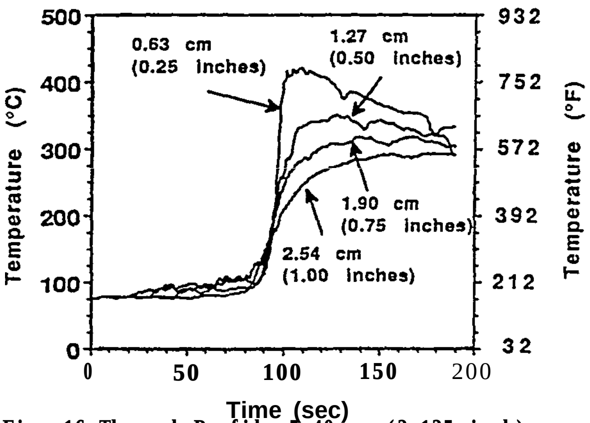


Fig. 16 Thermal Profile 5.40 cm (2.125 inch) Plate. Cutting Parameters were 15kw, 4.14 MPa (600 psig), air, .21 cps (5 ipm).

Coated .95 cm (.375 inch) Thick HTS Steel Plate With 1.71 cm (.675 inch) Rubber Coating on Bottomside.

Successful cuts were achieved with both air and N_2 used as cutting gases with the same power (12 Kw) and speed 1.69 cps (40 ipm). The observable difference in the cuts was the surface of the rubber coating. With air, a more oxidizing gas, the surface of the laser cut was rough, while for the N_2 the surface was smooth (Figures 17 & 18).

Higher cutting speeds were unsuccessfully attempted with both cutting gases. Smoke was generated With the use of N_2 and air.

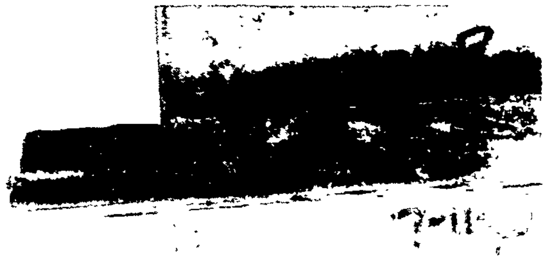


Fig. 17 Cut Surface Rubber & Steel)(Air)

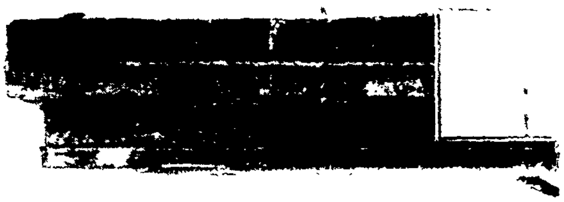


Fig. 18 Cut Surface Rubber & Steel (N_2)

Coated .95 cm (.375 inch) Thick HTS Steel Plate With Rubber Coatings On Both Sides.

The laser cuts were attempted using O_2, N_2, and air separately as the laser cutting gases. Various parameter settings were used but no successful complete cuts through all materials were made (Figure 19). The inclined nozzle design could be either aimed at the rubber surface where the laser beam was focused or at the steel surface where the laser beam was focused. The only test result was the cutting of the top rubber coating only at 10 Kw, 2.40 MPa (350 psi) air and 2.96 cps (70 ipm). No attempt was made to laser cut the exposed steel plate because of the nozzle configuration. Also, heavy **smoke** and flames were generated during cutting the rubber utilizing O_2. while only smoke was generated utilizing N_2 and air (less smoke with N_2). It was at this point in the test program that the need for a coaxial gas nozzle was realized. A coaxial design would be pursued for future cutting of layered materials.

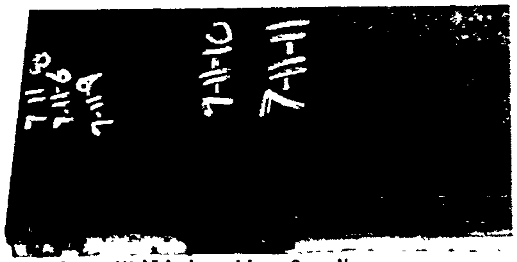


Fig. 19 Cuts Utilizing Air, O_2, N_2

Coated 2.86 cm (1.25 inches) Thick HY-80 Steel Plate With Foam Insulation on Backside.

Laser cuts through the combination of 1 l/4 HY-80 plate with foam insulation **were** accomplished utilizing O_2, air and N_2 as assist gases.

1. When O_2 was used as the assist gas at 3.45 MPa (500 psig and laser power at 20 Kw, the steel and insulation combination was cut at 1.69 cps (40 ipm). The typical exothermic reaction occurred with the steel cut surface. The backside insulation was ignited by the dross as accelerated by the

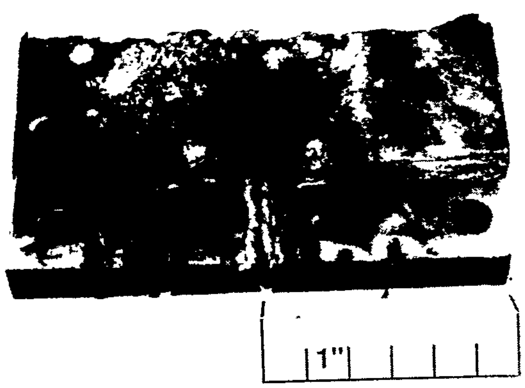


Fig. **20 Bottom View of** Cut & InsulatiOn(O_2)

pure O_2. The insulation burned for a 6.35 cm (2.50 inches) width centered on the laser cut line (see Figure 20, bottom view). The kerf width was approximately **.63** cm (.250 inch). Backside ignition of materials would be unacceptable in a field application and would require insulation removal prior to laser cutting.

2. When air (24% O_2) was used as assist gas at 4.83 MPa (700 psig) and the laser power at **22** Kw, the combination of steel plate and insulation was cut at .42 cps (20 ipm). The backside insulation burned but not as severely as with pure O_2 assist gas. The backside insulation charred similar to that shown in Figure 21A,B. The ignition of insulation would also require removal prior to laser cutting.

Fig. 21A Bottom View of Cut & Insulations (Air)

Fig. **21B** Top View (Typical) of Start of Cut. Note Width of Cut in Relation to Coin (Quarter). Also shown is Hypo Tube Gas Nozzle.

3. When N_2 was used as assist gas at 4.83 MPa

(700 psig) and laser power at 22 Kw the plate and insulation combination was cut at .42 c p s (10 ipm. There was no backside ignition and the insulation was vaporized (not burned) for a width of 3.81 cm (1.5 inch) centered on the laser cut. The cut was very smooth and the paint on the nearside of the laser cut was affected for a width of only .32 cm (.125 inch) (see Figures 22A & 22B).

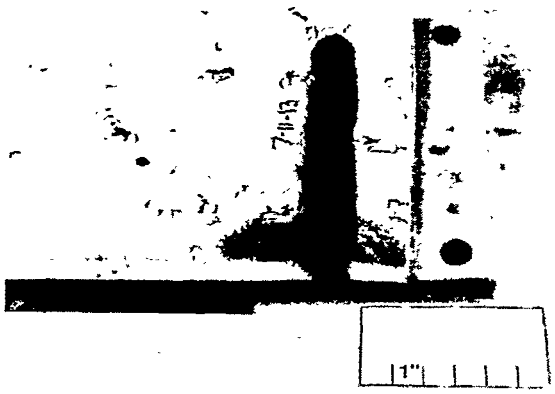


Fig. 22A Bottom View of Cut & Insulation (N_2)

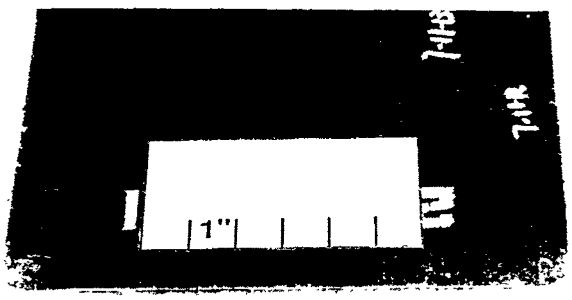


Fig. 22B Top View of Cut & Burned Paint

This cut was the most desirable from a field application standpoint as backside insulation would not have to be removed in way of the cut as would be required in conventional flame cutting techniques. Not having to remove backside interferences and insulation can be a great cost savings, especially when considering piping, wireways and equipment that must be removed in order to obtain access to the backside area. Laser cutting utilizing N_2 as assist gas has even further application and needs more testing to obtain environmental data on cutting steel plates with PCB contaminated material on the opposite side of the cut. A comparison of the cutting speeds of all three assist gases is shown in Figure 23.

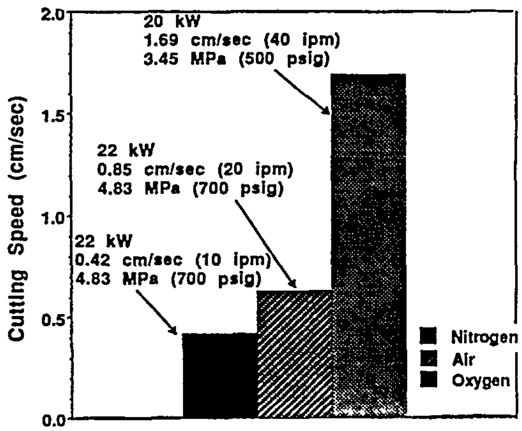


Fig. 23 Cutting Gas Composition

<u>Coated HY-80 Steel Plate 5.08 cm (2 inches) Thick With Foam Insulation On Backside.</u>

Successful laser cuts were made from the steel side through the combination of steel and insulation. Air was used as the assist gas at 4.83 cm (700 psig) and laser power at 22 Kw. The cutting speed obtained was .34 cps (8 ipm). Some opposite side combustion did occur of the insulation (see Figure 24, bottom view). Also, examination of the striations on the cut surface of Figure 24 shows the molten metal started in a vertical direction but changed direction due to the reduction of the gas flow momentum with increased depth of the cut. This indicates that more gas throughput is needed with the thicker materials. This condition also existed for the uncoated 5.40 cm (2 inches) thick steel plate.

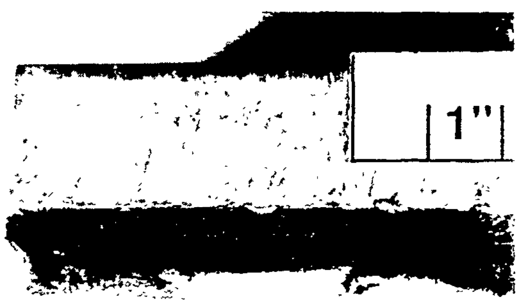


Fig. 24 Cut View of Striations & Insulation

Shielded 400 Ampere Power Cable, 6.35 cm (2.50 inches) In Diameter, Reinforced Wire Braiding And Three Internal Copper Cables 1.90 cm (.75 Inches) In Diameter.

A single pass of the laser beam at 20 Kw power level .85 cps (20 ipm), and O_2 at 1.38 MPa (200 psig) produced a cut through approximately 3/5 of the cable (see Figure 25). This cable is usually cut with a mechanical saw with great effort. The CO_2 laser illustrates that with some development work, this could be a very practical application.

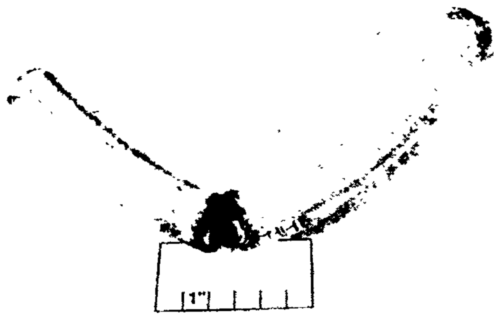


Fig. 25 Laser Cut 400 Ampere Power Cable

5.08 cm (2 inches) Diameter Copper Nickel (CUNI) Pipe With 5.08 cm (2 inches) Of Asbestos Insulation All Around (see Figure 7).

A single pass of the laser beam at 10 Kw power level, .63 cps (15 ipm) and 0_2 at .69 MPa (100 psig) produced a 2.54 cm (1 inch) deep cut into the asbestos. The laser beam melted and cauterized the asbestos into a black silicone glass structure. (Figure 26). Environmental samples taken during the cutting operation indicated no airborne fibers were generated during the cutting. This application of laser cutting has far reaching potential and cost savings for adaptation to a shipboard or commercial system to cut asbestos covered piping with little or no hazard to the environment or workers and little protective clothing required to perform the work.

Fig. 26 Laser Cut Into Asbestos Insulation

CONCLUSION

The cutting tests performed (sec. Table 1) demonstrated all materials provided could be cut The use of an oxidizing gas such as O_2 or air (24% 0_2) increases cutting speed but also significantly increases temperature adjacent to the cut. On coated materials , O_2 as air assist gas causes ignition of the backside coating, however, N_2 as an inert assist gas neutralizes the combustion effect. The type and orientation of the nozzle is critical for successful cutting. A coaxial nozzle would be much more effective in cutting layered materials and thick steel sections (greater than 5.08 cm (2 inches)). Assist gas pressure also has a great effect on cutting speed. As our 'K' size cylinders lost maximum pressure due to volume usage, cutting speeds were reduced. Connecting several cylinders in parallel would help minimize this pressure loss. Aiming the gas nozzle at a laser focus spot . 13 cm (.050 inch) on the surface of the material to be cut was also difficult. Again, a coaxial design would solve the aiming problems plus shield the laser beam from organic smoke which decouples the beam. All environmental data taken was within allowable specifications. The asbestos cutting was a pleasant surprise as was with the heavy power cable. The 25 Kw co_2 laser certainly demonstrated sufficient power to cut all thicknesses provided especially when the proper gas pressure and gas momentum was achieved.

Future Applications

The use of N_2 assist gas at 4.83 MPa (700 psig) with the 25 Kw CO_2 laser proved a winning combination With the design and manufacture of a beam delivery system. this system could be used to cut heavy sections In shipyards and other heavy industrial activities. Using this combination. preliminary tests indicate Insulation may be left in place realrzing a large cost savings as opposed in having to remove interferences plus insulation. With the high temperature of the laser beam (greater than 5000 degrees Fahrenheit) and high power density 10^{10} watts/cm^2 (10^9watts/in^2). the ability of the laser to incinerate/vaporize hazardous materials such as PCB's certainly warrants further testing. If the backside material had to be removed, with the low temperature .63 cm (l/4 inch) away from the centerline of the cut and steep thermal gradient. the amount of material required to be removed is far less (could be less than 2.54 cm (1 inch) than conventional flame cutting in a PCB environment. A fire watch would still be recommended for laser cutting.

The asbestos cutting has potential to be developed into a delivery system (perhaps a Yttrium Aluminum Garnet (YAG) Laser/Fiber Optics combination) that could be used to cut asbestos coated piping with little effect on the environment and worker, again another potential large cost savings over conventional methods.

Materials (Thickness; Condition)	Power (kW)	Speed cm/sec (ipm)	Gas Comp.	Gas Pressure MPa (psig)
1.9-5.4 cm (0.75-2.13 inches); Bare & Coated Plates	10-22 kW	0.64-2.96 cm/sec (15-70 ipm)	Nitrogen Air Oxygen	2.8-4.8 MPa (400-700 psig)

Table I. Summary of Laser Test Parameters Performed

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Optimizing Maintenance: Models with Applications to Marine Industry

No. 8B-l

Dr. Bahadir Inozu, Associate Member, University of New Orleans, and **Dr. Nejat Karabakal,** Visitor, University of Michigan

ABSTRACT

Past and current replacement models with applications to the marine industry for determining the optimum maintanance stratefy are discussed. A new approach to multi-item replacement under budget constraints is presented. This approach considers all replacement decisions of an entire ship fleet. (or all component replacements of a single ship) simultaneously. A Lagrangian methodology for the replacement problem is also described.

LIST OF ACRONYMS

ARP	Age Replacement Policy
IFR	Increasing Failure Rate
MAM	Multiplier Adjustment Method
MARP	Modified Age Replacement Policy
MTTF	Mean time To Failure
TTR	Time To Repair

INTRODUCTION

With rcduced manning levels and the ever increasing competition, ship maintenance has become one of the major problems in marine industry. Optimization of maintenance and replacement is very challenging due to highly restrictive and harsh operating conditions of ships. Moreover, these operating conditions, in many cases, are only known with a high level of uncertainty which makes the optimization problem evenmore complicated. However, lowering extremely high downtime costs by reducing emergency repairs caused by insufficient maintenance practices is always desired. In the mean time, there is a delicate tradeoff between the cost of overmaintenance and the cost of avoided maintenance in keeping the shipping company competitive. Hence, the maintenance and replacement problem in the marine industry has conflicting multiple objectives, such as maximizationing reliability and safety and minimizing costs simultenaously. As a result, optimization of marine maintenance becomes a very difficult and complicated problem (19,20).

Traditionally, many ship operators have been trying to solve maintenance optimization problem based on "experience" and "judgement" of managers basically using conservative manufacture's recommendations and rules of thumb (1,23). However using scientific techniques as opposed to ad hoc methods in maintenance optimization has been proved to be very rewarding in other industries (18). Naturally, there is a growing interest for just-in-time for maintenance and replacement management in the marine industry. During the last decade, artificial intelligence methods have been successfully applied to shipboard monitoring, container stowage planning (16,42), spare parts inventory management(34), and marine diesel engine fault diagnosis (29.30,35). In the mean time, the speed, storage capability and flexibility of computers have been tremendously improved during the last decade. At the same time. the use of computerized database systems for maintenance records has been growing. Hence, sophisticated maintenance models will increasingly become applicable as more data and computing capability are available.

In this paper, first past and current maintenance and replacement with applications in the marine industry are discussed. Then, a new approach to group replacement under budget constraints is presented. This approach considers all replacement decisions of an entire ship fleet (or all component replacements for a single ship) simultaneously. A Lagrangian methodology for the replacement problem is also presented.

MODELS

Marine maintenance and replacement optimization has conflicting multiple objectives. Simultaneous optimization of these objectives can be achived by utilizing interactive techniques which involve the decision maker throughout the optimization process. A comprehensive list. of papers (1965-1988) dealing with interactive multiple objective decision making is provided by Aksoy (2).

Maintenance and replacement models can be classified based on information availability, system type as single or multi-unit, time-event/action relationship relationship, state-event/action relationship, model types, optimality criterion, solution methods, planning time horizon. Pierskalla and Voelker (43) surveyed maintenance models developed until 1976. Then, Sherif and smith(45) classified deterministic and stochastic models in their 1981 survey. The authors used two distinct categorics in their classification: preventive and prepareduess models with and without complete information. Valdez-Florez and Feldman (48) presented models for single-unit. Systems. Very recently, Cho and parlar (14) surveyed literature 0n Optimal maintenance models for multi-unit systems.

We Start this survey with a discussion of Some basic characteristics of past and cur rent. optimal maintenance/replacement models based on planning time horizon, system State transition and maintenance criteria. We then briefly discuss individual replacement papers of potential interest to marine industry.

Basic Characteristics

Planning time horizon. Replacement problems may have a finite, infinite or random time horizon. Finite horizon problems occur when a SyStem opertores until a known termination time. For finite time horizon problems, the objective is finding the policy that will maximize the expected the total revenue (or minimize expected total cost) generated by the system. One solution approach for the finite horizon problem is referred to as value iteration (27). The objective is to maximize average revenue per unit time (which is referred t0 as "gain") when no discounting is used, or to maximize the expected present value of future rewards in the case of discounting. To meet either objective, the policy iteration method is used (27).

System state transition. To model system state transition behavior, many existing replacement models assume a Markov process (4,17,24). Assuming exponential lifetimes (and hence constant hazard rates) for system components, these models ignore the effects of aging. However, the hazard rate of a mechanical componet allmost always varies with time. Hence the Markovan assumption is not very realistic for many mechanical components. To iilfhk the effects of break-in failures and/or aging, many authors (7,28) model the system behavior as a semi-Markov process (embedded Markov process).

Maintenance criteria. When a failure occurs, a decision maker usually has the "repair," "replace" and “do nothing" options. Mauy existing maintenance models assume that, When a failure occurs, it. is best to replace thc failed item, completely ignoring repair as another option (5,8,12,28,46), whereas some models also consider repair as another option (49,37). The time to repair and the time to replace are also considered in Some models: While many models assume instantencous repair and replacement times (10,36,33), others consider rcpair and replacement times as random variables.

There are many replacement policies, such as the Age Replacement Policy (ARP) (21 ,10,50,33), the Modified Age Replacement Policy (MARP) for intermittently used sys- tcms (36,7,8), replacement after N repairs (or N uses), and replacement based on failure risk.

Repairs are also classified as minimal and complete repairs. A minimal repair returns the failed item to its functioning condition just prior to failure, whereas complete repair brings the failed item to the "as good as new" condition (9,45). The degree of repair is also integrated into some models (33).

Selected Models

In the following, Some selected papers on system maintenance and replacement relevant to marine maintenance are discussed. The characteristics of models in terms of time horizon, system state transition and mainenance criteria are examined.

Kao (28) assumed that the system may be' in one of i states (i=0,1,2,...,L), where state 0 corresponds to a “brand-new” System, state L corresponds to a failed system and others (i = 1, 2, . . . , L - 1) correspond to degraded (imperfect performance) states. He also assumed that there is only type Of replacement, and treated the system as one component. He proposed three replacement. models, using the policy iteration method to minimize expected costs per unit time, under three rules; replacement based on system state, replacement. based on system age and replacement based on both system state and be age.

Mine et al. (36) considered optimal preventive replacement for intermittently used systems under two different criteria: 1) replacement after N USes, assuming time durations of uses to be random variables; and 2) replacement when Cumulative operating age reaches a specific. time, T, before failure. Their objective was to find the values of N and T that minimize the mean cost rate over an infinite time horizon..

Berg (8) also studied preventive replacement policies for intermittently used units. He considered a modified age-replacement policy (MARP) under which the unit is replaced preventively When its age exceeds a critical Operational age. Provided that replacement times coincide with no-demand periods. Otherwise, preventive replacement is delayed until the end of the current. demand period. His objective was to minimize the probability that the unit is down when it. is demanded.

Thomas (47) developed a replacement model assuming that both the system (as a framework, like the body of a car) and its components (like tires, engine etc,) are inde-- pendent of each other and can be replaced upon failure with many replacement alternatives. He ignored preventive maintenance completely. Repairs were not. allowed.

WellS (49) examined a System over a finite random time horizon with non-zero repair and replacement times. To select whether to repair, replace or ignore a failed component, he introduced an optimal maintenance policy (which uses policy improvement. and linear programming techniques). He assumed that a component will be repaired for its first. N failures before ultimate replacement. He also assumed that duration of the System mission (life time etc.) is a ramdom variable.

Most existing existing replacement models are restricted to single component models which can not be applied to multi-component SYStems in an arbitrary setting, since some policies, as control limit policies, may not. be optimal for multi-component systems. Most. models developed` for multi-component systems assume that the components are stochastically independent of each other, with increasing failure rate (IFR) lifetime distributions.

özekici (-10) studied the economic dependence between system components. He particularly focused on optimal replacement policies for functioning components in the presence of failed components. He discussed the stochastic and economic dependencies among system components, and formulated a simple path analysis of the reliability system using Markov decision theory.

Boland and proschan (11,12). considered a system where replacements and overhauls were made at fixed multiples of some predetermined time, T. When a failure occured, a minimal repair was performed. They calculated the period that minimized the total expected cost of repair and replacement cal-another period that minimized the total expected cost per unit time over an infinite time horizon.

Zuckerman (51) developed a maintenance strategy to optimize long-run average cost and total expected discounted cost over an infinite horizon. The system was subjected to shocks causing a random amount of damage to the system components. The system failed when failed when the accumulated damage exceeded a fixed threshold. For the optimal maintenance policy, the diffusion approximation model was Zuckermann showed that the optimal maintenance expenditure rate is monotonically increasing in the cumnlative damage level.

Assaf and Shanthikumar (4) developed optimal maintenance policies for a system of N machines. Exponential lifetimes were assumed, with the same Mean Time to Failure (MTTF) for each machine. They formulated the total repair cost as the sum of a constant which reflected the overhead cost of repair and a cost of repair per machine which changed linearly with the number of failed machines. Instantancous repairs were assumed. They also considered a second type of cost. Which incurred due to machine failures and was the same for all machines proportional to Time to Repair (TTR). They minimized the expected cost per unit time over an infinite horizon, and showed that an optimal policy is either never to to repair or to repair all failed machines as soon as their number exceeds a certain threshold. They also assumed that the number of failed machines is known at every instant.

Sethi and Chand (44) focused on planning horizon results for the replacement problem. They developed three machine replacement models under an improving technological environment over time, aiming at cost. ered minimization, profit maximization, and cost minimization with stochastic failures, respectively.

Oakford, Lohmann, and Salazar (39) considered technological improvement. Their model permitted implemention of technological improvement in a flexible manner without reformulating the dynamic program for each replacement problem.

Derman and smith (15) considered a system which should operate for T units of time, where T was a random variable with a known distribution function F. It. was assumed that , when a vital component failed, it had to be replaced with a new component. For each component there were n possible types of replacements. The objective was to choose the type that minimized the expected total cost. of providing an operative component for the entire life of the system. They generalized the results of earlier work, where lifetimes were assumed to be exponentially distributed, enabling them to treat components with increasing failure rates.

Bryant and Murphy (13) considered systems subject to both repairable and non-repairable failures. They considered a system which was subject to three modes of failure. Type I failures were catastrophic ones, terminating the system's life. Type II failures were the ones whose damage was repairable . Type III failures were non-repairable and resulted from the system's aging. They also considcred non-zero repair times.

Shaked and Shantikumar (45) studied systems whose components have dependent life lengths and failed components are imperfectly repaired until they are scrapped. They developed models in which more than one component can fail at the same time.

Numerous investigators developed some complex preventive maintenance models for which each item was replaced upon upon failure, and all identical items were replaced at multiples of some period T, without. considering the ages of the items in question (46,11,12,38).

Berg (9) constructed an age replacement procedure for mission-critical items by adopting a Bayesian approach. His purpose was to ensure that the system is capable of completing the mission without a failure by controlling the reliability of mission-critical items. Berg defined p as the probability that the item will operate failure-free in the next period of some specified length l. In order to at.-tain failure-free operation, he suggested that an item should the replaced when p falls below some specified value, He combined two uncertainities associated with the process, namely incomplete knowledge of the item's life distribution, (which is a function Of a parameter, l) and the stochastic behavior of the failure process given l. In his model, Berg considered a replacement criterion which was based on failure risk.

InözÜ and Perakis (23.41) studied reliability and replacement characteristics of Great Lakes marine diesel engines. A Colt-Pielstick PC2-400 series marine diesel engine has been used as a prototype for the modeling. The authors developed and implemented reliability based models to rationalize current winter layup replacement practices. Two systems have been considered: one for a ship equipped with one engine only and another for a two-engine ship. Incorporating the age dependent nature of system failure characteristics. a semi-Markov competing-process approach has been used in their models, where system failure behavior has been treated as a race among engine components. Howard's one-set, competing process model has been implemented and extended to two sets of competing processes (27). A recursive iteration procedure has been used in the expected cost calculation. Computer codes have been developed using the above models, and several examples have been examined. Sensitivity analyses have been performed for several parameters to see the influence of their vairation on the expected costs and corresponding winter layup policies.

The models discussed above ignored the budget constraints usually faced in implementation. In the following section, a new deterministic approach which explicitly considers budget constraints is introduced. This approach is applicable to ship fleet mintenance and replacement. In addition, the same same approach is equally applicable to maintenance and replacement of the components of a single ship.

CAPITAL RATIONING

Traditional replacement and maintenance models usually assume unlimited capital in practice, however decision makers frequently are restricted by limited maintenance and investment funds. Under capital rationing, the replacement and maintenance decisions must be determined simultaneously. Due to the interdependence of decisions, the computational difficulty increases significantly. In this section, we present an integer programming model and discuss a Lagrangian-based solution methodology.

The following assumptions characterize the decision environment.

- The service under consideration is provided by a number of components, each of which competes for a fixed budget in each period for maintenance or replacement.
- All cash flows and budgets are deterministic, i.e., they are known with certainty at the time of the analysis.
- Decision maker's objective is to minimize the total discounted cost of replacements and major maintenance actions over a finite planning horizon.
- Maintenance and replacement costs are dependent only on the components's age and time of installation. A key feature of this assumption is that we can specify future costs a priori using time-dependent "functional relationships" once the age-dependent. costs of current components are known. Usually, these functional relationships reflect the decision maker's estimates of technological improvements and inflation for future components (39).

l Budgets constraints are provisional limitations imposed for the purpose of controlling replacement and maintenance expenditures. They do not represent "hard" bounds in the sense Of an absolute limit on finance.

Let a zero-one Variable X(c,a,i,j) be set to one if action a is taken on component in period j and doing nothing but routine maintenance until period .j; X(c,a,i,j) is set to zero otherwise. Actions on a certain component can be replacing it with a new one as well as performing a major maintenance activity, such as an overhaul, a major repair and so on. Also let

II	=	planning horizon,
II	=	number of components,
P(c,a,i)	=	cost Of action a on component c in period i,
B(i)	=	budget in period i. and
C(c,a,i,j,)	=	discounted cost of keeping component c in service from period i to period j after taking action a in period i.

Then, the problem can be formulated as an integer program as follows: Mnimize

$$\sum_c \sum_a \sum_i \sum_j C(c,a,i,j)\, X(c,a,i,j)$$

subject to the following constraints:

1. Replacement and maintenance actions must be sequenced in series over time on each component. These constraints are' to prevent any interruption of service. For each c:

$$\sum_a \sum_j X(c,a,0,j) = 1$$

$$\sum_a \sum_j X(c,a,i,j) - \sum_a \sum_j X(c,a,j,i) = 0 \quad i = 1,\ldots,H$$

$$-\sum_a \sum_j X(c,a,j,H) = -1$$

2. Expenditures should be within budgets. So, for i = 0,.. . . H - 1:

$$\sum_c \sum_a P(c,a,i) \sum_j X(c,a,i,j) \le B(i)$$

3. Integrality

$$X(c,a,i,j) \in \{0,1\} \quad \forall\, c,a,i,j$$

Solving the above integer program would be significantly easier if the replacement and maintenance decisions of individual components were not interdependent by the capital rationing constraints (constraint set 2 above). This observation suggests a Lagrangian relaxation approach in which the capital rationing constraints are dualized up into the objective function with fixed multipliers. Let. $\mu(i)$ be the multiplier associated with the budget constraint of period j. Then, the Lagrangian problem can be specified as follows:

$$L(\mu) = \min_x \sum_c \sum_a \sum_i \sum_j [C(c,a,i,j) - P(c,a,i)\,\mu(i)]\, X(c,a,i,j) - \sum_i B(i)\,\mu(i)$$

subject to constraint sets 1 and.

Under certain conditions, multipliers can be determined SO that a solution of the Lagrangian problem generates an optimum solution to the original integer program satisfying the budget constraints 21). However it, is also likely that no such conditions are satisfied for a given problem data. In this case, the solution of the Lagrangian problem is still of interest for two reasons.

1. Given the assumption that the capital rationing constraints are imposed primarily for expenditure control purposes, and hence' they are usually not binding to the extent implied in the problem formulation, the Lagrangian problem may produce acceptable solutions.

2. The Lagrangian problem yields lower bounds (for minimization problems) on the optional objective of the original problem. Therefore, if a strict optimum is desired, they can be incorporated into branch-and-bound algorithms.

With Lagrangian relaxation, the problem is decomposed into n Separate and independent replacement-maintenance problems, each of which is that of finding a shortest path on an acyclic graph. We use a dynamic program to solve efficiently each shortest path problem. For a given $\mu \geq 0$, let

$$C(c,a,i,j) = C(c,a,i,.j) - P(c,a,i)\mu(i)$$

for all c,a,i,j. Define $f(c,i)$ as the discounted cost of an optimum replacement and maintenance policy over a planning horizon i. Initialize $f(c,0) = 0$ for all c. For each c, the following recursive equations find the shortest path from period 0 to H.

$$f(c,j) = \min_{a} \min_{i \cdot j} C'(c,a,i,j) + f(c,i)$$

for j = 1.. . . . II. At. each j, store the minimizing arguments:

$$A(c,j) = \underset{c}{\text{argmin}} \quad f(c,j)$$

$$l(c,.j) = \underset{i}{\text{argmin}} \quad f(c,j)$$

The optimum solution is then given by a dynamic programming tree completely specified by A and I on the acyclic graph.. The Lagrangian value, which is a lower bound on the optimum objective of the original integer program, is the sum of individual shortest paths minus a constant term.

$$L(\mu) = \sum_{c} f(c, H) - \sum_{i} B(i)\,\mu(i).$$

Finding the best multiplier vector so that the solution Of the Lagrangian problem approximates the solution of the original integer program as close as possible is a. nondifferentiable optimization problem. Basically, there are' two approaches: 1) Subgradient illgorithins, and 2) multiplier adjustment methods (MAMs).

Subgradient algorithms have been used on many practical problems Successfully. Given an initial multiplier vector, its basic step requires solving the Lagrangian problem to compute a subgradient direction for the multipliers. The multipliers are them changed in the computed direction. Details of subgradient algorithms including convergence properties can be found in (25). Held, Wolfe and Crowder (26). and Goffin (22). Karabakal (31) describes a subgradient algorithm for finding the best multipliers to solve the above' Larangian relaxation of the capital-rationed replacement and maintenance problem.

MAMs are heuristic algorithms for determining best multipliers exploiting the special structure of a particular application. The advantage of a MAM over a subgradient algorithm is that it. usually guarantees monotonic improvement of the bound. The disadvantages are' 1) it. depends on a specific problem structure, and 2) it. cannot guarantee bounds better than those obtained by a subgradient algorithm. Karabakal, Lohmann, and Beau (32) describe an efficient MAM for the capital-rationed replacement and maintenance problem when the constraint set rather than Set 2 is relaxed. They also discuss a specific branch-and-bound technique that uses this MAM as its bounding technique.

An Extension

We can extend the above formulation to include the decision situations in which the maintenance costs are dependent on the condition of the service as well as the age and time of installation of components. Suppose the conditions represent the productivity levels. After each periodic inspection, assume a component's productivity is classified into one of L + 1 conditions. It. is in condition 0 if it. is least costly to operate in condition L if it is most costly to operate. Then, in order to compute any future maintenance we need to know the condition of the service at the time of the maintenance action.

We assume that the decision maker can make deterministic estimates about the future conditions of the service given the current time period, condition and the last maintenance action taken. Given the deterministic deterioration assumption one way of formulating the problem is to modify our basic formulation to incorporate the condition-dependency of maintenance costs. Let X(c,a,i,i',j,j')j') be set to one if action a is taken on component c in period i at condition i' and doing nothing but routine maintenance until period j to end up with conditions .j'. Redefine C(c,a,i,i',j,j') accordingly. Then, we wish to minimize

$$\sum_c \sum_a \sum_i \sum_{i'} \sum_j \sum_{j'} C(c,a,i,i',j,j') \, X(c,a,i,i',j,j')$$

subject to the following constraints:

1. Replacement and maintenance actions must be sequenced in series over time on each component. For each c and i'

$$\sum_a \sum_j \sum_{j'} X(c,a,0,i',j,j') = 1$$

$$\sum_a \sum_j \sum_{j'} X(c,a,i,i',j,j') - \sum_a \sum_j \sum_{j'} X(c,a,j,j',i,i') = 0$$
$$i = 1,\ldots,H$$

$$-\sum_a \sum_j \sum_{j'} X(c,a,j,j',H,i') = -1$$

2. In each period, at most one' maintenance Or replacement action can be taken over all conditions, SO for each C and i:

$$\sum_{i'} \sum_a \sum_j \sum_{j'} x(c,a,i,i',j,j') \le 1$$

3. Expenditures should be within budgets. So. for i = 0,. . . , H - 1:

$$\sum_c \sum_a \sum_{i'} P(c,a,i,i') \sum_j \sum_{j'} X(c,a,i,i',j,j') \le B(i)$$

where $P(c,a,i,i')$ is the cost of action a on component c in period i at condition i'.

4. Integrality

$$X(c,a,i,i',j,j') \in \{0,1\} \quad \forall c,a,i,i',j,j'$$

The above formulation has many more variables and constraints than the basic formulation. However, the structure that allows us to develop efficient Lagrangian relaxation techniques for the basic model is still there. Again, when we relax the budget constraints, the Lagrangian problem consists Of many shortest path problems on acyclic graphs. Good multipliers can be determined using a MAM similar to that described for the basic model.

CONCLUDING REMARKS

First., various maintenance and replacement models with applications in the marine industry are discussed. Second, a new approach to solve the multi-item replacement under budget constraints is presented. As it, was mentioned above, a number of computer based decision support systems have been introduced to the marine industry. However, each of these systems focuses on on a specific aspect of the entire ship operation and maintenance On the other hand, effective maintenance planning of a ship aims at minimizing failures, equipment downtime, spare parts inventory, maintenance costs and emergency maintenance simultaneosly while satisfying regulations and meeting voyage schedules with a limited crew capability and under budget constraints.

Various onboard decision systems recommend a variety of maintenance actions consuming resources at different levels and assigning different replacement (or overhaul) times depending on the user selected risk level. On the other hand, the ship fleet operator has to distribute limited resources among the ships efficiently so that the overall profitability of the shipping company is maximized. Hence the optimization model detailed above could be implemented to fleet. replacement and maintenance as well as to rcplacement and maintenance of a single ship, considering different options under budget constraints.

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The Evolution of Cost/Schedule Control (Direct Labor) in Naval Shipyards

No. 8B-2

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ABSTRACT

The evolution of a Cost/Schedule Control System (C/SCS), for direct labor, in naval shipyards can be traced from the cost/schedule control concept used in the Air Force in the 1960s, as an initiative toward more reliable data. Subsequent C/SCS programs were initiated across the Department of Defense (DoD) in the late 1960s and early 1970s. As private shipyards came under what is known as Cost/Schedule Control System Criteria (C/SCSC), and its validation requirements, the issue of C/SCS in naval shipyards rose to the surface.

In 1984, the Naval Sea Systems Command (NAVSEA) issued a directive which called for C/SCS implementation in naval shipyards. Expanded use and standardization has followed. This paper reviews basic C/SCS principles, how naval shipyards have used C/SCS in improving performance, and how it has been standardized while still retaining a degree of flexibility.

NOMENCLATURE

ACWP. Actual Cost for Work Performed.

BCWP. Budgeted Cost for Work Performed.

BCWP. Budgeted Cost for Work Scheduled.

CPI. Cost Performance Index.

C/SCS. Cost/Schedule Control System.

C/SCSC. Cost/Schedule Control System Criteria.

CV. Cost Variance.

DoD. Department of Defense.

FBS. Financial Breakdown Structure.

NAVSEA. Naval Sea Systems Command.

OBS. Organizational Breakdown Structure.

PEC. Predicted End Cost.

SPI. Schedule Performance Index.

SV. Schedule Variance.

WBS. Work Breakdown Structure.

INTRODUCTION

In the 1960s various organizations recognized the need for improved performance on projects while they were taking place instead of trying to apply "lessons learned" after the fact. It became clear that if one expended 50 percent of the planned total budget, one wasn't necessarily half done.

Cost/schedule control is not another system but a set of criteria, or principles if you will, that an organization uses in undertaking major defense programs (1). Cost and schedule variances can be traced to the source by analyzing management exception reports and graphics, which display performance data. C/SCS provides feedforward control as opposed to feedback control. Feedforward control attempts to identify future deviations early enough so action can be taken to avoid problems as a result of those deviations (2). Through trend analysis and review of C/SCS information, the need to take corrective action can be identified. Without corrective action, the greatest C/SCS system in the world is meaningless.

In the 1970s private shipyards came under DoD Instruction 7000.2 for new construction contracts. The intention of the instruction is to outline requirements of C/SCSC for selected acquisitions (3). Previously, contractors' reporting systems were not effective regarding progress assessment. DoD Instruction 7000.2 outlined C/SCS criteria in a Joint Implementation Guide (4). The JIG outlines 35 criteria in five major areas: Organization, Planning & Budgeting, Accounting, Analysis, and Revisions and Access to Data.

In 1984, NAVSEA issued NAVSEA Instruction (NAVSEAINST) 7000.13, directing implementation of C/SCS in the naval shipyards. C/SCS was customized within the naval shipyard community so that performance could be maximized via robust management using C/SCS principles and not focusing simply on meeting a reporting requirement.

COST/SCHEDULE CONTROL PRINCIPLES & CRITERIA

NAVSEAINST 7000.13 outlined ten basic principles for cost/schedule control,

1. The system will be based *on* integrity. Actual cost and schedule progress data will be accurately collected and accumulated to report actual performance.

2. A hierarchical work breakdown structure consistent with specified scheduling requirements will be used to define work scope and subdivide the work into logical tasks.

3. The highest level of the cost hierarchy will be the project budget. The aggregate total of the lower level budgets will be traceable to, and will not exceed, the project budget.

4. The project work scope will be broken down into manageable and relatively small work task elements to facilitate the productive effort. Appropriate shipyard line managers should be involved in determining how work is broken down into work task elements.

5 Actual cost data and actual schedule performance data will be collected at the work task element level.

6. Cost performance will be measured by comparing actual costs for work performed to planned costs (e.g., budgeted or estimated costs) at the work task element level and at appropriate higher levels.

7. Schedule performance will be measured by comparing actual progress to planned progress at the work task element level and at appropriate higher levels.

8. Schedule performance and manning levels should continue to be planned and monitored below the work task element

level where required by the separate scheduling directives.

9. Deviations of actual performance from planned performance will be resolved by the responsible line manager.

10. A revised Predicted End Cost (PEC) or Schedule will be developed whenever significant deviations from planned performance occur

These ten principles were translated into finer details that could be measured in some manner. The details became embodied in 15 C/SCS criteria for the naval shipyards, which follow.

1. Accurate Charging. A specific level of accuracy is required; a formal policy is published; supervisors are held accountable for correct charging; an internal review process is operative.

2. Phvsical Progress Assessment. Progress is updated weekly for line items charged including support codes; physical is collected at or below the Key Operation (Key Op) (000) level; independent assessment procedures are implemented at Key Op level; Key Ops are closed in a timely manner. NOTE: Key Ops are basic work tasks.

3. Hierarchical Work Breakdown Structure. Work breakdown is consistent with NAVSEA scheduling directives; Key Ops for all direct labor, except general production services and non-production support, must be structured with clearly defined schedule and budget, and support only one Milestone (next higher level event); general production services and non-production Key Ops are sized and time-chased for practical manageability; functional management responsibility is established for each level of the WBS; Technical Work Documents (TWDs) are structured consistent with the WBS.

4. Hierarchical Financial Breakdown Structure. The total project budget is the sum of discrete parts which aggregate hierarchically from the Key Op or below.

5. Line Management Acceptance of the Work Breakdown Structure. A mechanism is in place for feedback from line managers and for participation in WBS development; there must be demonstrated use; there is general acceptance of the WBS.

6. Line Management Acceptance of Budgets. The responsible manager is aware of his/her budget; accountability is established; a feedback mechanism for line managers is in place.

7. cost Performance Data Aggregation, Cost data is identified at or below the Key Op level; cost data and cost performance data are aggregated to all levels of the FBS, OBS and WBS; cost performance data is displayed to

supervisors at appropriate levels of accountability.

8. Schedule Performance Data Aggregation. Schedule data is identified at or below the Key Op level; schedule data (BCWS) and schedule performance data are aggregated to all levels of the OBS and WBS; schedule performance data is displayed to supervisors at appropriate levels of accountability.

9. Performance Measurement Baselines. The BCWS is used as the Performance Measurement Baseline (PMB).

10. Resolution of Performance Variances. Performance data is used to ascertain status and identify reasons for significant variances; corrective actions are taken.

11. Cost and Schedule ections. Whenever there are significant deviations, C/SCS performance data is used to assess the need to revise Project Schedules and PECs

12. Iternal Reports. Cost and schedule data is grouped and reported for all levels of OBS and WBS; cost data and cost performance data is aggregated and reported for appropriate levels of FBS; cost and schedule performance data is reported and displayed at appropriate levels of accountability; applicable reports are distributed at all appropriate levels for use in performance analysis.

13. Graphics. C/SCS performance data is graphically displayed for appropriate levels of the OBS and WBS.

14. Training. Lesson plans are established; classes are held; there is a continuing education program. Training is effective based on interviews and test records.

15. Directives. A C/SCS directive is issued and all criteria are addressed (6).

C/SCS USE

Once the need for C/SCS was established, a directive issued, criteria laid out, and the "system" implemented, the next, important task was application of C/SCS principles in the execution of naval combatant overhauls. When the naval shipyards had fully implemented C/SCS by early 1988, the emphasis shifted from framework implementation to comprehensive use of the "system" and resolution of any associated problems. Daily management of shipyard operations using C/SCS was more important than just reporting performance. Reports are not the be-all and end-all of shipyard operations. Use of C/SCS tools in monitoring status, and then taking action, is the crux of the matter.

The basic C/SCS tool, in graphical form, is the set of curves depicting ACWP, BCWP and BCWS. See figure 1. ACWP represents actual expenditures through "time now." BCWP represents actual physical progress, or earned value, through "time now." BCWS represents the scheduled load of work over the projected length of the project.

The development of the BCWS as the baseline is shown in figure 2. Using the management--by-exception technique, a Group Superintendent can view his/her group graphs and reports and trace a problem to its source. Figure 3 shows a graph depicting C/SCS information for a Structural Group. Ideally, BCWP, or physical progress, would be at or above BCWS, the baseline, and at or above ACWP, actual cost. But there is both a negative Schedule Variance (SV) and Cost Variance (CV). The BCWP line is below the BCWS and ACWP lines. So the Group Superintendent would go to the next level. Figures 4, 5 and 6 show performance for the various Shops within the Group. Shop 17's C/SCS performance in figure 5 immediately catches the eye. There is a definite gap between BCWP and the BCWS and ACWP lines. One would then check Shop 17's graphs for the two major areas as in fiqures 7 and 8. Obviously the problem lies in the second-area, depicted in figure 8. Figures 9 and 10 further focus on Shop 17, area 2, by displaying performance of work centers. Figure 10 shows large negative variances in Work Center 20 for both cost and schedule. Now one may review a detailed report to key in on the particular line items that are causing a problem.

Various "growing pains" were noted with C/SCS implementation and use. A sample of the problems many of the naval shipyards had is outlined below:

-time and attendance data input too early for accuracy;
-progress not reported on small tasks (e.g., less than 40 manhours);
-some overlapping of events (i.e., work tasks associated with more than one upper level event);
-many Key Ops/work tasks too long in duration and/or too large in size, making accurate progress assessment and consistent work breakdown difficult;
-lack of adequate feedback from line managers in the work breakdown and/or budgets;
-PEC and/or Schedule not revised based upon C/SCS information or matched with actual costs & schedule, and
-most local C/SCS instructions failed to address all criteria.

Since 1988, naval shipyards have advanced on the learning curve and have demonstrated more intensive use of cost/schedule control principles and criteria. All of them have instituted regular C/SCS briefings in monitoring status of availabilities in progress.

MEASURABILITY & EFFECTIVENESS

RADM Roger Horne, a former Deputy Director of NAVSEA's Industrial and Facility Management Directorate, summarized the cornerstones of an effective C/SCS "system"' as three things: quality estimates, accurate physical progress assessment, and accurate labor charging. If the estimate base is not accurate, then there will be many deviations of performance. Physical progress assessment inserts reality into the equation as opposed to merely calculating progress based on expenditures. And if charges are not accurate, then one does not know how much a task really costs. Without accurate information it becomes a case of "GIGO" (garbage in, garbage out).

The shipyards have tried to develop a consistent and accurate estimate base via engineered and technical standards, and, for submarines, Class Estimate Standards (CES). Standards must be reviewed periodically because they can deteriorate over time due to procedural changes, new regulations

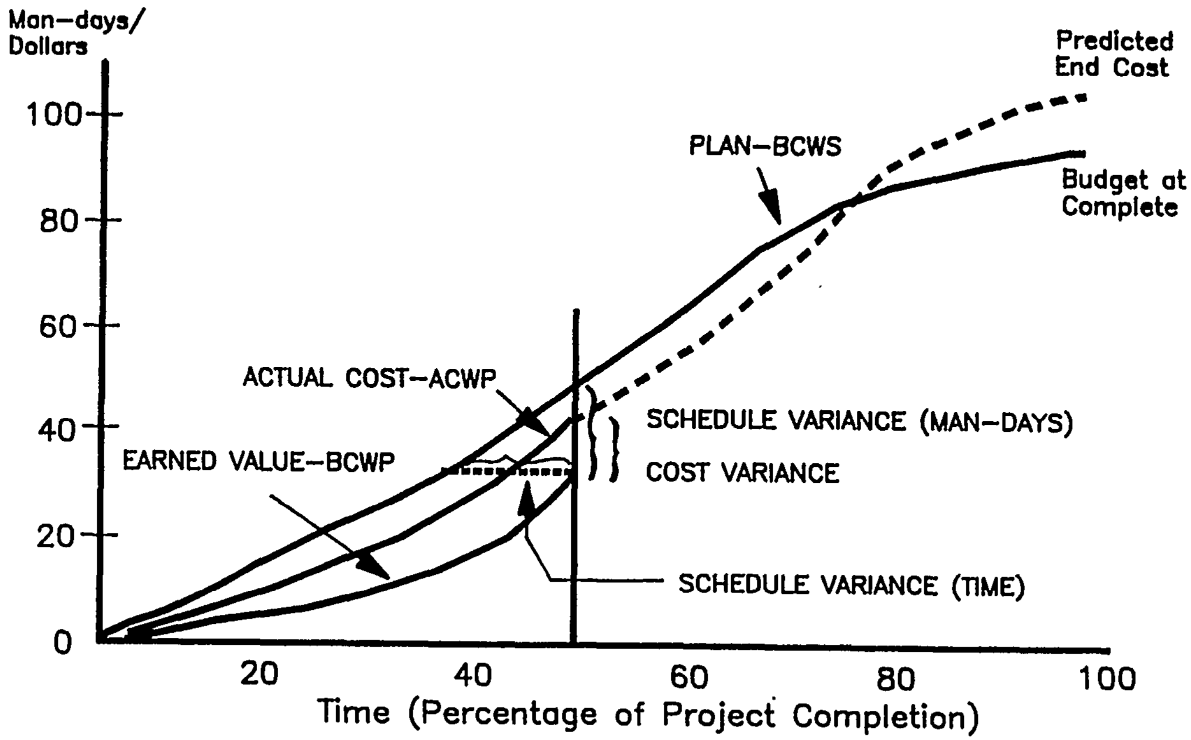

Figure 1 Project Cost and Schedule Performance

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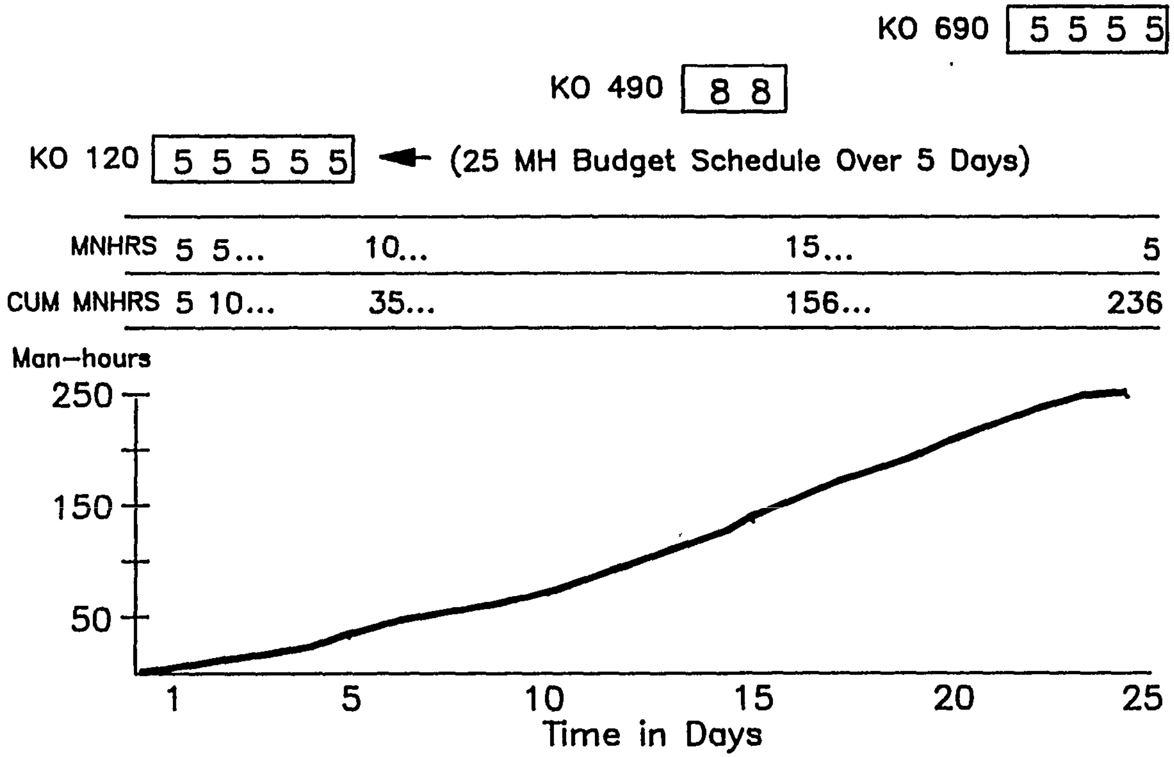

Figure 2 Building a Plan (BCWS)

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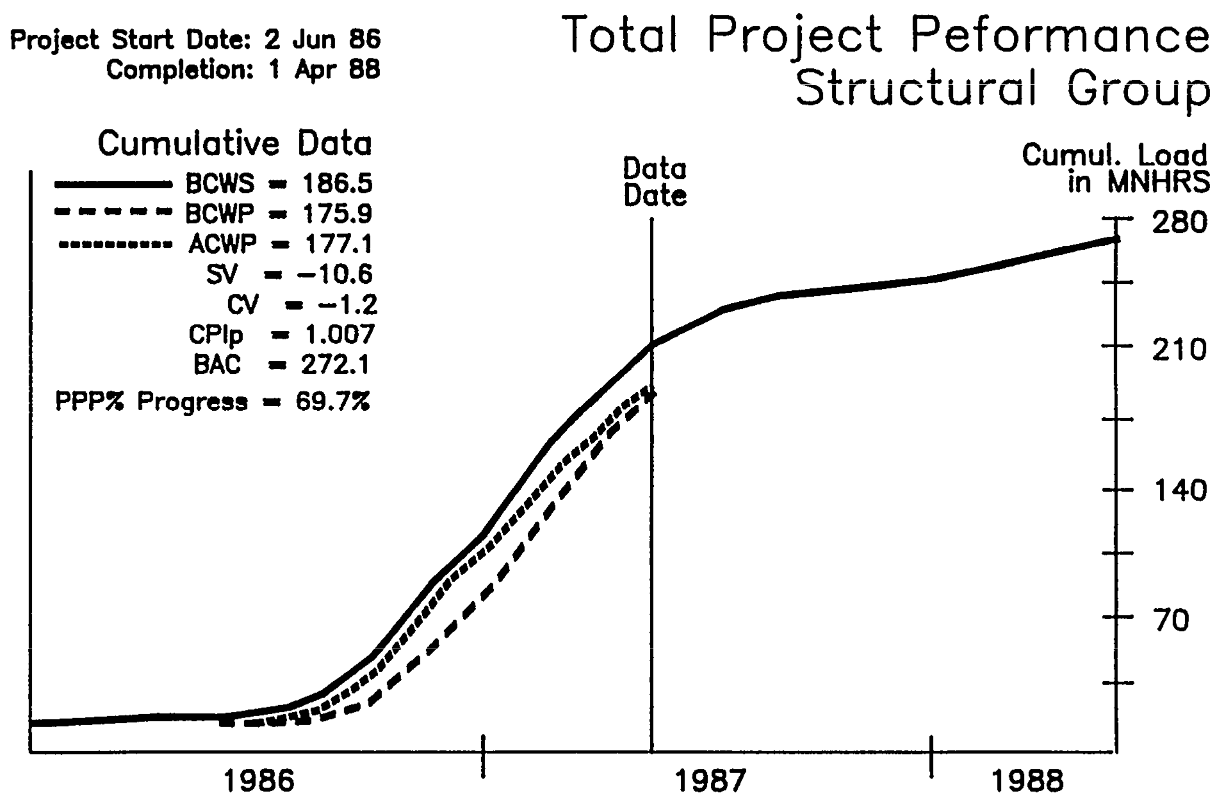

Figure 3 Variance Analysis/Graphics

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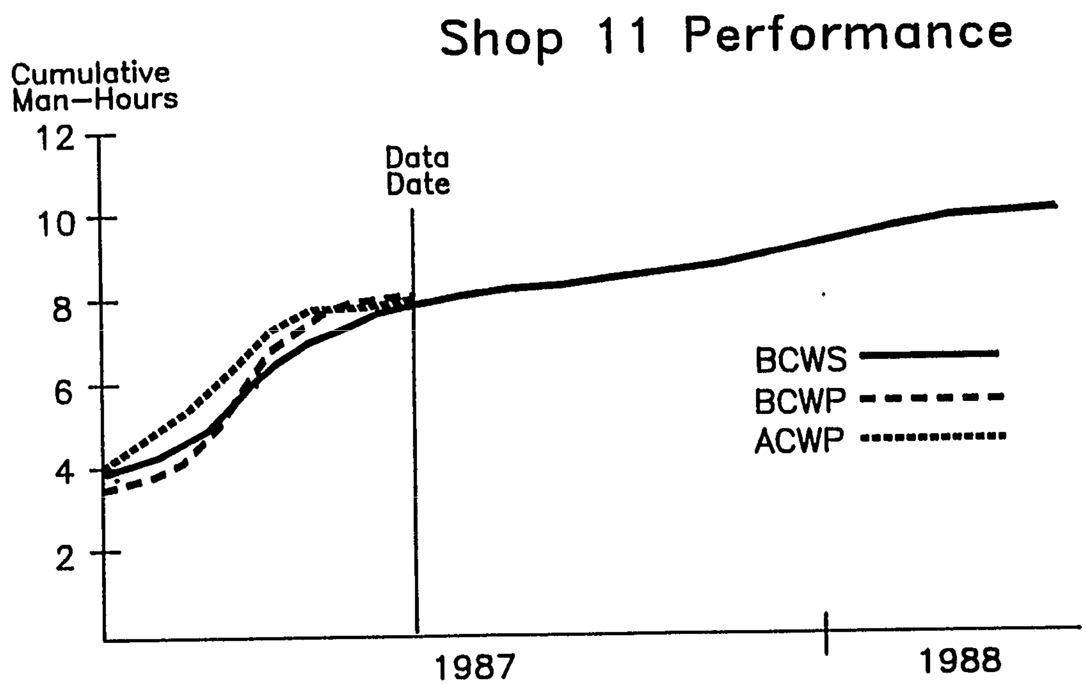

Figure 4 Variance Analysis/Graphics

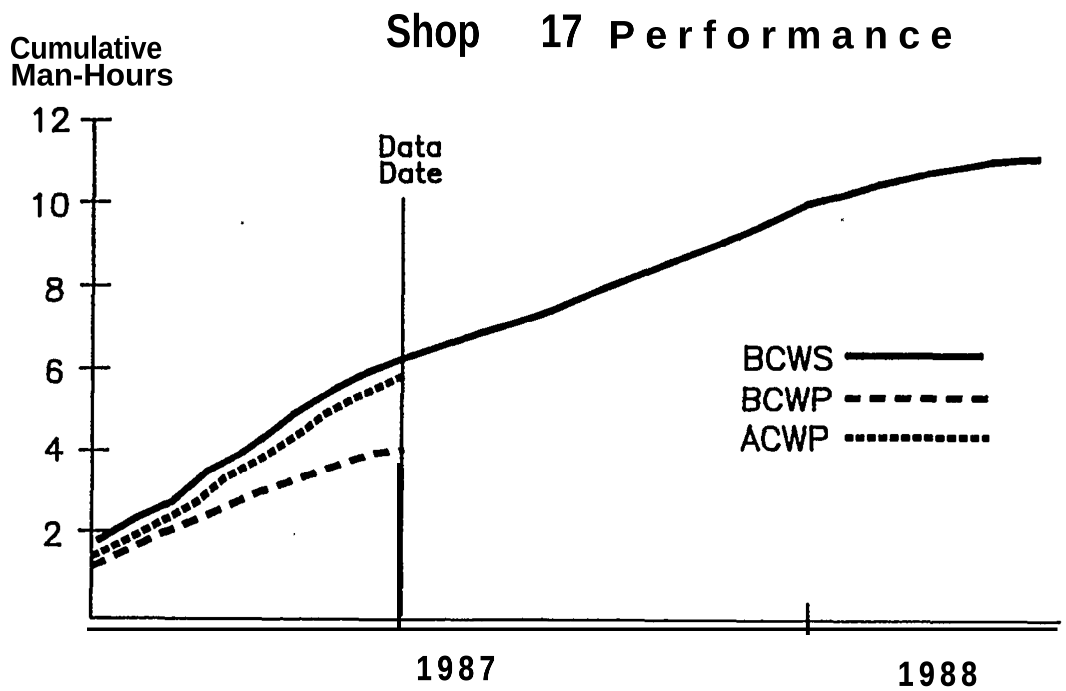

Figure 5 Variance Analysis/Graphics

(C/SCS Performance Graphics Indicate Poor Performance Trands in Shop 17)

8B2-11

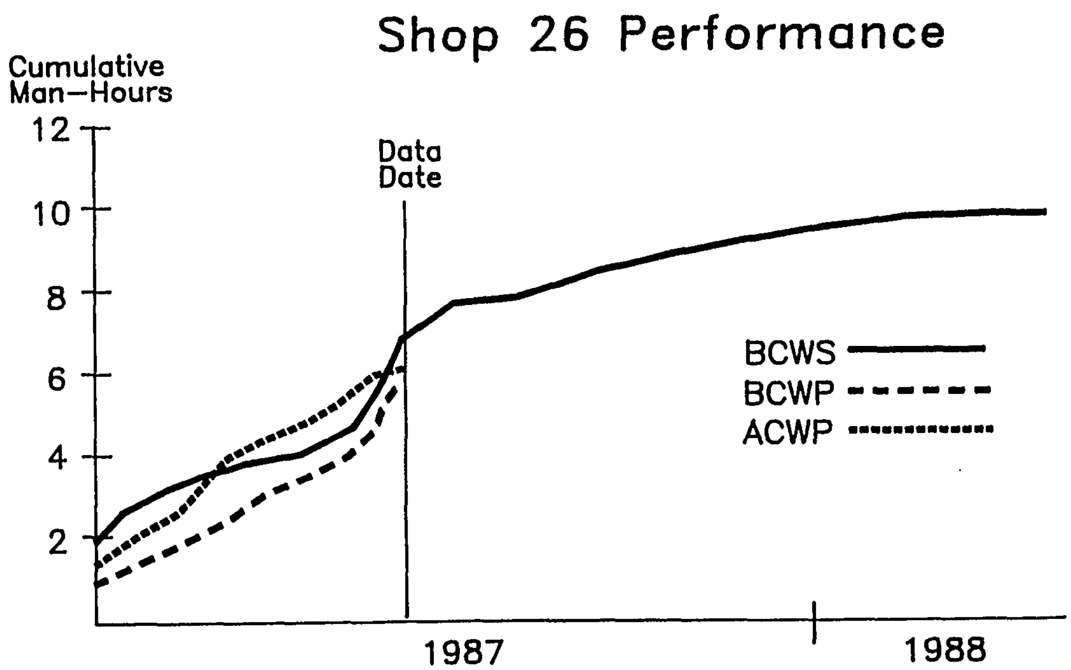

Figure 6 Variance Analysis/Graphics

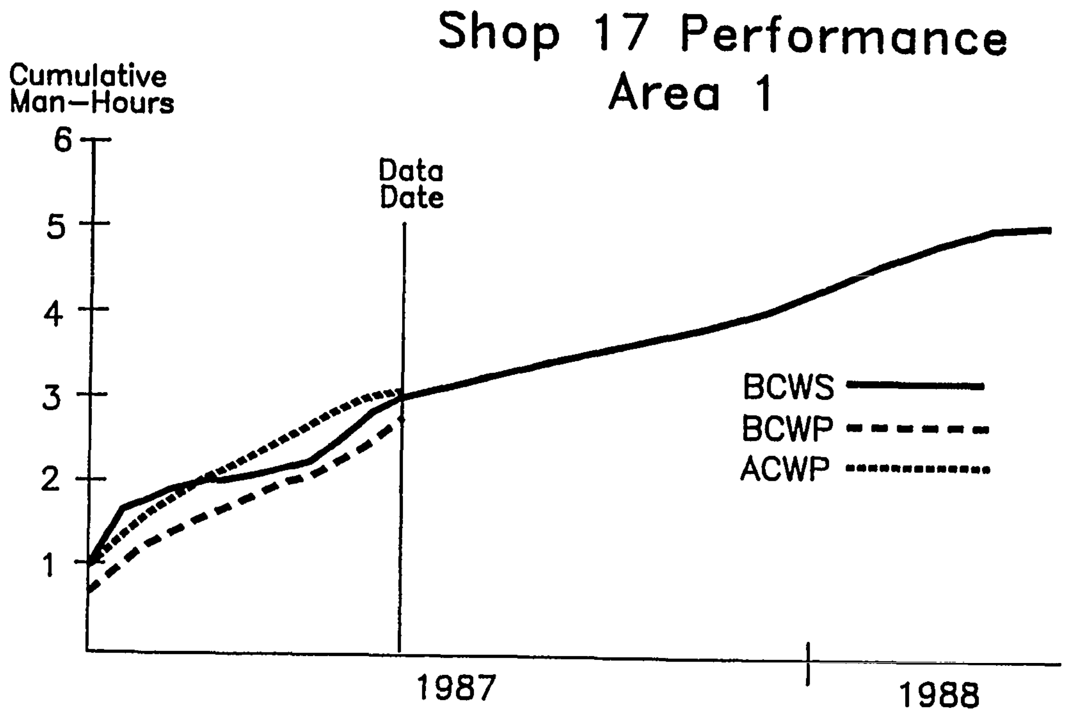

Figure 7 Variance Analysis/Graphics

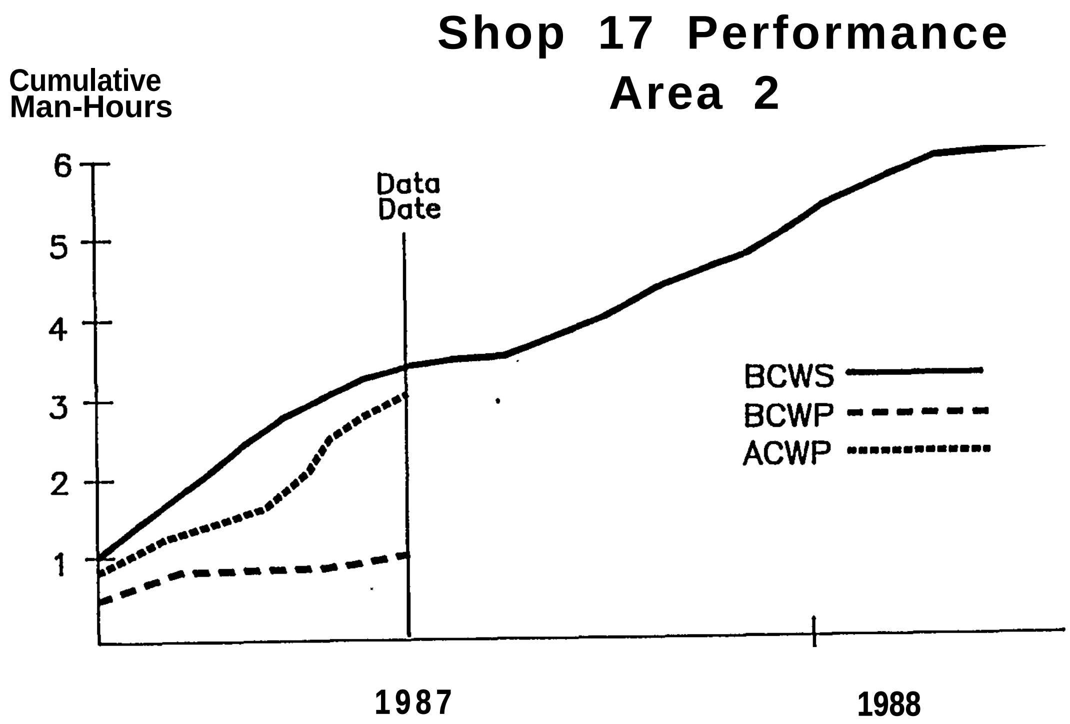

Figure 8 Variance Analysis/Graphics

(C/SCS Performance Graphics Can Trace Schedule and Cost Variances to Source for Corrective Action/Resolution

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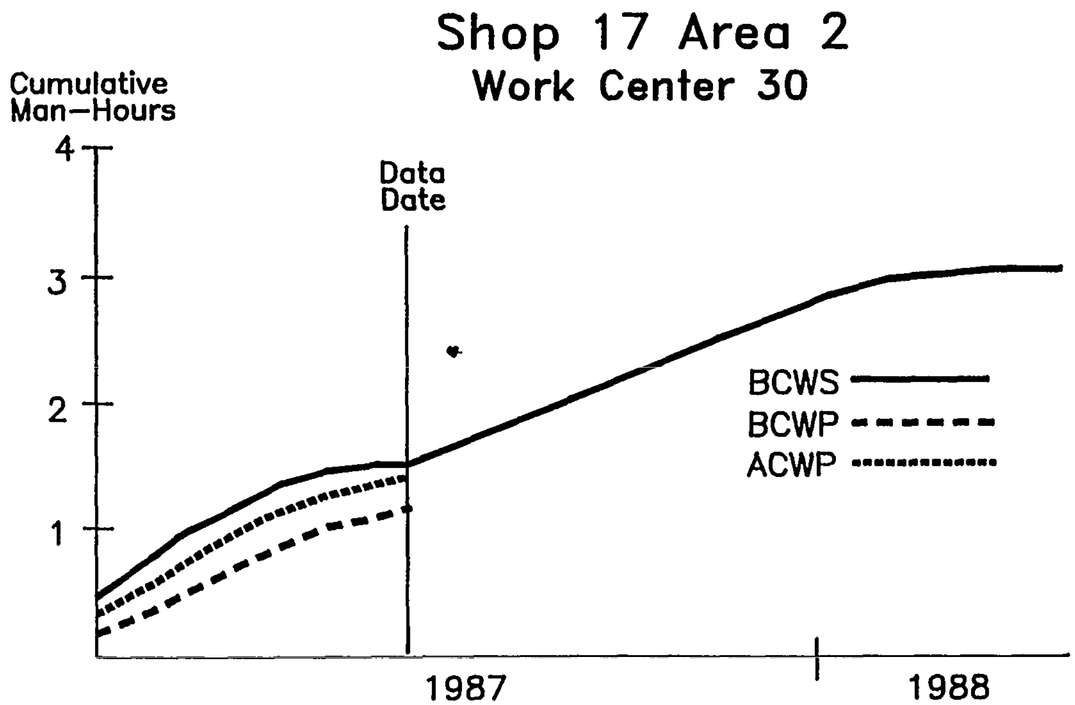

Figure 9 Variance Analysis/Graphics

Shop 17 Area 2
Work Center 20

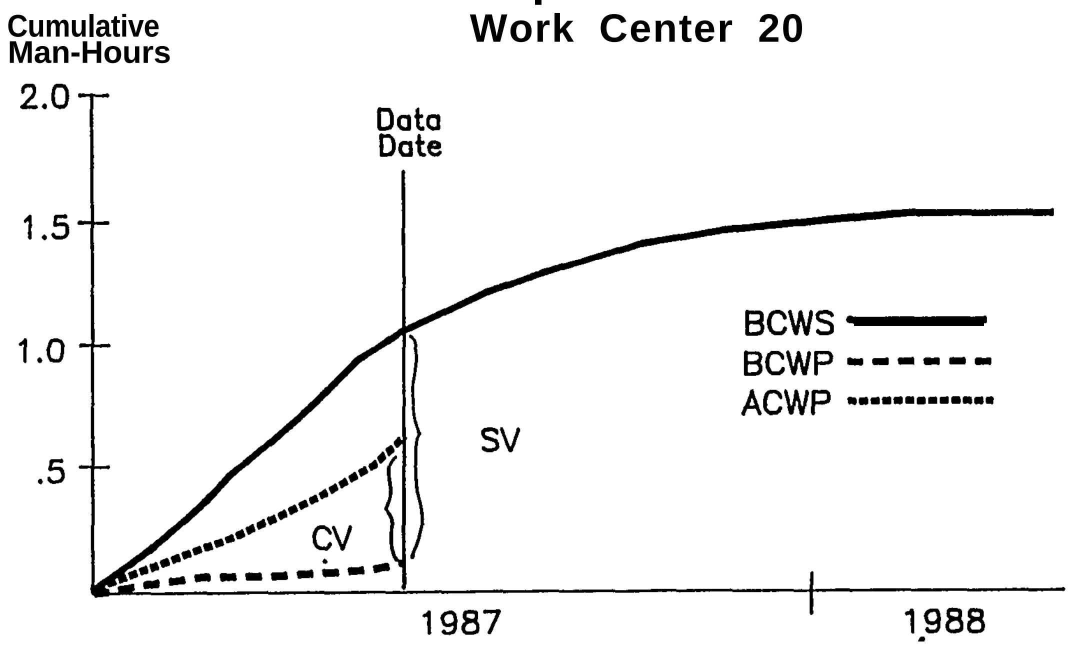

Figure 10 Variance Analysis/Graphics

(Utilization of C/SCS Performance Charts through the WBS and OBS, provide increased visibility and traceability to source of poor performance to enable rapid resolution)

and productivity improvements (7).

Physical progress assessment can seem subjective at times, such as estimating what percentage of a compartment is painted. But more often than not assessments can be objectively performed fairly well. Physical progress accuracy has improved greatly due to smaller work packages, independent assessment by other parties and through training in actual assessment procedures. Sometimes it's simply a component count to capture the correct progress. In cases where different size or type of components are in the same task, shipyard personnel have worked to analyze the situation so that certain "pieces" of a job equate to a certain percentage. In the service area, progress is captured based on a time-phase methodology. For example, rigging services may be broken down by pre-drydock phase, in dock, post-drydock. Each phase, or portion of a phase, equates to a certain level of progress.

Accurate labor charging requires use of methods such as smaller work packages, proper work sequencing and control of Job Order/Key Ops (tasks). There also must be proper charging and no "balancing of the books" where a foreman might use manhours on a job that performs well, or has not started, on a job that has reached its limit (estimated manhours for the entire task).

The evolution of progress in effectively using C/SCS Can be described by the chronological account of validation reviews of a particular shipyard. The author participated in most of the reviews. In 1986, C/SCS was in its infancy at the shipyards. This was reflected by review teams' observations. Many Key Ops/tasks were too long and crossed Milestones (next upper level event). Accurate charging was a formal policy only. There were major problems reporting BCWP and ACWP due to the inability to aggregate data through the various hierarchies. By 1988, tremendous progress had been made. Accurate charging was at the 90% range.

Independent assessment of physical progress had been instituted. The WBS had been restructured so that lower level tasks aggregated up through the higher level events without crossing boundaries. The number of Key Ops/tasks had increased from about 5,000 to about 11,000. While this required a lot of effort on the Planning Departments, dividends were paid on the other end. Accurate charging was achieved much easier, progress assessment was more accurate, etc.

The effectiveness of C/SCS in naval shipyards can be somewhat gauged by reviewing some performance trends. Overhaul and repair of modern warships is very complex, and many factors come into play. At Long Beach Naval Shipyard, a particular destroyer availability had the best performance for that class of ship to date. In the late 1980s the shipyard had won several "bid ships" in competition with other shipyards, with the shipyard firmly believing that implementation of C/SCS drove better planning and discipline in the system. More recently, cost and schedule performance improvement has been documented for a string of Depot Modernization Period (DMP) availabilities. A DMP is an SSN depot availability for installation of high priority warfare alterations, maintenance necessary to ensure unrestricted operations to design test depth. It is designed to increase SSN fleet operational-availability (8). While it is likely is that a combination of a sense of purpose, continuous improvement/TQM and C/SCS has led to improvements, it was C/SCS that first helped institute more effective planning, objective status assessment, ability to trace problems to their source and early detection of problems than otherwise might occur.

STANDARDIZATION

Since NAVSEA, and SEA 07 in this particular case, is a corporation in every sense of the dictionary's meaning, corporate information requires a certain level of standardization regarding policies, procedures, and the like. Also, as many people in the corporation may transfer or rotate among the various shipyards (e.g., military officers, detailed personnel), it behooves the local sites to have some degree of commonality. The trick becomes how detailed to get regarding standardization. Should Darwin's theory of variation hold among the shipyards? That is, should each shipyard interpret the broad principles and criteria as they see 'fit? This is subject to debate, but the record shows an increase in standardization as C/SCS evolved from those first principles outlined in NAVSEAINST 7000.13.

In 1984 the principles and basic directive for implementation were issued. Subsequently 15 C/SCS criteria became the benchmark for validation of a shipyard's "system." In May of 1990, NAVSEA conducted a survey of C/SCS practices in the naval shipyards. The surveys were summarized in June of 1990 and discussions led to a change *in* the criteria. The criteria were further standardized to be used in the day-to-day operations and as a guide in future compliance reviews. Compliance reviews of the shipyards is an ongoing check of demonstrated use of c/scs. Highlights of the changes follow:

-designated charging accuracy of 95% to be achieved; -manhours used as a basis for accurate charging vice incidents;

-statistically valid sampling to confirm independent progress assessment;

-emphasized product-orientation above event-phasing or time-phasing for service type Key Ops/tasks;

-standardization of Schedule Performance Index/Cost Performance Index (SPI/CPI);

-designation of how BCWS (performance measurement baseline) is to be revised;

-enforce the discipline of rescheduling once C/SCS information makes it apparent that the current schedule cannot be executed.

Actions toward further standardization are objective, common-sense changes. The changes are good in that information Headquarters receives, and detailed or transferred personnel use, will be more consistent. The naval shipyard community uses standard, corporate criteria which facilitates report analysis, training, etc.

SUMMARY

C/SCS has been implemented in all the naval shipyards. The C/SCS concept is based on earned *value,* or physical progress assessment, as well as quality estimates and accurate charging. It is a feedforward *system* as opposed to an after-the-fact feedback concept. This allows early detection of problems and the ability to take corrective action while there is still time. c/scs information will not, by itself, improve performance. It does provide a valuable tool in monitoring trends and status.

Standardization of the cost/schedule control system has evolved within the naval shipyards since 1984 via basic principles, designated criteria and changes to standardized procedures. Further changes are being contemplated based on lessons learned through the implementation and demonstrated use over the last several years. c/scs has proven to help improve performance through early detection of variances and the synergy derived from participation of all levels of the shipyard in developing and using a consistent, well-planned process.

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TQM and JIT need TOC, TOC needs TQM and JIT

No. 8B-3

Frank Rack, **Member, Managing Change Inc.**

ABSTRACT

In the last. two decades, three management philosophies have emerged that have greatly improved America's competitiveness: Total Quality Management (TQM), Just-In-Time (JIT), and the Theory of Constraints (TOC). TQM has proved that customer service and product quality are vitally important. JIT has proven the importance of reducing inventories and eliminating waste. TQM and JIT are forcing management to a new scale of importance not only as to how they view throughput., inventory and operating expense, but more importantly the role of people-their most important resource.

TQm has proven to virtually everybody in the. industrial world that improved quality , necessary for success. Were it not for JIT, inventory would still be considered an asset in most situations. If it were not for TQM and JIT, those actions that are essential to improve future throughput would not have been implemented. This paper discusses how the TOC needs TQM and JIT, and how TQM and JIT needs TOC. TQM and JIT needs TOC in three very important areas:

1. primary focus,
2. measurements, and
3. scheduling.

BACKGROUND

E. M. Goldratt provides a good description of "What a company tries to achieve". He reviews the slogans of TQM: "Quality is Job One", JIT: "Inventory is a liability", and TOC: "Balance flow not *capacity",* and then states:

"Those are just a few of `the slogans that have shaken the foundation of industrial management. In the eighties three powerful movements were witnessed-Total Quality Management (TQM), Just In Time (JIT), and Theory of Constraints (TOC). Those three movements have challenged almost everything that was previously accepted. Those movements each had their modest start in some local technique. But all have evolved with breathtaking speed."

Goldratt concludes that the initial perception of what these movements encompassed was much too narrow. The change in perception is described in the following way:

It is about time to realize that JIT's primary focus is not the reduction of inventory on the shop floor. It is not just a mechanical Kanban technique. It is definitely a new overall management philosophy.

It is about time to realize that TOc's primary focus is not bottlenecks on the shop floor. It is not just a mechanical optimized production technique. It is definitely a new management philosophy.

IL is about time to realize that TQM's primary focus is *not* the quality of the products. It is not just a mechanical statistical process control technique. It is definitely a new overall management philosophy (1).

All three of these management philosophies have the same overall objective:

IMPLEMENT PROCESS OF ONGOING IMPROVEMENT (POOGI).

A POOGI is a process of ongoing change, something cannot be improved without changing it. As a result managers trying to put their company onto such a process must have the ability Lo continually answer three questions.

1. What to change?

Not everything needs to be changed. Managers must be able to identify the few changes that if they make them (solve the core problems), will add most Lo the performance of the organization.

2 . To what to change?

Many Limes it is obvious that something

must be changed, yet it is far from obvious what to change to. cost allocations is a good example. Managers need to be able to develop simple, practical solutions to the core problems.

3. How to cause the change?

Even when managers have done an excellent job of addressing the first two questions, they still face the mammoth task of causing the organization to adopt it. Managers must have the ability to induce people to take ownership of the solution.

TOTAL QUALITY MANAGEMENT (TQM)

Virtually all the players in the industrial world today agree that quality is necessary for success. Deming's 14 points listed below have become gospel to many Fortune 500 and other companies:

1. Create constancy of purpose toward improvement of product and service.
2. Adopt the new philosophy. Refuse to accept defects.
3. Cease dependence on mass inspection.
4. End the practice of awarding business on the basis of price tag. Require suppliers to provide statistical evidence of quality.
5. Find problems. Continually and forever make improvements.
6. Institute modern methods of training on the job.
7. Give the employees the proper tools to do the job right.
8. Drive out fear, so that everyone can work effectively.
9. Break down barriers between departments; encourage different departments to work together on problem solving.
10. Eliminate numerical goals, posters, and slogans that ask for new levels of productivity without providing specific improvement methods.
11. Eliminate work standards that prescribe numerical quotas; use statistical methods to continuously improve quality and productivity.
12. Remove barriers to pride in workmanship.
13. Provide vigorous and ongoing education and retraining.
14. Clearly demonstrate managements commitment to the above 13 points every day.

The TQM movement has evolved from an internal quality program to comprehensive effort that Put the customer's requirements as the key point. The customers are the ones who really pay the salaries of all in an organization. TQM programs highlight everything that should please the customers: better customer service, higher reliability, improved due-date performance, faster response to client's needs, lower cost of most products, etc.

"Total Quality Management induced a real revelation to Western industry. It shattered the fixation of saving nickels and dimes and brought the industry back to its senses. The goal of the company is not to save money but to make money, 'and making money you can do only through pleased customers. In short, the power of Total Quality Management stems from the fact that it set a new direction, or more precisely I should say that, it rediscovered the old direction.(2)"

Successful implementation of any TQM program requires a commitment from the top and the empowerment to the people in the organization to make decisions. Employee empowerment and true commitment at the top of an organization has always been a major obstacle for TQM. The primary reason is the perception by many managers that they must give up the power and authority that they have fought to gain throughout their career.

JUST IN TIME (JIT)

Unlike their American counterparts, Japanese businesses were receptive to the TQM philosophies of Deming, Jurand, and others. As with any process, improvements can be made and the JIT movement provided a new strategy to help in achieving a competitive advantage and increased profits for the implementors.

S. Brown discusses the following ten Principles that JIT is based on:

1. Reduce manufacturing lead time.
2. Cut inventories to a minimum.
3. Synchronize all production processes to the rate of customer demand.
4. Use demand flows to control the shop.
5. Reduce lot sizes and set-up times.
6. Strive for linear production.
7. Make it right the first time.
8. Eliminate waste, in the form of rework.
9. Dedicate work cells to product families.
10. Form partnerships with vendors.

Brown also states: "JIT enables managers to solve deep-rooted operating problems. It enables management to stop "putting out fires", running from one crisis to another and papering over problems by accumulating inventory. (3)"

Inventory

The Japanese JIT philosophy has proven the important role played by reducing inventory. JIT treats inventory as a liability. Nevertheless conventiona1 cost accounting lists inventory under the heading of assets. However for quite a long time auditors have been feeling more than a little uneasy about inventory profits-profits generated by increasing work-in-process (WIP) and finished goods inventory. Since lately most corporations have started to view inventory as a liability, it is more than a little inconsistent. to record inventory as an asset. To consider inventory in a way that treats an increase of WIP or finished goods inventory as contributing positively to the net profit is becoming more and more indigestible to top managers.

When value added is discussed, what is meant by this term? Value added to what? Can value be added to the product (such as a pump or Valve)? No, unless it is a one product company. Value can only be added to a company's (shipyard's) bottom line when the ship is sold. In shipbuilding the policy of partial payments based on physical progress results in a very misleading picture of true physical progress and worse than that a very erroneous picture of true shipyard profits.

This policy also greatly inflates the value of inventory by adding labor (added value) to the inventory. This added value is really the labor content of each work order which is assigned a agreed to value usually before the start of construction. The value for the material on each work order also has been agreed to and is measured separately from the labor content for partial physical progress payments. It is common practice not to pay 100% of the value of WIP until the ship is delivered and fully accepted.

How can shipyards who have been operating under this and many other such erroneous policies change? Many U.S. manufacturing companies have made the scheduling shift from Just-In-Case (JIC) to JIT, but the total paradigm shift is not made until companies implement the TOC methodology of Drum-Buffer-Rope (DBR). The basics of DBR are described in Reference (4). In the TOC, DBR is also referred to as "Buffer Management." In the TOC the conflict as to inventory being a liability or an asset is resolved as follows;

Inventory is only an asset. when it. protects throughput.

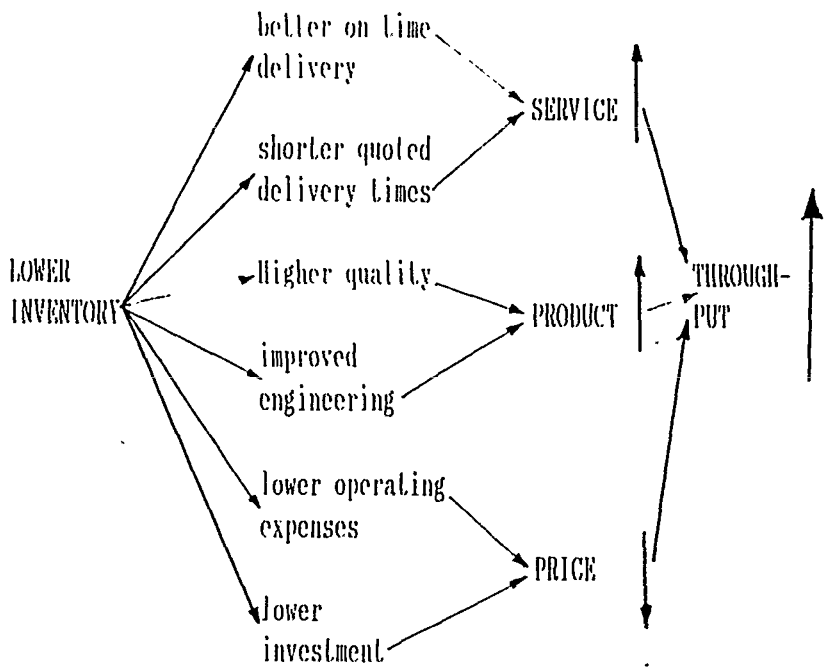
JIT follower's have used and improved upon the TQM techniques and have focused their efforts mainly on finding the causes for high inventory and then worked to eliminate the causes. Americans usually try EXPEDITING.

Goldratt and Fox call the 6 elements shown in Figure 1 as "the six competitive edge issues in today's and tomorrow's market. The real race today is not just in one of them, but in all six. Oddly enough, most of these e1ements are considered by our financia1 systems as intangibles. Maybe they should be thought of instead as our future throughput. (4)"

THEORY of CONSTRAINTS (TOC)

The TOC is an all encompassing management philosophy that includes a consistent. set of principles, procedures,

THE IMPACT OF INVENTORY
ON FUTURE THROUGHPUT



source: "The Race ",R.M.Coldratt,R.E.Fox

Figure 1

and techniques, where every program, every decision, and every action is evaluated in terms of whether it contributes to the successful accomplishment of the common goal of the organization.

In any organization there are usually very few real constraints, and these are not always limited resources that would be considered as bottlenecks. A constraint is defined as anything that limits a system from achieving a higher performance toward its goal. There are only two types of constraints:

1) physical constraints and
2) Non-physical constraints.

Physical Constraints

physical constraints fall into three major categories:

1. resources,
2. material (vendors), and
3. market.

Resources. Resource constraints are mainly people and machines. This type of physical constraint once identified should be fairly easy to break. Some examples of how resource constraints are overcome is by purchasing additional resources (hire more people or purchase or rent or lease additional equipment), work more overtime, subcontract out that portion of work that caused the constraint. and other actions that will break the bottleneck.

Material (Vendors). To have a material physical constraint really means that the material is not available. The only way to overcome this type of physical constraint is to find an alternative material that will satisfy the requirements. In general, material constraints arc really policy constraints in that the purchase price that an organization may be willing to pay for the material is too high or that the quoted delivery time may be later than that organization is willing to accept. The material in fact exists but some organizational policy prevents it from being obtained to meet existing requirements.

Market. Market physical constraints are very similar to material constraints in that they exist only due to the "0rganizations" perception of their market. The true market for a "company ' s" products is global. Another perception that appears to cause market physical constraints is that most organizations limit their Products to a specific type? or segment of the global market place.

Non-physical Constraints

Non-physical constraints also normally fall into three major categories:

1. rules,
2. training, and
3. measurements.

These rules, training, and measurements constraints hereinafter called RTMs, are usually established and implemented to solve a problem and arc based on certain assumptions that are very valid at that time. However, since these RTMs have proven to be successful, assumptions that they were based on are not challenged to verify that they arc still valid. Present cost accounting RTMs are a good example.

Goldratt in The Haystack Syndrome states: "We must come to terms with an unpleasant reality: the more powerful the solution, the faster it might make itself obsolete. Ignoring this reality leads to only one conclusion-

THE POWERFUL SOLUTION OF YESTERDAY MIGHT BECOME THE DISASTER OF TODAY! (1)"

PRESENT SITUATION

J. Rogness identifies the present situation facing American shipbuilding and other industries in today's competitive marketplace:

"The intent of this paper is not to cast blame upon shipyard executives for the productivity constraints in U.S. shipbuilding, but rather to raise questions, stir debate, and perhaps break some new ground in management philosophy. The enemy of U.S. shipbuilding has been identified as authoritarian bureaucracy. The action that has been proposed is an intellectual revolution based on a simple rule: When data are accurate and reasoning is sound but the answer is still incorrect, there is only one avenue remaining: Check the premises, the assumptions upon which the equation or argument is based. (5)"

TQM and JIT have provided many new techniques that have had a very positive impact on improving the competitiveness Of companies who have successfully implemented these techniques. However there are a growing number of companies that are experiencing some difficulties in developing and maintaining a process of ongoing improvement (POOGI).

Goldratt states: "Making money you can do only at the end of the pipe, through the customer. This means that the desired outcome will be achieved only through the synchronized efforts of many resources. This new direction implies that we should view our organization not as a mere pile of links but as a chain. One function doesn't do its job and the end result is jeopardized. (2)"

TQM and JIT provide many powerful techniques and the 14 points of TQM and the 10 principles of JIT listed above all are very helpful but deal primarily with the links-a function or level in the organization and not the "weakest link" in the organization. The main reason that people and managers deal with links is because of the basic pyramid organizational structure which consists of many different functions and many levels within each of these functions. Reference (6) discusses the two major inherent problems that exist in almost every organization:

1. more functions and levels cause more distortions, and
2. walls of distrust are formed between functions and levels.

TQM and JIT efforts are usually successful within functions because the managers in charge of those functions have the authority to direct the change or can more easily build a consensus within their sphere of influence (control). However if the problem is in another function or in a level above their sphere of influence those managers have little influence on implementing the required changes.

TQM AND JIT NEED TOC

TQM and JIT need TOC to provide the necessary synergism to help those involved in the implementation to make the following three major paradigm shifts:

1. Logistics,
2. "Cost. World" to "Throughput World", and
3. Thinking Process.

The logistic paradigm shift was discussed briefly in the Inventory section above. JIT techniques are playing a major role in starting this paradigm shift but do not provide the techniques needed to completed this paradigm shift. Reference (4) provides a detail description on the buffer management techniques that must be implemented to complete the logistic paradigm shift.

Reference (6) addresses "Moving Shipbuilding From the "Cost World" to the "Throughput World" and Figure 2 lists six of the most important areas of "cost world" thinking that should be changed to permit a company to make the second paradigm shift to "throughput world" thinking.

The Thinking Process (TP) paradigm shift will be discussed later.

TOC also provides the required information in the following three important areas:

1. primary focus,
2. measurements, and
3. scheduling.

Primary Focus

Deming's point 5: "Find problems. Continually and forever make improvements" and JIT's principle 2: "Cut inventories to a minimum, and finally 5: "Reduce lot sizes and set-up times," are good examples of why TQM and JIT efforts deal with focusing on links and not on the chain's weakest link. In addition TQM and JIT techniques deal mainly with physical constraints.

Focusing on Physical Constraints. The primary consideration in focusing on constraints is to aim the effort to what is important. TQM and JIT established

"COST WORLD" AND "THROUGHPUT WORLD" PARADIGMS

EVERYTHING IS IMPORTANT	WEAKEST LINK
INDEPENDENT VARIABLES (20:80 Pareto)	DEPENDENT VARIABLES (0.01:99.9 Pareto)
FIRST ORDER SOLUTIONS (Correlations)	SECOND ORDER SOLUTIONS. (Effect-Cause-Effect)
COST ACCOUNTING (Wrong Local Measurements)	THEORY OF CONSTRAINTS (Control Measurements)
ORDER OF SIGNIFICANCE #l. Operating Expense #2. Throughput #3. Inventory	ORDER OF SIGNIFICANCE #l. Throughput #2. Inventory #3. Operating Expense
FIREFIGHTING	TEAMWORK

Source: Managing Change, Inc.

Figure 2

Throughput (T) as the most important area. The TOC defines Throughput as the rate at which the system generates money through sales. Throughput is considered the most important area because there is no apparent limit to increasing T. JIT clearly established Inventory (I) as next in importance. Operating Expense (OE) is now ranked third. How much can OE and Inventory be reduced before the reduction limits T? Money is saved by TQM and JIT efforts but the goal of an organization is to make more money now and in the future while simultaneously increasing the quality of life of customers, co-workers, families and the organization.

Throughput clearly has the most significant impact on the bottom line.

Goldratt raises the following question relative to the techniques use in TQM:

"Where arc the techniques that management needs to deal with the chain? The unavoidable results of not having such techniques is a very slow improvement in performance of the chain. After a while, when people realize that many of their efforts are not leading to real improvements in performance of the company, they start to shy away, and their actions are just lip service. This situation is caused by the inertia of the inventors rather than the inertia of the implementers. (2)"

The same situation as stated above results from using JIT techniques.

TOC Five(5) Focusing Steps

The TOC employs the following 5 step approach when dealing with physical constraints:

1. Identify the system's constraint(s),

2. Decide how to exploit the system's constraint(s),

3. Subordinate everything else to the above decision,

4. Elevate the system's constraint, and

5. If, in the previous step, the constraint was broken, go back to step one and repeat process.

Using the above 5 steps is very effective when dealing with physical constraints, but there is a major concern:

WARNING: DO NOT allow INERTIA to cause a system's constraint.

Focusing on Non-Physical Constraints. Identifying and dealing with non-physical constraints can be very, very frustrating. The managers, the workers, the consumers, and the stockholders must have a better understanding of how a company must manage to be competitive.

The five steps of the TOC listed above are very familiar and powerful. Managers must realize that the underlying assumption in these five steps was that the constraints were physical: resources, material, or markets. Most managers are well aware that the real constraints of a company are always erroneous Rules, Training and Measurements (RTMs). These erroneous RTMs do not always give rise to a physical constraint. Row should a manager 60 about improving an organization in the more difficult case, where no relatively permanent, physical constraints exists?

The first stop still holds, managers must identify the erroneous RTMs that, right now, arc blocking the performance of the entire company. There is no point in just seeking erroneous RTMs, as there are too many of them in any organization. Trying to deal with all of them is not only ineffective, but it will throw the organization into chaos.

The problem is how to identify the RTMs which arc currently the organization's constraints. When the constraints are physical it is quite easy to identify them, but how can managers do it when the constraints are RTMs? Direct observations, statistical methods, and the like, are totally ineffective in this case. Thus, the first step must now be viewed in a different light. "Identify the system's constraints" should no longer be regarded as a practical recommendation of where to start; it should be regarded as a mandatory demand for a process that will enable management to identify the constraint.

This is the first step of the thinking process, the Effect-Cause-Effect Current Reality Tree. It deals with What to Change? This technique enables management to pin-point the core problem, to clearly identify the system's constraints-even when it is not physical.

When managers are dealing with non-physical constraints, the second and third steps become irrelevant. There is no point in exploiting an erroneous policy? Why should managers even try to subordinate everything to an erroneous policy? Therefore, when the constraints are not physical, managers must proceed directly to the fourth step, to elevate the system's constraints. Rut once again, this fourth step now presents a major stumbling block. If the constraints are physical, how to elevate them is clear but elevating an erroneous RTM means to replace it with a more suitable RTM.

"Elevate The System's Constraints" should be viewed as a mandatory demand for a technique that enables management to construct a replacement. RTM for their organization. Clearly, this process is not available for most organizations. This is exactly the task of the second step of the thinking processes, The Evaporating Cloud and the Effect-Cause-Effect Future Reality Tree. It deals with What to Change To?-with how to construct a suitable solution to identify the core problem- checking carefully that it will eliminate all the negative effects of the existing, erroneous RTMs, without creating devastating now ones.

The real challenge comes when managers examine the fifth step, in a case where the constraint is an erroneous RTM. "Do not allow inertia to cause a system's constraint", in a case where managers want to replace an erroneous RTM, translates actually into a cultural change. The fifth focusing step of the TOC used for dealing with physical constraints should now be viewed as a demand for a management process that enables a smooth transition from an old rooted RTM into a new one. This is the task of the third step of the thinking processes, the Prerequisite Tree and the Transition Trees. It deals with How to cause the Change?-with how to smoothly transfer an organization from one mode of operation into another.

The thinking process should NOT be viewed as a replacement of the five steps. It should be viewed as what it is, as a process that enables the execution of the steps in a very common case where the constraints arc not physical, but no less tangible, devastating RTMs.

The Three Major Blocks of the Thinking Process (TP) are shown in Figure These three major blocks not only provides the primary focus for dealing with non-physical constraints (RTMs) but also provides the means to make the third paradigm shift in the:

THINKING PROCESS

MEASUREMENTS

TQM is silent in the area of measurements and relies upon present outdated cost. accounting methods. JIT considers inventory a liability but accounts for it as an asset, a direct conflict.

The recognized measures for making money are net profit and return on investment. But Goldratt presents a slightly different outlook:

"These two measurements seem sufficient, but many a company has been rudely reminded by the threat of bankruptcy, that there is also a survival measurement, like cash flow. Cash flow is an on-off measurement.

THREE MAJOR BLOCKS
of the
THINKING PROCESS

WHAT TO CHANGE ?
Finding the core problem(s)
METHOD:
Effect-Cause-Effect (Current Reality Tree)

TO WHAT TO CHANGE?
Finding a simple solution
METHODS:
Evaporating Cloud & Effect-Cause-Effect (Future Reality Three)

HOW TO CAUSE THE CHANGE?
Finding the needed actions for the transition
METHODS:
Prerequisite tree, transition trees & Socratic method

Source: Avraham Y. Goldratt Institute

Figure 3

When we have enough cash, it is not important.. When we don't have enough cash, nothing else is important. (4)"

The present cost accounting concepts and procedures that are a bridge between actions and the bottom line measurements have proven to be inadequate. Johnson and Kaplan are just two of many writers that describe these inadequacies (7). How then is the impact that a local decision or action has on the bottom line measured?

Theory of Constraints(TOC) Measurements

The TOC uses the same global measurements that are also used by today's cost accountants, but with clearer definitions. All measurements use at least two of the following inclusive TOC definitions:

THROUGHRPUt (T) - The rate at which the system generates Money through sales. This is defined as the Selling Price minus Raw Materials.

INVENTORY (I) - All the Money the system invests in purchasing things the system intends to sell. This is the total amount of investment in the system, including such things as buildings, equipment, vehicles, and conventional inventory (but not including added value for labor in inventory).

OPERATING EXPENSE (OE) - All the Money the system spends in turning inventory into throughput. This is all the money constantly poured into the system to keep it operating, such as expenses for labor, supplies, maintenance, depreciation, etc.

The above definitions differ from the standard cost account methods in several ways. The major differences are:

Throughput only occurs when the money is received from the customer. Throughput is not when a work order is completed or when a product such as an automobile is sold to a distributor. In both these examples, the completed work order and the auto at the distributor are defined in the TOC as inventory.

Inventory includes everything purchased (invest money in). Money, paid to others (not your employees). There is no value added in the TOC definition of inventory.

Operating expense is all the money paid to the employees of a company. In addition such items as depreciation and interest on investments are defined as operating expenses. All material that is scrapped is defined as operating expense as is all material or services paid for that are used in the operations required to make the product.

These definitions can be used to judge the results for an overall organization by using the following formulas:

Net Profit =
Throughput - Operating Expense

$$NP = T - OE$$

Return on Investment = Throughput - Operating Expense divided by Inventory

$$ROI = \frac{T - OE}{I}$$

At the operating level of an organization, any decision which increases Throughput, decreases Inventory, and decreases Operating Expense for the overall organization, will move the organization towards its goal of making more money.

Goldratt in the "TOC Journal," refers to other uses of T, I, and OE for measuring non- financial measurements.

For example one of the most used non-financial measurements is Inventorv Turns. Inventory turns is expressed readily by the ratio between Throughput and Inventory. Likewise the ratio between Throughput and Operating Expense is a good way of measuring Productivity. The formulas are expressed:

$$\text{Inventory Turns} = \frac{T}{X}$$

$$\text{Productivity} = \frac{T}{OE}$$

present cost accounting methods do not provide correct measurements for local and non-financial areas such AS productivity, efficiency and inventory turns to mention a few. However local measurements like productivity and inventory turns can be expressed as shown above.

Reference (6) described other "cost world" measurements that when used without challenging the basic assumptions upon which they are based often lead to erroneous decisions. Examples discussed are :

1. Cost Accounting,
2. Performance Measurements,
3. Worker Time Standards,
4. Departmental Efficiencies,
5. Plant Utilization, and
6. Inventory and Value-Added Costing.

Reference (6) also described the TOC Control Measurements used to monitor subsystems as well AS complete systems. The real meaning of control is having the knowledge of where things are versus where they are supposed to be, and who is responsible for any deviation. The three TOC control measurements are:

1. local operating expense,
2. throughput-dollar-days (TDD), and
3. inventory-dollar-days (IDD).

With TQM being silent in the area of measurements and JIT presenting a conflict AS to how Inventory is measured how does an organizations trying to implement TQM and JIT use present cost accounting methods and procedures to effectively measure the impact of A local action or decision has on the bottom line?

Whereas the standard method of allocation of overhead to the cost of making a product resulted in very accurate Profit calculations in the Past, today it is virtually impossible to determine "product costs" unless it is a one Product company. Shipyards face the impossible task of determining the "product costs" of every line item in order to arrive at the cost of a ship. Perhaps the right answer is to not try to revise the present cost accounting system which WAS based on assumptions that are no longer valid but to develop a system that meets the goals of the organization. (6)

SCHEDULING

TQM is silent in the Area of scheduling, therefore present systems like Critical Path Networking (CPN) and Manufacturing Resources Planning (MRPII) are commonly used. These systems essentially try to balance capacity, whereas the TOC advocates the balance of flow and protection of constraints AS the real key elements to ensuring throughput. Present scheduling systems treat physical constraints AS bottlenecks. In reality most physical constraints arc not bottlenecks but resources that have sufficient capacity on average, but which lack capacity during some intervals of time. These resources have enough "productive capacity" but not enough "protective capacity. (1)"

Many present manufacturing Planning And scheduling techniques attempt. to optimize the use of all resources. This practice results in a tremendous build up in work-in-process (WIP) or A better name, <u>inventory</u>. The full negative impact of this inventory buildup is somewhat disguised because of the policy of partial physical progress payments required in many contracts.

In addition many present manufacturing planning and scheduling methods such as:

1. standard interval scheduling,
2. establishing schedule start and completion dates for all work orders, and
3. assignment of budgets do not consider the TOC philosophy of constraints and balancing flow not capacity.

Many present manufacturing planning, scheduling, performance measurement and progressing practices all result in a very negative effect on throughput and bottom line profits.

In Reference (8), Numbers 4, 5, and 6, Goldratt presents a very good discussion on JIT and the conflicts between the "Push-Pull" and "Pull-Push" methods of scheduling. JIT uses their KANBAN cards as a mechanism to "stop the push." However, "JIT or MRP, who is better? Who cares. Both are not good enough for our plant." Goldratt then provides his reasoning:

"We have to protect the performance of the plant as a whole. Trying to protect each unit of the plant causes us to spread protection everywhere.

Let's face it, we can afford only A limited amount of protection. We can not fill the plant with unlimited numbers of containers, we can not release material years before we have to ship the order. We Can not be too generous with protection, we can not waste it.

We must reserve the protection for what really counts. We must concentrate protection on what really matters. And in our plant it's crystal clear, we must protect our clients. We must deliver to them on time. (8)"

Reference (1) provides A detailed description of how data and information effect the decision process and how it can be used in the development of A scheduling system that deals with physical constraints. However as emphasized above the real problem is Policy Constraints (RTMs). TOC provides the tools to synergize TQM and JIT efforts and develop a true POOGI.

TOC NEEDS TQM AND JIT

The TQM and JIT movements are commonplace in most organizations today. The degree of implementation varies greatly from devout practitioners to interested parties to skeptics and even those who have discontinued their efforts. One thing is obvious-almost all have at least heard about TQM and JIT and in more and more situations some form of TQM and/or JIT is specified as a contract requirement. The present IS0 9000 movement also relates directly to these movements.

The TOC works well for those people and organizations that arc familiar with TQM and JIT and those that arc using TQM and JIT as A base to build upon. The majority of the techniques developed by TQM and JIT are very powerful and very effective in solving physical constraints (Links). The commitment of top management and their people in many organizations in many industries exist and there is also a growing consensus of the need for the TQM and JIT management philosophies. Many debate the merits of TQM, JIT and TOC as if there needs to be a choice. All three movements have the same objective:

"To make more money, now and in the future while simultaneously increasing the quality of life of our customers, co-workers, families, and organization."

It is obvious all three movements are essential ingredients to a successful implementation of A

PROCESS OF ONGOING IMPROVEMENT.

CONCLUSION

All elements of the traditional Approach used by the maritime industry and the government for purchasing ships from U.S. shipyards needs to be challenged.

THE TECHNOLOGY EXISTS.

The challenge is:

HOW TO CAUSE THE CHANGE!

TQM JIT and the TOC together provide the "tools" that will enable the parties to develop and implement a process of ongoing improvement. The adversarial relationships that exist today must be replaced with total cooperation and all efforts when implemented will result in a:

WIN-WIN SITUATION

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Training Shipbuilders With the Classroom of the Future

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ABSTRACT

To achieve the quality and productivity gains necessary to compete successfully in a global market, shipbuilders must prepare employees to apply diverse principles to complex problems. Rote learning of facts is no longer a useful paradigm for training employees to accomplish a wide range of shipbuilding jobs.

Imagine a classroom where the instructor has the ability to monitor the trainee's level of comprehension and motivation, even as the presentation is underway. This same classroom provides the instructor with instantaneous control over a complete suite of advanced instructional equipment and environmental conditions. Newport News Shipbuilding has used the interactive technologies provided by such a classroom, combined with group facilitation methods to significantly improve pass rates in a trades radiological control training program from 67% to 89%. One result of this improved pass rate is that retraining requirements in this program have been reduced by 67%. This report describes the use of this Advanced Technology Classroom (ATC) to meet customer requirements to upgrade classroom performance of radiological control employees. The customer's challenge, our review of the available technology, and the characteristics of the ATC will be discussed. The effects of organizational variables, normative change in the classroom, and relevant research concerning the use Of interactive instructional technology will also be covered. Finally, the implications of the ATC for other shipyard training will be addressed.

INTRODUCTION

The shipbuilding industry faces increasingly competitive markets on a global basis. bower demand is driving the cost of products down, while business costs continue to rise at a rapid pace. Additionally, customer quality requirements are changing. Industry customers expect delivery of consistently higher quality products with no significant increase in the price of these products. In this environment, shipbuilders must use training as a resource to prevent unnecessary rework and lost time, promote flexibility in the workforce and reduce cost. Employees in a competitive work force must be able to apply knowledge gained through training to an infinite variety of work situations. To meet these expectations, without significant growth in budgets, training departments must adapt available training technology to the unique needs of the shipbuilding and repair industry.

The Shipyard has combined the power of technology with the best practices in classroom training to design, develop, implement and evaluate a 40 hour radiological control course intended to qualify or requalify over 2000 skilled employees per year. The heart of this project has been the adaptation of International Business Machines (IBM's) Advanced Technology Classroom (ATC) to the training of skilled trades personnel. The use of this "classroom of the future" combines the best of traditional training with emerging instructional technology.

Over hundreds of years, educators have developed pragmatic, psychological methods for classroom instruction. Using the ATC to integrate these classroom methods with the robust and powerful efficiencies of instructional technology, the program exemplified the best of both approaches. Proven adult classroom methods, supported by instructional technology, have resulted in a course which minimizes memorization and rote learning and emphasizes problem-solving and decision making skills. These "thinking skills" require higher cognitive strategies. They are particularly important in job situations where employees must deal correctly with highly variable and complex situations. Since all variable situations cannot be anticipated and individually dealt with during development and presentation of training programs, rote memorization of "canned[a] responses is an inappropriate learning style for these job conditions.

THE CHALLENGE

In 1958 the Shipyard began building the first nuclear powered aircraft uss ENTERPRISE. This began a long and valuable relationship with the nuclear shipbuilding branch of the U.S. Navy. This customer continues to be influenced by Admiral Rickover's philosophy of continuously raising the standards of performance in all sectors of the Navy nuclear program. Like a winning football coach, the Navy continues to send the nuclear shipbuilding team back to the practice field for further improvements. This demand for continuing improvement includes contractually required training. Every year, the Navy demands improvements in nuclear-propulsion related training programs. These challenges require flexibility, adaptability and hard work.

The latest escalation in the Navy's expecfations has been especially challenging. Over the past two years a much higher level of performance has been expected of employees qualifying for radiological control work. Trainees are now expected to:

1. master course content of increased scope and range;
2. respond to test questions which require situational analyses and problem-solving rather than rote memorization; and
3. deal with radiological control situations of increased scope and complexity.

Training that covers not only facts and principles, but also their application to complex and highly variable situations is appropriate for all employees performing high-risk jobs, whether they be radiological control, fire fighters or plant protection personnel. All employees working in high-risk jobs must be prepared to respond correctly and quickly to a wide spectrum of unanticipated events.

To further complicate the challenge, the employees participating in the radiological control program have varying degrees of writing skills. This is a significant consideration since contract specifications require the confirmation of trainee learning through the use of written examinations containing scenario/case studies. The new Navy requirements are that trainees be able to analyze a radiological situation and describe the corrective actions that must be taken. Therefore, trainees must have the ability to develop written responses that clearly, logically, and accurately describe the actions and justifications they would take to correct a range of complex radiological problems.

The task was to create a course which would teach factual and procedural information about radiological control work, and also would provide the trainees with the critical thinking and problem-solving skills necessary to apply this knowledge to variable and complicated situations. At the same time, the course had to provide instruction, practice, and feedback using in the skills necessary to describe the correct response in acceptable written essay form. Along with developing these skills, the course had to impart the radiological principles used in shipbuilding trades. Think of the connectability and relationship between analytical thinking. writing skills, radiological principles and trade knowledge. Developing a program to address these issues and requirements was the challenge.

THE TECHNOLOGY

Training technology consists of more than hardware. It involves a logical, systemic approach to the analysis and solution of training problems. The Shipyard's training and development departments have adopted the Instructional Systems Development (ISD) philosophy as the paradigm for training program development. The ISD philosophy demands the systematic analysis of many variables as a prerequisite for program design, development, implementation and evaluation. This model was the foundation upon which the response to the increased customer requirements for radiological control training was built. Cost-effectively training over 2000 persons per year in problem-solving, decision making and writing skills, as well as the principles of radiological control, required an in-depth analysis of existing teaching methods, instructors, and facilities.

Analysis indicated that the Shipyard's traditional lecture methods could not meet the challenge, and suggested the use of some form of interactive training. Interactive Video training, which allows for a great deal of participation on an individual basis, appeared at first to be the most likely candidate. IVD's capability for individual pacing and instant remedial feedback, combined with the ability to present realistic full-motion- color video simulations of radiological control situations, seemed ideal. In addition, the content of radiological control employee training is fairly stable, which is a requirement for the effective use of IVD, since revisions to IVD courses can be costly.

A search of the literature confirmed that IVD is widely accepted in education and business as a cost effective and efficient training delivery medium. Five major literature reviews (1, 2, 3, 4, 5) have been conducted on IVD's effectiveness. These studies supported our expectations for IVD's usefulness in shipyard training. McNeil and Nelson (3) state, "Many teachers, business leaders, and administrators are enthusiastically investing in interactive video instruction as a solution to spiraling training costs and limitations in instructional time and personnel."

This finding is supported in a 1990 report by the American Society for Training and Development's BED Executive Survey:), which states that, of 200 human resource executives in Fortune 500 companies, "eighty-one percent report using computer-based technology to train. their employees, while half employ interactive video." They go on to say that by 1992, 71% of these companies will be using IVD systems. There is strong interest and growth in IVD use the military, business and industry, evidenced by the following endorsement from the federal government, "The Office of Productivity, Technology and Innovation (OPTI)- U.S. Department of Commerce, 'hopes that - increasing numbers of U.S. firms, factories, and educational institutions will look into and take advantage of Technology Based Learning (TBL) systemfP* (7).

However, the analysis indicated that IVD training had important limitations for use in the Shipyard's training environment, i.e.:

1. the number of persons to be trained was so large that a major investment in facilities would have been necessary to allow for the timely training of all radiological control employees in an individual instruction mode;
2. the organizational constraints associated with scheduling employees off-the-job for individual instruction were significant in the current operating culture; and
3. previous limited use of IVD indicated that, even though the instruction is individualized, some form of supervision or assistance is needed in the IVD training area, negating the often claimed IVD benefit of reducing instructor costs. These were significant factors inhibiting the choice of IVD for delivering radiological control employee training.

Nevertheless, the training staff was convinced *that* interaction was needed to impart the problem-solving and decision making skills necessary to meet the Navy's challenging requirements. Most literature describes IVD application as a one workstation-per-student teaching method. Trainees can call up their personal files, establish their own learning pace, and select content and tutorial support to fit their level of competence in the topic. What was needed was a system which combined the advantages of individualized instruction with the logistical and motivational strengths of group instruction.

Social needs including affiliation, recognition and influence are powerful motivators in shaping attitudes and values in a learning environment, and effective training design should mobilize these efforts to ensure learning. Social conventions frequently inhibit direct and purposeful design to bring about changes in attitude and values *in* many public educational settings. However, in business and industrial settings this hesitancy to encourage positive attitudes toward learning and job performance is less prevalent. A technology was needed which would support a program designed to link learning, job performance and positive work values. Using group norms to move disruptive or inappropriate behavior toward more desirable areas was desired, e.g., taking personal responsibility for one's own learning and job performance and taking maximum advantage of learning and growth opportunities offered by the company. Training staff have no influence over many aspects of the trainees' jobs. However, the training development program wanted the trainees to derive of personal growth from participation in the electronic classroom. The program was intended to be challenging as well interesting and to emphasize the trainees' involvement in a learning adventure that would help prepare them to take an active role in the accomplishment of company goals. The Shipyard's employees are technical experts and professional shipbuilders. They expect linkage between their performance in training and their expectations for challenge and growth in their jobs. The approach and linkage was not subliminal or hidden. Classrooms and settings, as well as course materials, were specifically designed to facilitate motivation and team building through increased instructor and trainee interaction. During instructor and trainee dialogues, values which support company business objectives were surfaced and reinforced. This impetus for trainees to change their outlooks and behaviors toward the collective good, i.e. company success, would be reinforced by their knowledge of business conditions affecting the shipbuilding industry.

The benefits of high levels of interaction between trainees, content and instructor became a major factor in selecting training technology. The successful implementation of training technology at the Shipyard would involve re-purposing traditional classroom instruction to the desired interactive approach. The instructor would no longer act as the technical expert, but would be a facilitator and coach, with the information-transfer role provided by the technology. Research (8, 9) indicates that computers have increased value when used as instructional support vehicles rather than exclusive methods of delivery. That is, computers function best in programs that integrate technology with live instruction, rather than as a replacement for instructors.

A fifteen year review of the use of computers in teaching conceptual and procedural skills in mathematics revealed the following.

1. Using Computer Assisted Instruction substitute for regular instruction is of questionable value, especially when compared to using it to supplement such instruction.
2. Using computers for instructional support is best achieved in the tutorial mode.
3. Using computers as a supplement to more traditional training increases the speed of learning and improves student achievement.
4. Using computers in this way seems to have the greatest impact on disadvantaged and low ability students.

These findings suggest that the integration of technology with more traditional group methods would work well with procedure-based learning requirements. This integration of technology with traditional group methods was the keystone upon which the project was built. Facilitation and group activities to support the social forces which enhance learning had to be combined with the technological hardware and courseware to support individualization of the learning process and provide instant prescriptive feedback for real time remediation.

A number of important organizational questions had to be answered prior to purchasing equipment and implementing an electronic classroom approach. First, did the Shipyard have the knowledgeable and experienced staff required to design and author a sophisticated computer-based interactive course on radiological problem-solving skills? The Shipyard training and technical staffs had worked well in the past, using a cross-functional team approach on projects of similar complexity, and it was felt they could succeed again. Although there were risks, training management and members of the project team were willing to accept them. Second, could the company get an adequate return on its investment in such training? Calculations, based on reduced time away from the job and predicted improvement in the passing rates, indicated that the potential payback was worth the risk. Success would depend on other factors beyond technical competency of the staff or the level of risk everyone was willing to take.

Organizational factors such as

skills in communication, decision-making, goal setting, conflict resolution, problem-solving and team building were also critical to success. Much effort would be needed to ensure organizational buy-in prior to critical milestones. To ensure a permanent institutional change, innovative programs such as the electronic classroom require organizational learning. The full gamut of organizational change strategies were built into the project's implementation process, including: staff role clarification. resolution of cross-functional expectations, use of new scheduling tools, agreed-to milestones, and staff and facilitator training. Decisions design strategies, presentation strategies, visual design, video program segmentation, embedded tests, graphics formats, keypad questions, final exam scenarios and grading requirements were among thousands of decisions that had to be agreed to. Since three departments would be involved in the project: (the training systems department that would develop the program, the skills training department that would deliver the training, and the radiological control department that would provide the technical experts and interpret customer requirements), attending to these organizational variables would be as much a requirement for success as was the correct selection of hardware, software, and courseware.

ADVANCED TECHNOLOGY CLASSROOM

The mission of the Shipyard's Training Systems and *Services* Department includes staying aware of current applications of training technology. In carrying out this responsibility, training program developers learned of a system which IBM was using for its own in-house management development. This "Advanced Technology Classroom'' (ATC) combined the presentation options of videodisc, videotape, audio cassette and VideoShow" (a graphic display system made by General Parametrics Corporation) with a high resolution rear projection screen and a student response system. All of these components were controlled by a Smart Lectern, consisting of a personal computer and a touch sensitive plasma display panel. Further investigation determined the ATC could serve as the centerpiece of our group-interactive program. The ATC transforms the traditional teaching environment into a state-of-the-art, fully integrated electronic classroom. It facilitates interactions between student and teacher with computer-based, pre-authored lesson plans supported by a variety of instructional media. *The* instructor becomes a facilitator, who orchestrates the outputs of the personal computer with graphics and text, videodisc, audiotape and linear video programs to meet the learning needs of the trainees. In the electronic classroom facility, even the environmental factors can be adjusted by the facilitator, as appropriate to the learning situation. The facilitator is able to exercise control of the media and program, either through a hand-held remote control device or from the Smart Lectern?

At a touch of the built-in plasma panel screen, the facilitator can move back and forth through the learning events making up the lesson, and show any sequence of content, including trainee responses. An electronic blackboard allows the facilitator to produce and project original illustrations and annotate existing visuals. Simultaneously, the facilitator can view prompts or cues and the sequence of upcoming content. The facilitator's personal notes can also be programmed into the system and read from the smart lectern screen.

The ATC offers employees a means to actively participate in the learning process in the classroom environment. An electronic keypad at each student's desk allows individual responses to questions programmed into the instruction at critical lesson junctures. Using data generated by these student answers, the ATC system tabulates and displays, for immediate use, all responses for comparison to others in the current class and all previous classes.

This multimedia system, when developed using learning strategies intended to teach problem-solving, confronts the issue of teacher proficiency. By training top-notch classroom instructors during the development of a program, they become facilitators in presenting the program and can be elevated to a higher level of effectiveness.

The system resolves a number of methodological issues encountered by all instructors, regardless of course content or student audience. First, the system provides a rapid paced mixture of stimuli, which is a salient feature of all effective instruction. Each time the stimulus changes, and that is often, the learner naturally refocuses his or her attention.

Increased attention from increased stimuli leads to faster learning and longer retention. Second, logistics problems encountered in coordinating the use of several media devices, such as videotape, slide projector, chalkboard, overhead projectors, computer graphics and laser discs, are no longer an excuse for non-use. In its normal mode, the ATC automatically turns these devices on and off, as needed. When the devices are being controlled by the facilitator, they are energized from a single controller, either the smart lectern or the hand-held remote control device Third, management of class time is controlled through the automation of the pre-authored- presentation. The intellectual burden on the facilitator is shifted from remembering what to say next to interpreting the meaning and importance of the content. Fourth, the facilitator/instructor's age old question, "Am I getting the message through?" is resolved through immediate electronic feedback. After each keypad question, the facilitator can see how each trainee responded using the display panel on the lectern's plasma screen. Subsequently, group response data are compiled and graphically displayed on a rear projection screen to stimulate discussion and reinforce the correct response. The keypad questions embedded in the program can include both content and attitude inquiries, so that both comprehension and motivation can be monitored. Fifth, the classroom's shape and seating arrangement are designed to increase student interaction. The students are encouraged to address comments to one another as well as to the facilitator. The facilitator reinforces this behavior, which enhances interest and motivation to the point that discussion of critical points often extend into breaks and after class. Once the students learn it is acceptable to speak up and join in, the flood gates holding back enthusiasm and participation are opened wide, releasing supportive anecdotal job examples of job situations confirming the concepts and principles presented in the lessons.

PROJECT IMPLEMENTATION

The Shipyard took delivery of its first ATC on June 1, 1990. This was essentially a prototype product which IBM had previously used for its internal management development. Their research and marketing staff worked closely with the Shipyard instructional design staff as development and courseware production began. This collaboration led to a business partnership between the companies intended to expand and improve the capabilities of the ATC. As a result, the developer is now marketing a second generation product called the Interactive Multi-Media Classroom (IMMC). The Shipyard has obtained two IMMC systems and-is using them interchangeably with the ATC as components of the electronic classroom.

A multi-department team was formed to develop our radiological control course. The team consisted of training program developers and video production personnel from the training systems department, instructors and supervisors from the trade training department and technical experts from the radiological control department. The team's original mission was to convert a course module which dealt with handling unusual radiological control situations from a traditional training approach to an electronic classroom approach. The segment on controlling unusual hazardous situations was the course component that the Navy was most anxious to have strengthened. Developing and pilot testing this difficult segment provided both experience in developing electronic classroom strategies and confidence that the new approach would enable the Shipyard to meet everyones expectations.

By October 1990, the training department was ready to begin a series of pilot tests that continued through May, 1991. After these tests, the department was convinced that the electronic classroom should become the primary method of presenting radiological control training. In June 1991, the development team began conversion of the remainder of the radiological control course to the electronic classroom. This project was completed in September, 1991. Since that time, all initial radiological control qualification training has used the new interactive courseware. In May of 1992) conversion of the radiation requalification lecture courses to the electronic classroom format was completed. Opportunities to expand this approach to other training programs that may be suitable for conversion are being identified.

PROJECT EVALUATION

Converting radiological control training to the electronic classroom approach was a project of such size and complexity that evaluation had to be conducted on many levels. Prior to determining whether the project met its return-on-investment objectives, the results *in* terms of increases in learning and training efficiency had to *be* measured, and such seemingly peripheral items as trainee satisfaction and staff acceptance of the new technology evaluated. Another important evaluation question was whether the introduction of new hardware processes and relationships strengthened or weakened our training organization.

The answer to the question, "Did introduction of the ATC result in increased learning and a more efficient training process?" was an unconditional "Yes." The percentage of trainees who failed the course declined dramatically after introduction of the ATC. In 1991, using traditional training methods, our failure rate for first-time radiological control trainees was 33%. Since the Shipyard started using the electronic classroom, the failure rate has declined to 11%. These improvements in pass rates and average scores have been achieved while significantly increasing the scope and difficulty of the course. These *new* standards of trainee performance satisfy the Navy's need to be more comfortable with radiological *control* employees' ability to respond correctly to a wide range of radiological control situations. Navy representatives have reviewed the program and found our resolution to their challenge to be "unique" and "very positive." Although a formal analysis of the return on investment from these improvements has not been completed, these increases in learning, learner motivation, course efficiency, and customer satisfaction should more than pay for the costs of the ATC conversion.

On a more personal and subjective level, the question, "Would we do this again?" can be answered with a another resounding, "Yes." Being part of a project to invent and implement a project to success is very rewarding. It has also resulted in increased job satisfaction and promoted a spirit of camaraderie among all of us who took the risk. The training program developers and instructors agree that the project was challenging, rewarding, and has resulted in a great deal of personal growth.

The three departments participating in the project gained new skills and were strengthened internally. The group processes and shared viewpoints learned through participation on the project team will have a long lasting impact on all future interactions.

The operating departments and trainees, who are the Shipyard's internal customers, also believe that the multimedia technology incorporated into the ATC represents a more effective approach to training, especially when the objectives include the application of principles rather than mere memorization of facts and procedures. The line managers who supervise the trainees completing the program see the benefits in terms of less time off the job, less need for retraining and better trained personnel. There seems to be no question that the trainees prefer training that is interactive, fast paced, and directly related to their jobs. Evaluations conducted after each class confirm that the trainees' motivation and attention levels, general attitudes about company training and level of confidence in course content are all quite positive. Finally, on measures that are always of vital importance in the shipbuilding industry, the project was completed on schedule and within budget.

IMPLICATIONS FOR OTHER SHIPYARDS

There is an old joke that goes, "Profits are down. It must be time to cut the training budget again." cutting the training budget is not the answer to a downward spiral of profits. However, increasing training effectiveness and efficiency can be a proper response. This experience with multimedia at the Shipyard has shown that a judicious integration of innovative technology with traditional training methods provides a profitable solution to a type of training problem which will become more and more prevalent as U.S. shipyards reorganize for global competitiveness. That is, training employees to apply principles and problem-solving methodology to a wide range of work situations which cannot be anticipated when designing or presenting training programs. In addition to high-risk training, of which the radiological control program is typical, other uses might include application of quality techniques such as Statistical Process Control (SPC) to shipbuilding situations and training of test and maintenance personnel in troubleshooting. Similarly, Hartigan's paper, "Shipyard Trade Skills Testing Program" (10), pointed the way to effective use of training technology for "just in time" training of individual employees.

However, for an industry attempting to redefine itself for global competitiveness, shipbuilding is far behind other industries in the use of educational technology. In 1991, the NSRP sponsored an investigation into the feasibility of using interactive instructional technologies in U.S. shipyards. This landmark study was managed by William E. Wilson, National Steel and Shipbuilding Company, technically supervised by Mr. John W. Hartigan, Director of Shipyard Training, Naval Sea Systems Command and performed by Richard B. Cooper of Ship Analytics, (11) -

This study found that the conditions for successful use of interactive video disc technology were present in many shipyard training applications. These conditions exist when:

1. there are large numbers of students;
2. instructors with subject matter expertise are difficult to obtain;
3. simulation of equipment, procedures, or activities is required;
4. potentially hazardous procedures are to be taught;
5. the training requires continuous practice, re-training or re-qualification;
6. the content is relatively stable over time;
7. training requires problem-solving or decision making; and
8. students vary in experience or skill level.

All these criteria need not be present in order to bring about performance improvements or 'cost efficiencies. However, if several of them are present, a detailed job-task analysis followed by a cost-benefit analysis should be conducted to determine if expenditures for the introduction of- technology are justified. A lack of knowledge of interactive technologies, and in-deed, of task analysis and cost-benefit analysis skills may be one reason for the lack of more widespread use of training technology in U.S. shipyards. The NSRP Report (11) states that, "Few shipyards, private or naval, currently use interactive instruction for skilled-trade training." When asked to rate their familiarity and knowledge on this topic, 90% of the private and 86% of the naval shipyards reported they were either "mostly" or "completely unfamiliar" with the technology: This is a disturbing finding, considering that interactive technology has been in public use for almost a decade. This lack of knowledge or interest is further substantiated in a follow-up question that asked, "If assistance were offered, would you be interested in implementing this technology?" A response of "Possibly welcome or Not be interested" was given by 84% of the private and 57% of the naval shipyards.

There are many reasons for this lack of knowledge, experience, and interest, foremost of which may be the shipbuilding industry's generally conservative and traditional approach to innovation. However, the end result under utilization of technology in areas where it could cut costs and improve the effectiveness of shipyard training.

Insight into the organizational effects of unbridled trust in tradition is provided in a paper presented by Rogness, "Breaking the Chains of Tradition and Fantasy - A Revolutionary Approach to - the Constraints on Productivity" (12) - Rogness states most eloquently and forcefully of the lack of change in American shipyards: "It is very difficult to overcome the inertia and incumbency of tradition in an environment where it is not realized that all facets of a tradition are nothing but precipitates of earlier changes. It is extremely difficult for a creative thinker to survive in a repressive environment which ENFORCES unquestioning acceptance of tradition, rather than ALLOWING the vigorous pursuit of new knowledge." The personal risks to bring about change in an authoritarian system are often so high that the final outcome is institutional atrophy.

To be an effective instrument of change in the movement to streamline the ship production process, training must accomplish the following.

1. Employees must learn the principles behind shipbuilding processes and techniques.
2. Training must teach employees how to apply these principles to manufacturing shops and shipboard production environments. Training developers and instructors can never anticipate the problems and decisions employees will encounter on the job. Therefore, the application of principles, and not rote

memorization of "canned" solutions, must be the intent of training.

3. Labor costs and time away from the job required for training must be minimized.
4. Offer training programs that are like laser beams targeted to specific employees just prior to a specific job.

As indicated by the Wilson, Hartigan, and Cooper study (11), Hartigan's just-in-time training scenario, and our experience with the electronic classroom, the judicious and imaginative use of available training technology provides an avenue for reaching these goals. Conservatism and reliance on tradition must not blind the shipbuilding management to the advantages to be gained. Effective and efficient training of the workforce in U.S. shipyards must be an issue for everyone in the industry. Global competition demands continual improvement in product quality and labor productivity. U.S. shipyards' manhour productivity per unit of output is reported as being only 40% that of Japan and 82% of Korean shipyards. Certainly, a contributing factor to this state of affairs is the "comparatively low level of education and training of employees, staff, and management"-(13). The implications of this productivity gap for the shipbuilding industry's survival are too significant to leave to the evolution of traditional training methods, geared to the comfort level of training departments. As is true *for* all revolutions, change rarely comes from within, it must be imposed by those with visions and intestinal fortitude. Operating management must articulate the strategic targets for improved job performance which training can meet through the application of technology. Operating management must then provide the necessary resources and demand accountability from training departments for improved trainee performance on the job.

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Training Initiatives for Classifications Society Personnel

No. 9A-2

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ABST`RACT

The Ship Classification Society is an institution unique to the commercial maritime industry. For a single vessel the classification society may act on behalf of a number of client organizations: owner, shipyard, underwriters, furnishers of capital, flag state, port state, etc.

The interests of these various groups require a professional staff totally familiar with the uses and practices of the industry, codes and laws of vessels trading nationally and internationally, flag and port state regulations and, of course, the engineering disciplines and practical skills associated with the design, construction, maintenance and operation of vessels.

In the not too distant past it was possible. to acq uire experienced professional staF requiring litte additional training. With the shrinking U.S. flag fleet, this pool of professionals has largely disa pearcd in this country. Todays professional stafP of engineers and field surveyors is drawn largely from recent graduates of the maritime academics and colleges of engineering.

Although well prepared these personnel do require extensive on the job ancl classroom naming to meet the objectives of the American Bureau of Shipping. In addition to our internal objectives, the quality assurance constraints of the European Community and others place a special emphasis on documented training.

This paper will discuss some of the problems encountered in delivering training for a multt-national, multi-cultural and multi-lingual organization, and the initiatives being undertaken by the to provide the necessary skills and lo ensure reasonable and consistent inter rctation and application of codes and Stancards and professional execution of assigned tasks.

In order to realize these objectives, a training program must be aggressive and pro-active and look into the future to anticipate the requirements of developing technologies and it must do this within severely defined budgetary and manpower constraints.

INTRODUCTION

The scope of the activities of the company and other ship class societies has expanded dramatically the past 40 years. From a relatively narrow concern with the hull structure and machinery plant of the ship it has grown significantly to include many other as aspects of the maritime enterprise. In addition from being almost totally free from constraints, the maritime enterprise itself has become subject to extensive international and port and flag state regulation. At the same time, driven by technology, the size, character, types of ships and arrangements have changed. Mobile and fixed offshore rigs have come on the scene in large numbers in the search for petroleum beneath the seas.

QUALITY OF SEKVICE

Within the members of IACS (International Association of Classification Societies) there is a concern for the quality of service and for surveyors to have the skills and training to deliver that quality. In the past the concept of quality was largely intuitive and subjective; what has changed is that quality has become formalized with standards mpr;tviding for an objective measure With the development of IS0 9000 by the International Organization for Standardization, certainly the most well known of quality standards, there are now specific requirements by which to judge a quality system. Two of these requirements are of interest here, namely, trainin and documentation . One of the things, flowever, which IS0 9060 does not provide is a definition of quality; in this respect all are left to fend for themselves. A reasonable statement might be that when clients receive what they bargained for and expected they have received a quality service. This presupposes, of course, that the clients' expectations were reasonable and were understood by the provider of the service.

In many cases the services involve transactions with multiple clients.In the process ot classmg a vessel and related statutory work, for instance, although normally retained by the shipyard, the classification society has direct or indirect responsibilities to the owner, to the port and flag states, to the vessel's multiple underwriters, to the financial institutions providing the capital, to the vessel's future crews, to the future cargo interests, to the environment and many others . The task of attaining a consonance of expectations with each of these many parties is considerable. A provider of services must be concerned with the quality of the services provided: whether the company prospers or fails depends largely if not entirely upon the quality of the work done. At the end of a contract regardless of whatever disputes may arise between the other parties, they should all be satisfied that services have been provided in a professional manner and as advertised. Of course this may he easier to sty than to achieve, but for now this is what is proposed as a quality service. In other words in the case of a contract for classification for new construction direct and indirect clients are offered an oversight service which is consistent and professional in applying rules for classification, statutory instruments, regulations and standards as required and in carrying out other oversight obligations with skill and diligence.

This is the goal, but how to get there from here? Compliance with IS0 41000, and to the standards of quality set by IACS is a first step. An important element of each of these standards, and truly im ortant in its contribution to quality is **training.** -**Th**e IACS document is based on IS0 9000 and is customized for the particular aspects of classification work; since, there are no serious discrepancies between the two, IS0 9000 is used as a model. Figure 1 below identifies the IS0 training requirements.

* Identify the need for personnel training
• Identify necessary skills
* Estabhsh training methods
* Qualifying basis:
  Apporpriate education
  Training and/or experience
• Maintain training records and
* establish Procedure for:
  identification
  collection
  indexing
  filing
  storage
  maintenance
  disposition

FIGURE 1
IS0 TRAINING REQUIREMENTS

THE NEED FOR PERSONNEL TRAINING

Traditionally most professional training has been " on the job" (0JT);in general the required skills can be learned faster and more efficiently on the job than in a classroom environment provided that the candidates possess the prerequisite schooling and sea going or shipyard or related experience. A licensed chief engmeer, for instance, can be expected to have a substantial grounding in the engineering systems of a vessel and has probably dealt with classification society personnel in the course of previous employment. Today the number of such persons, however, is severely limited, and the candidates are mainly entry level people who, although graduates of maritime or engineering colleges, have only a limited knowledge of the industry.

Because of the worldwide nature of mllritime commerce, clients corn rise peoples of many diverse languages and cuPtures, and to seme this clientele offices are located in all friendly maritime nations staffed principally by local nationals. While there are a few expatriates in key administrative positions, the bulk of the day to day work involving plan review and survey is carried out by nationals. Although a certain command of English is expected this is sometimes less than perfect, and even thou h there may be a good comprehension of t1e rinted word, the intent of the text may remain fiidden because of a different cultural background. Consistency in the interpretation and application of the rules and practices of classification throughout the organization is a fundamental requirement for providing a quality service. This is difficult at best even in the U. S. with U. S. nationals working with English texts; worldwide it becomes a matter of great concern and requires training which provides very explicit guidance, and this guidance must comnrise not only the technical aspects of the particular discipline, but also it must ensure that there is an understanding of the translation of the printed word to a physical arrangement.

In addition, a changing regulatory environment, new technologies and trading patterns as well as changes in the rules for classtfication require a constant updating of skills for all members of the field and technical staffs.

Figure 2 which follows illustrates the next step in developing the training program.

1) Deternmine those work processes which hll under ISO 9000; this includes all which relate to the delivery of a product or service 10 a client.

2) Determine and document training and knowledge requirements for each of these work proccsscs.

3) Determine status of each person within the work process as it relates to the rrquirments.

4) Prepare a detailed training pkm 10 correct deficiencies.

5) Estnblish pl:in for rccortlirig training mnnlioun. status vs. rccluircnicnls, and control to ensure qualilicd persons are assigned to tasks.

6) Review for corporate consistency.

FIGURE 2
PROGRAM DEVELOPMENT

Please note particularly Item 6 in Figure 2 i. e. "corporate consistency". Too often plans are developed and carried out without regard to consistency throughout the organization: this leads to dissatisfaction for external clients and confusion and frustration for internal clients and an overall degredzltion in the quality of the service.

PROGRAM REQUIREMENTS

In order to determine and define the training requirements some method of analysing and recording the various tasks carried out in the course 01 classing a vessel was required.

What has been done was to define certain Work processes. Engineering Review. for example, which was then broken down into categories, proccdurcs and work instructions. To go a little further. Engineering Services which comprises the review of machinery drawings becomes a Category and next under the Procedure heading would come "Electrical & Control Systems," and finally under Work Instructions - One Line Electrical Diagram.
When this has been completed for all l'roccsses a great volume of' work instructions has been accumulated. From this great volume OC work instructions a very clear understanding of the tasks routinely pcrformcd and the knowledge and skills necessary to perform these tasks successfully can be ascertained. The work instructions are useful not only for truini!lg, but are a lool to be used regularly III tlic performance of each task.

In drawing review, for instance. XII engineer can call up tlic work instructions for the particular system under study together with the applicable sections 0f the rules and any other standards or comments that may apply. On a company wide basis this will ensure the maximum in consistency. As noted earlier many different tanpages and cultures are represented in the statf and also in the clientele and since the rules and other relevant tcxfs are written in arid arc to be interpreted in American English, it is vital that their sense be conveyed to the staffs of other countries in the most explicit form possible. A corollary to this is that formulations of SOLAS (Safety of Life at Sea - 1974 and Amendments) and other international documents are sometimes in a form of English noI consistent with US usage.

Having determined what training is requircd ,thc next problem to be Czced is how il is to be provided. First a range of entry level requirements has been been developed. 13med on these requirements formal programs for entry level technical and field candidates have been constructed. The training will start with a module covering the history of classification and other inforamative and administrative subjects.
Next come modules covering the rules, survey practices and duties of the engineering and field staffs with instruction carried out by experienced personnel. Although the programs for technical and field staffs will not be identical, both will require that the candidates spend designated segments of time in the techmcal departments and in the field. Evaluations will be carried out on a continuing basis. At the end of the indoctrination period each candidate will be assigned to a field office or a technical dcpartmcnt to continue on the job training in accordance with a schedule to be prepared by the head of the department or field office withz modules prepared from the work instructions developed previously. For experienced candidates from Ihe industry an inventory of tranng modules wltl be available to supptcment or fill any gaps in previous training or experience.

Figure 3 which follows on the nest page illustrates the systems analysis for the trarning function.

Of vital importance in addition to the actual training is the maintenance of an inventory of the skills of each individual employee in such a manner as to make information available on demand.

It is intended that all classification ahhociatcd training be carried out by in house staff, and. the individuals sclccted to do the training will require training themselves in the substance of the technology, in methods of instruction and in record keeping. Another vital part of the procc.ss is the development of training pl;un~ and study material.

Outside Irourccs will be used as ncccasary to assure diversity and to remain in touch with with currcm technology.

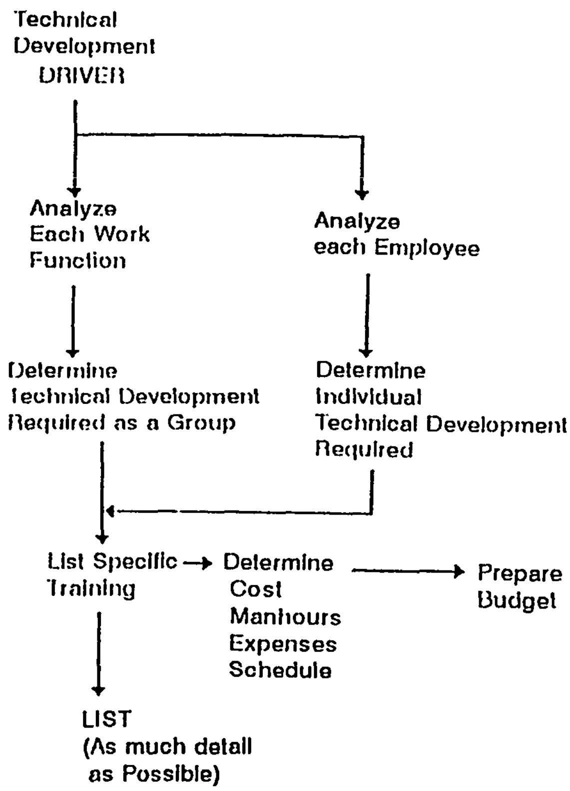

FIGURE 3
TRAINING FLOW CHART

CLIENT PARTICIPATION

An additional and important goal of the training initiative is to encourage client interest and articipation . This is being done today in a limited way, but a concerted effort will be made in this direction. Earlier in the paper mention was made of the many diverse client interests in any given vessel being classed. It is a fact that the better informed each of these clients is with respect to the service to be provided and in the manner in which it is accomplished, the simpler it is to represent their interests. As a case in point, certain functions carried on behalf of the U. S. Coast
subject to their oversight. Although not a requirement of the overstght program, training has been offered to their staff which has resulted in a better understanding of how each of the organizations approaches its assigned tasks. Familiarization programs have also been have been offered to ship operators, underwriters and others with an interest in maritime affairs.

SPECIALIZED TRAINING PROGRAMS

There is a trend for certain professional organizations to provide "certification" for candidates who have completed a course of instruction and been examined as to their competence in certain special skills; among these are the following

ASME (American Sw. of Mechanical Engineers) Authorized Inspector
ASME Supervisor
IS0 YOOO Assessor
Auditor -Steel Structures Painting Council
Auditor - American Petroleum Inst.
CertifierJ Welding Inspector
Nondcstructivc Testing

These certifications are valuable as cvidcnce 01 roficiency in the respective skills, or they may fle required in certain cases (ASME cUC IS0 for instance) for certain tasksIn house training in weld inspection and nondestructive testing is conducted for the staff and clients.

For engineering staff professional . registration is encouraged and supported.

BUDGET

In order to provide for the financial and manpower budget a precise breakdown is made for each office worldwide with allocations for the staff to deliver or receive training. This is an important consideration for quality planning in order to prevent manpower constraints from interfering with scheduled training.

CONCLUSION

Training is fundamentnl to providing a quality service.

Emphasis in this paper has been on the operational and engineering staff, but training is required throughout all parts of the company.

Training is required to remain competitive.

Training is necessary to retain competent staff.

A mixture of classroom and on the job training is considered the best mix.

The tkning budget should include manpower as well as money allocations.

Training does not come cheaply, but without it the organization will not prosper.

Technology,operational constraints, management practices etc. in the maritime industry are changing constantly; under these conditions it is unportant to recognize that training does not and must not end after six months or a year or five years, but must continue until the engineer or survevor retires from active service. This is the program to which the classification societies are committed.

THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
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Standardized Designs Within a Shipyard - Basing Decisions on Costs vs. Returns

No. 9B-1

Tom Soik, **Member, Soik Associates**

ABSTRACT

While the US. shipbuilding industry strives to establish a program of standards on ;I national level. the concept of inlemal (company) dcsipn Standards is often neglected as a basic principle of industrial economics. Most shipyard executives will readily agree with the basic concepts 01' standardization. hut II~WII closer examination It appears that. with a few cxcrptions. the level of implemented standardization within U.S. shipyards lags significantly behind Ihat of other indtlstries and shipyards in competing nations. The initial reasons for this arc many and varied. hut it is usually rcduccd IO the prohlcm of identifying specific 0pporUmities for standardization of design and quantifying potential savings.

This paper will define the principles of design standardiwtion as they apply to the internal functions of a shipyard and examine the economic factors that drive their implementation. Within its limited length and scope. it attempts to provide ;I vision of ;I basic economic principle applied to its optimum cl'effectivencss in U.S. shipbuilding.

INTRODUCTION

'I'hc notion Ihat the detail dc.\lFn procc~s for il shipbuilding contract can only commence II~OII ;Iwitrd of tlw COIHIXI is ;I throwback to the relative boom years of shipbuilding when delivery schedules and profit margins allowed the "luxury" of having an engineering staff develop every detail for every contract from scratch. The marketplace today will tolerate nothing but the highest level of efficiency and cost-effectiveness from its suppliers. *Repetitive design of standardizable fabrications is non-value added work.*

Yet. engineering staff today arc continually called upon to redesign hardware and systems that look and perform identical from one contract to the next. Draftsmen draw up the same designs. planners process the same designs. and material control procures for the same designs from one contract to the next as if they were new&srj~~~. All of this wo~~ltl be excusable if there were improvements made IO the product. hut in many cases this is not the reason for the redesign. Kedesign is called for simply hccausc the engineers have no other way of getting it built. draftsmen have *no* other way of drawing it. planners have no other waly.... Ultimately. this wasted effort is telt not only in the engineering and administrative budgets. but in the production trades as well. Design information. the life-blood of the triIdtTS. does not flow IIS cfficicntly as possible and more importantly. there is no asstlmnce that a component will bc designed the same way twice, resulting in retooling. relearning. and dchugging cvcry time the part is designed and fahrlcatcd.

AII alternative system is needed by which repeatable designs can be invoked from contract to contract without going through all the processes required for new designs. This is *design standardization. It* should *be* achnowledged that all manufacturing enterprises. including shipyards do practice some degree of design standardization. Most shipbuilders usually have components and assemblies what arc rccogniycd as hcing "standard" designs (pipe and cable hdnpers. penetration details. small foundations, etc.) that manage to short, circuit the onerous "new" design process. usually on an informal basis. This process evolves simply because it is more cost-effective to build with standard designs. Whether it is actually called standardization or not that is exactly what it is. What needs to he done is expand that thinking beyond the obvious candidates that beg for standardization and explore opportunities that might not be quite ils obvious. hut just as profitable. Defining profitibility in terms of standardized versus non-standardized design requires a mechanism by which to compare costs of each to enable engineering managers to make standardization decisions based less on short-term expediencies and more on long-term economics. This is the optimization of the principle of standardization.

DEFINING OPTIMUM STANDARDIZATION

The only real test of a concept introduced lo a manufacturing environment is. "Will it contribute to our profitability?". While it is difficult to put specific dollar values on the design and other processes that contribute to a product's design without doing a detailed cost analysis. it is possible to present their relationship in mathematical models as shown below. These equations take into account only the most direct and easily identified costs of design. It dots not factor in less tangible peripherdl benefits. such as improved quality. reduction of inventory. and reduced production costs that can accrue from the use of standardized designs. These benefits will be discussed later.

EQ 1

$$\text{COST, NON-STD'D DESIGN} = \frac{C_d + C_a}{U\,(C_u)}$$

EQ 2

$$\text{COST, STD'D DESIGN} = \frac{(C_d + C_a)}{U\,(C_o)} + \frac{C_s}{n}$$

where:

C_a = Cost of administering the design (or Design Standard) through the planning and procurement processes

C_d = Cost of developing a new design (EQ I) or invoking a Design Standard (EQ 2) for a specific item

C_s = Cost of development of a Standard for a specific design

C_o = Direct Cost (labor and material) of each unit to be manufactured to a standard design

C_u = Direct cost (labor and material) of each unit to be manufactured to a non-standard design

n = Number of applications over the life of the standard design that it is anticipated the item will be required to be specified for manufacturing

U = Number of Units to be manufactured as the result of the development of a new design (EQI) or the invoking of a Design Standard (EQ 2)

The product of the equations is a ratio of the cost of design and administration to the cost of manufacturing an item. Therefore. in order to justify a standardized design:

EQ 3

$$\frac{(C_d + C_a)}{U\,(C_o)} + \frac{C_s}{n} < \frac{(C_d + C_a)}{U\,(C_u)}$$

A cursory review of this equation would suggest that the cost of the standardized design would be greater than for the non-standardized since the cost of developing the design standard (Cs) must be factored into the end cost. However, an analysis of the factors is needed to demonstrate their offsetting affects.

COST OF design. C_d

obviously. one of the most important consideration IS the difference in cost between doing a "scratch" design and invoking a standard design. A conservation estimate based upon case studies places the cost of non-standardized design at 2-4 times that of standardized. depending upon the sophistication of the srandardization format and processes.. To look at the extremes of either method. it is the difference between researching, designing. and drafting a component every time it is used and simply calling out a standard part number for the component.

The main objective here is not to try to quantify the costs of standardized design versus non-standardized design for individual designs. but to identify candidates where the spread of their relative costs is a.. great as possible, this. of course assuming that costs for the standardized design is less than non-standardized , which in almost all cases. it will be.

COST OF AMDINISTRATION. C_a

Just as the engineering staff struggle with each new design that they put out the planners and material people must also manually wade through repetitive non-slandardized designs. process by process and material by material. Standardized deigns. on the other hand can be automated similar to macros on a computer program to greatly reduce these repetitive tasks. Again. the objective is to identify those candidates most conducive to automation of these administrative processes and which will show the greatest pain.

COST OF` STANDARDS. C_s

The cost of a standard design is simply that which it takes lo research, design. approve and publish the Standard. This process is much the same as it design were hemp done for a contract's construction drawings. but with one important difference Since the Standard will be expected to be invoked upon a variety of applications with a minimum of research and at the same time with a high level of confidence. it must be developed with a much higher level of diligence if it were a one lime application.

While there are a number of factors affecting the cost of developing a standard design, a rough rule of thumb is that it will be approximately five times that of developing a design for an individual application.

NUMBER OF APPLICATIONS. n

This is the key factor in amortizing the investment made in the development of the standard. C_s.. it is this factor alone, more than any other that determines the value of standardized design over non-standardized since n must be high enough to offset the initial expense of developing the standard. As the number of anticipated applications increases. the cost of the standard per application decreases.

There is no scientific method in determining this number. it is a subjective call. based largely upon anticipated markets. changing technologies. and historical perspective. A peripheral benefit of determining this factor is that it provides engineering managers the opportunity to look a head and plan for future design work. regardless of its being standardized or not.

NUMBER OF UNITS U AND MANUFACTURED OF UNIT. *C_o and Cu*

A general depiction of manufactured cost savings due to variety reduction can be derived from an equation developed by Dr. Ivar Martson.

EQ 4

$$C_u / C_o = (P_o / P_u)^{-x}$$

where:

C_u / C_o - fractional cost savings, C_u being unit Cost after Variety reduction (standardization). c_o being unit cost before standardization.

P_o/P_u = ratio of variety reduction. P_o and P_u being the number of the part type before and after standardization. respectively
% - empirical exponent whose Value ranges from 0.25 - 0.30 for manufacturers

P_o/P_u, can further he defined by relating it to the ratio the volume of units volume of units manufactured before and after variety reduction:

EQ 5

$$P_o / P_u = R_u / R_o$$

where:
R_u and R_o = **the output volumes of the** part types before and after variety reduction. respectively

As stated in EQ I and 2. U is a given , there being a finite number of components and assemblies that can be installed on a ship. The motivation must be toward variety reduction such that U approaches thc total number of manufactured components and assemblies on the ship. Where Ru can quite concievably equal I (U as used in EQI), R_o (U as used in EQ2) can more readily be increased to approach unity with the total number of required applications. using standard designs.

By applying the principles of economy of scale brought on by the reduction of variety and the increase in units manufactured. C_o the manufactured cost of the unit will inherently be reduced. This is due not only to the ability to manufacture in larger runs. hut also due to the fact that as the design stabilizes improved manufacturing processes can be more readily applied to it. Tooling. fixtures. and procedures can be developed with the confidence that new and unexpected designs will not obsolete them.

CASE EXAMPLE

(using a hypothetical. but very common candidate for standardization. the costs of standardized versus non-standardized design can be examined more closely and in tcrns of real dollar\. The candidate to be cxamined is a common round bar hand grab found throughout a Variety Of ships. A typical design. based upon ASTM Standard 1. 783-88 is shown in Figure I.

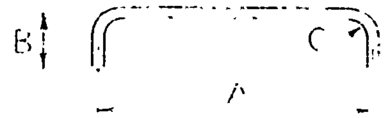

Figure I
Round Bar Hand Grab

Applying estimated values to the equation for non-st;lndardized design:

$$\frac{C_d + C_a}{U(C_u)}$$

C_a = $25
C_d = $25
C_u = $2.00
U = 40

Plugging in values. the ratio for the cost of non-standardirzed design to manufactured cost is:

$$\frac{\$25 + \$25}{50(\$2)} = \frac{\$50}{\$100} = .5$$

Applying estimated values to the equation for standardized design:

$$\frac{(C_d + C_a)}{U(C_o)} + \frac{C_s}{n}$$

C_a = $10
C_d = $10
C_u = $2
Cs = $50
n = 5
U = 50

Plugging in values. the ratio of standardized design to manufactured cost is-

$$\frac{(\$10 + \$10)` + \$50}{50(\$2)} = \frac{\$30}{5} = \frac{.3}{\$100}$$

Hy this highly simplified example. the efficiency of standardized design is readily apparent. However more important than the hypothetical values used in this example is the clear understanding of their relationship to each other in determining cost differences between standardized and non-standardized design.

THE SCOPE OF STANDARDIZED DESIGNS IN SHIPBUILDING

The example of the hand grab used in the previous section to illustrate the value of standardization was selected for its simplicity, but its simplicity should not be allowed to constrain one's visions of what designs are possible for standardization. Using the equations given. practically any well-defined design effort can be evaluated for the potential benefits of standardization. The intent here is not to look for justifications for standardization. There is no inherent value in standardizing designs - value in standardization only comes if it results in reduced costs. The intent, rather must be to evaluate the entire design effort and identify those areas where standardization is of value and. equally important to know when it is not.

AVOIDING THE PASS/FAIL SYNDROME

There is a tendency in evaluating designs for standardization to run everything through the calculation and cxpect that the answer will come out a clear cut "yes" or "no". if the answer is yes. the development of a standard proceeds - if it's no. it's dropped from consideration. However. there is a fertile gray area which must be explored.

Using an example of a machinery module for compressed air equipment. an initial evaluation of the design may indicate that. due to the number of anticipated variations in future applications, a is too low to offset the cost of developing the standard C_s

Rather than summarily declaring it unsuitable for standardization. it should he explored for elements of design that are common over a larger number of applications. The result may be that. even though a finished module cannot be standardized. a substantial portion of its design can be. Elements of design such as component layout. foundation footprint. component specifications. and piping and cabling routing may all be able to be standardized. providing the designer with a basic module to start with in designing in the variables. While it would be preferrable to have a finished module standard, a standard which provides 75% of the design information is certainly preferrable to starting the design from scratch. The key point is to keep minds open to new opportunities to avoid doing the same work over and over again. The mindset that standardized designs come in neat little boxes must be overcome if their potential value is to be fully realized.

COMMITMENT

"In comparison to many business and technical activitives standadizatiion appears to be fairly straightforward Anyone who has been invclved in standardization efforts quickly realizes. however that standardization is. at best. ditlicult and is offen very complex and frustrating. It is seldom easy. [2]

The first. and by far most important element to a proposed program is top-down commitment of the company. starting with the uppermost management and including every person in the shipyard that is likely to be affected by the program. And real commitment can only come as the result of the recognition of real economic value to the company. There can be no other reason.

If the establishment of a standards program appears lo he a daunting undertaking. consider a survey done on companies with standards programs in place. *Returns as high as $50 per $1. 00) spent on standards work have been reported.. . . however. .suggest that a rcturn of $5per $ invested in* *standards is a reasonable expectation."*[1]

The establishment of the program involves organizational change and expense. so it's vitally important that everyone understand the objectives to be achieved and their intended value. II these are not clearly defined and communicated from the executives. the program will meet resistance and falter.

OBJECTIVES

One of the first orders of business is to define in the company's own words, what standard designs really are, and secondly. what they are intended to achieve in as much detail as is possible at the time. Motherhood objectives. such as. "To standardize all aspects of shipbuilding design." don't tell much about what is to be achieved and even less about the value of that achievement. Objectives should he as specific as possible. Example: "To create a library of pre-qualified foundations for bulkhead mounting which will reduce the cost of design and fabrication by xx%".

ORGANIZATION

The type of organization set up is subject to the shipyard's size. corporate structure, operating procedures. and numerous other factors. In any case, the organization must he broad-based. encompassing not only engineering, but all of the users of its output: and it must be supported with the authority and access to carry out the program's objectives.

In structuring the program's organization. it is very important to recognize some of the standardization efforts that may already be taking place within the company on an informal basis and consider using those as a platform from which to develop a more formalized organization. However. in going from the informal to the formal. it should be remembered that cost-savings are the overall objective of the program and as the program organization becomes more formal. its costs will naturally increase. The program organization costs be factored into C_s of Equation (2) as an overhead cost which can be shared amongst all standards to be developed.

The question of formality of organization is illustrated in figure 2.

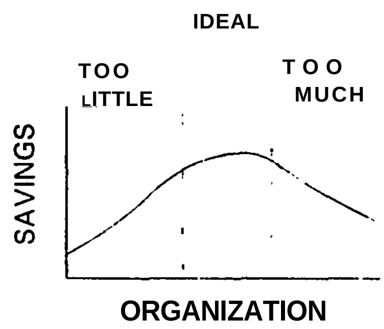

FIGURE 2
Standardards Program Formality

The characteristics of the various levels of organization are summarized below.

Too Little Organization
- low expenditures. but potential cost savings not fully tapped
- lacks stable. consistent policies
- tends toward short-term fixes. lacks long-term vision
- limited base of support, has difficulty implementing standards across department lines
- creativity comes easily. hut lacks authority to develop and implement

Too Much Organization
- organization costs are disproportionate to cost-savings
- policies tend to become overrestrictive and unyielding to change
- has difticulty dealing with short-term problems
- becomes autocratic. loses support of users
- creativity stilled by the status quo

ideal organization
- costs are proportionate to savings
- policies arc stable and consistent. but able to accommodate changing conditions

able to deal with short-term priorities. but within the context of a long-term vision
- provides a process that is open 10 all standards users for input .
- creativity and new ideas are rewarded with implementation

In this context it cannot he argued that formality is good or bad - only that there is a level of organization where optimal savings can be realized.

A typical progression of a standards program organization is to start with a core group of personnel from all affected areas of the shipyard. including management which will identify cost-saving opportunities through standardization. develop objectives. and establish a strategic plan for their accomplishment. This group would be headed up from at least the V.P. level, not only as a sign of management commitment, but to ensure cooperation across department lines. Once objectives and a strategic plan are in place, the organizational structure can be defined and the personnel for carrying them out. selected.

CONCLUSION

we don't build standardized ships. so why should we ha ye standard designs for them. How many times has this lament been heard? After all. it's been awhile *since* we've had a run of standard ship production on the scale of the Liberty ships. That was standardization carried out to its fullest promise. The classic story of the Kaiser shipyard building a Liberty from keel-laying to launch and trials in four days was more than just a carefully orchestrated public relations gimmick. It demonstrated in very real terms at a very high level. not only the value of standardization. but the value of what we today consider "new technology" shipbuilding processes - Group Technology. Manufacturing ('ells. Just-In -Time. etc.

Regretably it's unlikely that we'll see another production run such as that in the near future. However. the basic industrial principles that drove that kind of efficiency in the 1940's are still just as valid today. Hack then the motivation was national defense - today it's industrial survival.

liven though we're not building "standard" ships, we must look within the ships that we are building and identity opportunities for benefits from standardized design.

The general benefits to be realized through standardization of design are well documented4 outside this paper. However, when it comes right down to how standard designs can profit an individual shipyard. it becomes a matter of defining the cost differences between doing standard and non-standard design. In defining these costs. it becomes evident that they go well beyond those incurred on the drawing board or CAD terminal. An attempt has been made by this paper to provide a mathematical model to identify and rationalize the costs of standard versus non-standard design.

Since standardized design requires an upfront investment and yields a long-term return, the decision to establish a standards program and the maintenance of the program must be based upon sound economic principles and business planning. The purpose here was not to advocate standardization as an across the board panacea, but to provide an economic basis for making standardization decisions. It is as important for a shipyard's engineering management to know when not to standardize as it is to know when.

It is the motive of this paper to provide the impetus and a mechanism for them to just that. it is only after they have made an objective evaluation can they properly make the business decision to standardize or not.

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Shipbuilder/Supplier Design Process

No. 9B-2

Richard C. Condon, **Visitor, General Electric**

SHIPBUILDER/SUPPLIER DESIGN INTERFACE

ABSTRACT

The cost of warships has increased dramatically in recent years. Much of this increase is certainly justifiable in terms of enhanced capability -- *but* not all. A sizable portion can also be attributed to a design process for major equipment that does not pass a cost/value-added screen. There was a time when this process was less complicated, less controlled, and much less costly.

Depending on the type of warship, up to 2/3 of the total cost of a lead ship can be attributed to components that are designed and manufactured by the non-shipbuilder suppler base. As such *a* large part of the total *cost,* any serious effort to reduce the cost of warship production *must* include a rigorous review of the process that produces these components.

One way to reduce the cost of designing prototype equipment is to better define the roles and responsibilities of the participants. This simple step would go a long way. in preventing overlapping activities with their ensuing duplication of effort and non-value added work that. has become *common* in recent *years.* But in order to provide a clear and concise definition of responsibility and accountability for each participant in the process, it is first necessary to define the total process. As Dr. Deming teaches [I], it is only in the context of the total process that meaningful improvements can be achieved.

This paper presents one approach to reducing shipbuilding costs by utilizing the equipment specification to define and optimize the machinery design process. To the extent that the design process of major Hull, Mechanical, and Electrical equipment (HM&E) is similar to other shipboard equipment, the conclusions and recommendations may be applicable. Since the writer's experience is limited to a prime contractor of HK&E equipment, applicability to other equipments is left to the reader.

INTRODUCTION

The cost to design and manufacture major machinery for new ship classes has generally followed the same cost escalation of warships. As shown *on* figure (l), the cost of main propulsion and turbo-generator machinery in *current* dollars has quadrupled since 1968. If this exponential trend continues, the cost of this machinery for the next design could be twice the cost of the last. That would, of course, be unacceptable in today's environment where affordability is critical to maintaining the industrial base.

The adage "if you always do what you always did, you'll always *get* what you always got" is only partly true. In this case, it will get even worse and given today's budget realities, this would be untenable.

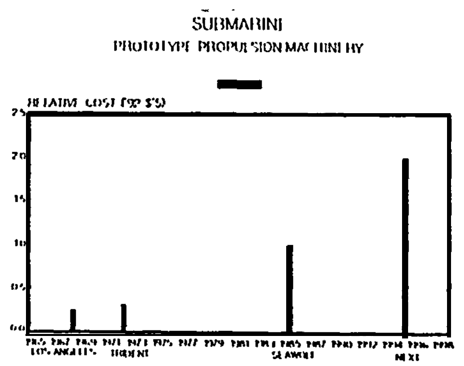

FIGURE 1

factors. In fact, it appears that as much as 50% of the design costs for prototype machinery can be attributed to factors not directly related to the actual design of hardware. To a large extent, these factors drive non-value added activity and accordingly. present good opportunity to lower future costs.

COST CENTERS

Prototype costs for major machinery can be placed in six separate areas. These are:

1. design,
2. raw material purchase,
3. finished goods purchase (designed by sub-tier supplier),
4. in-house manufacturing
5. assembly, test, and
6. package and ship.

Each of these areas have their own cost drivers and there is no question that each area has played a part in cost increases. External (non-design) factors such as inflation, material availability, shop loading, and work force skill level each impact the total cost of the end product. Also, more stringent functional demands on the product by the end user almost always add cost.

This paper focuses on the cost center for the design activity and those steps to be taken to reduce those costs.

All design activity by its very nature consists of a series of compromises and trade-offs. Depending on the particular application, certain attributes are given more importance than others. There are few hard and fast rules to follow but generally speaking, size, weight, complexity, output, and efficiency have significant impacts on cost. It is noted, however, that rarely can the designer and the customer have all that is desired. There are trade-offs to be made with every decision and there is a cost associated with each. Hard choices must be made and they must be made at the right time in the process. That is, each decision must be made at the time when. implementation is most cost effective. Decisions made too early in the process may unnecessarily limit the options of the designer but decisions made too late result in changes, wasted effort, rework, and subsequent cost increases. The key is to have a design process that facilitates - not impedes, a timely flow of information and decision making.

Consistent with the functional requirements, products can, and should, be designed for the lowest cost manufacture, assembly, installation, and maintenance.

EQUIPMENT DESIGN PROCESS

Depending on the type of warship, the design activity and preparation of the machinery specification may be lead by either NAVSEA or a shipbuilder. In some cases. NAVSEA retains cognizance for the specification but *farms-out" selected activities to a design agent. The latter, where NAVSEA farms out this activity but retains responsibility for the technical content, is often the case for complex combatant ships.

Considering the total process. the end user (operations) defines a functional need. The machinery specification is prepared and issued by either NAVSEA. the shipbuilder. or a design agent. Prospective suppliers submit proposals and a supplier is selected, The supplier then completes the design. procures material, builds and tests the equipment and then packages, and delivers the machinery to the shipbuilder for shipboard installation and testing. This process is shown on figure (2).

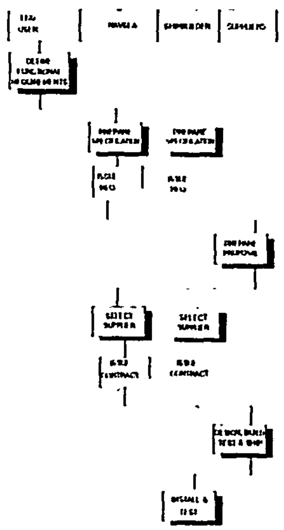

FIGURE 2

It is important to note that this type of machinery is usually not "off-the-shelf" and is. therefore, almost always custom designed for each new ship class. To meet the ship construction schedule, the contract for the design and manufacture of the machinery is released very early in the ship acquisition process and sometimes even before a shipbuilder is selected. Long-lead material such as castings and forgings must be ordered within weeks of contract award which means that detail design and manufacture of the equipment must progress in parallel rather than in series.

Fundamentally, the process is logical and at this level of detail, the responsibilities of the participants appear to be clear. The customer (NAVSEA or shipbuilder) is responsible for the specification, the supplier is responsible for the design and manufacture of the end product, ***and*** the shipbuilder is responsible for installation and test **of** the product. The reality is, however, that it is not quite that straight forward. The supplier has an obvious stake in the preparation of the specification and both the customer and shipbuilder have a stake in the execution of the design, manufacture, and test of the product. It is this apparent overlap that sometimes causes confusion with regard to responsibility and accountability of the participants. Lack of clarity with regard to responsibility and specification which leave room for interpretation, particularly when a third party is involved, is a prime cause of much of the cost increases of recent years.

Responsibility cannot be shared -- a single entity must be responsible and accountable for each element in the process. To do otherwise only adds unnecessary cost to the product with no real gain in total quality. That is not to say that each element in the process should be done independently of the others. Nor is it to say that input is not required from other participants in the process. Quite to the contrary, each element is dependent on the others and must be done in consort with the others. ***A*** cost effective design process, however. requires that roles and responsibilities of each participant be defined for every activity.

For example, the customer cannot possibly know what is available in terms of machinery functionality and capability without consulting with the supplier. Therefore, it is essential that the supplier be an active participant in the development of the specification process. And since equipment must ultimately fit into the ship, the shipbuilder must be an active participant in the preparation of the machinery specification but must also participate in the machinery design process to ensure integration. There is, however, an important distinction to be made -- that is the difference between the entity providing input to the process and that which is responsible for the output of the process. Ultimately, the participants should only be responsible and held accountable for their own efforts -- not the efforts of others.

If the process for developing the machinery specification does not provide for the participation of the machinery supplier, the supplier will be encumbered with requirements that will, most certainly, impede design optimization and add unnecessary cost. Likewise, to go one step lower in the process, if the machinery designer does not include sub-tier supplier input or the participation of the manufacturing components, the design will not be cost optimized. Each participant must provide the necessary input at the proper time.

If the total process is not defined and properly integrated. the result will be unproductive, non-value added activity that will continue throughout the life of the project.

Even though each of the participants must contribute outside of their own specific area of responsibility, it is not necessary to confuse roles and responsibility. As long as each activity can be defined, the responsibility for that activity can be assigned. Ownership for the specification is clearly with the customer. The customer is responsible for it and ultimately must be held accountable for it. The machinery supplier must participate in the preparation of the specification by furnishing certain information. In that case, the supplier is responsible for that information and should be held accountable for it. The customer, however, retains responsibility for the specification.

For the machinery design, however, responsibility must be solely with the supplier. Neither the customer, shipbuilder, or design agent is responsible **for** the machinery design. They each must participate in the design process and each should be accountable for their input but ultimately, the supplier must be the one held accountable for compliance to the specification and the performance **of** the equipment.

SPECIFICATION COST DRIVERS

To truly optimize the design process each piece must be viewed in the context of the total process -- and not as isolated sub-processes. The equipment specification is the common denominator of the total process. This is the one document that links each of the sub-processes together. The specification defines the functional requirements for the end product and also the quality assurance requirements. And to a large extent the specification also defines the business relationship that will exist between the customer and supplier throughout the project's period of performance.

The specification is absolutely key to the cost of the end product and as such, should be the first area to be addressed to achieve cost reductions in the machinery design process.

Fundamentally, the specification should define the functional requirements. If the requirements are achievable and understood, a capable supplier will be able to produce the product as specified. That is, within cost and schedule projections -- and meeting all specification requirements. In those instances where reaches in technology are intended, special provisions can be made to contain supplier's risk and still foster advancements. However, when specifications go beyond functional requirements and into the area of design and product verification, substantial cost is added. Depending on the way this is done. that added cost may result in very little added value.

In recent years there has been a proliferation of open-ended, loosely defined requirements that have made performance to plan (and cost control) extremely difficult. For the most part these requirements do not specify functional requirements for the end product but rather, they specify requirements for design verification. In most instances. these requirements are not necessary and only bring non-value added effort to the process. Except in very special cases, design verification should be left to the supplier but in cases where this cannot be done, the requirement should be invoked in a manner to minimize cost.

Take for example the case where the customer needs assurance on a critical machinery component that a specified surface hardness and case depth is achieved. One approach would be to specify the supplier's manufacturing process be submitted for approval. In that case, the supplier would have to spend additional effort to document the process in such a way that someone less familiar with it could first understand the process and then, pass judgement on its adequacy to produce the required results. This is not an easy task because processes are usually documented for the people working with the process and by definition. more familiar with it. Also, suppliers are usually unwilling to disclose process details outside their organization for proprietary reasons. What happens in this case is that the supplier submits what is believed to be an acceptable minimum. The customer then responds with a request for more information. With each iteration, final approval gets closer but in the mean time, the product is either on hold awaiting approval or more likely, product is being manufactured at the risk of the supplier. In either case the result is the same -- unplanned and unnecessary cost. A second and less costly approach would be to specify a test coupon to be produced and submitted as evidence of hardness and case depth. This would be a much lower cost approach providing the requirement for the coupon were included in the original issue of the machinery specification so it could be planned to minimize cost and schedule impact. A third approach, and the one recommended would be to simply specify the required hardness and case depth and leave it to the supplier to ensure compliance.

Another example of a specification cost driver is when a function or feature is specified with no acceptance criteria. Simply specifying the function or feature with perhaps a requirement for product verification (test or inspection) would not, by itself, add unnecessary cost. However, if the specification required the "design" to be submitted for approval, that is a different matter. This now becomes a series operation where the designer must first design the part/function and then submit the design for review. The reviewer, who. again, is by definition less familiar with the product must take the time to understand the design and pass judgement on its adequacy. Inevitably, the reviewer requires more information and the letter writing campaign goes on -- and on. Also. in this case there is another factor involved -- that is the introduction of another opinion into the design process. In the absence of specific acceptance criteria other than the "design" be approved, the reviewer is often inclined to force design changes based on personal preference rather than specific requirements. Changes at any time add cost but changes during the manufacturing cycle are extremely expensive and must be avoided. A compounding factor is that long lead material is in the procurement/manufacturing phase when many design details are still evolving.

These situations are not hypothetical nor are they isolated cases. In fact, the first example of surface hardness and case depth was from a recent project. In that case, final resolution took ten submittals, one meeting and two years to reach closure. After all that expense, no real value was added the product. Specification requirements such as these account for countless hours of engineering labor. In a recent lessons learned analysis by a NAVSEA/Supplier team, it was estimated these and similar requirements accounted for $15 million in additional design cost.

There is a better way to do business but it requires a different approach. The responsibilities of each participant must be defined in sufficient detail to prevent overlap and to facilitate a cost effective design process. The following guidelines should be followed.

<u>The Customer</u>

The customer is responsible for the specification. However, the customer must ensure that the process used to develop the specification includes the active participation of all the specification users. This includes all potential users if the specification is to be prepared before source selection. Oversight by the customer should be limited to verification that the supplier's design process is adequate for the product and that it is being followed as so defined.

<u>The Supplier</u>

The supplier is responsible for the product. The supplier must maintain a design process that ensures full compliance with the specification and provides for the participation of the customer, shipbuilder, sub-tier suppliers, as well as the supplier's own manufacturing components.

<u>The Shipyard</u>

The shipyard is responsible for installation and test of the equipment. The shipyard will participate in the specification preparation and equipment design processes to the extent necessary to ensure that ship functional and physical interfaces are properly defined.

<u>The specification</u>

The specification is the document which defines the responsibilities of all participants. Specification requirements should be primarily functional but When verification requirements are necessary, they should be specified in sufficient detail to facilitate one submittal. "submit for approval" should not be used unless the acceptance criteria is stated with sufficient clarity to prevent subsequent misinterpretations with the intent of the requirement.

IN SUMMARY

There is a role for each of the participants to play in the machinery design process. For some parts of the process a participant may have total responsibility but for some other parts it may be only as a contributor. It either case. only those doing the work should have responsibility for it and be held accountable for it.

The cost of shipbuilding can be reduced and it can be reduced without short changing functional capability. Substantial cost reductions can be achieved in prototype machinery design by simply eliminating non-value added effort. The first step to accomplish this task is to structure the machinery specification in a way that clearly defines the roles and responsibilities of the participants. This simple first step is essential to eliminating non-value added activity from the process.

Reference:

1. Dr. W. Edwards Deming, Out of the Crisis, Massachusetts Institute of Technology, Center for Advanced Engineering Study, Cambridge, MA 02139, 1988

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