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Productivity Improvements in U.S. Naval Shipbuilding

NOTICE: This report was written as the initial product of a multi-year effort. It is hoped that the work of the Committee on Navy Shipbuilding Technology can be continued, and additional reports published, but future funding is uncertain.

PRODUCTIVITY IMPROVEMENTS IN U.S. NAVAL SHIPBUILDING

Committee on Navy Shipbuilding Technology
Marine Board
Commission on Engineering and Technical Systems
National Research Council

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PREFACE

Origin of the Study

The U.S. Navy proposes to authorize construction of 133 new ships in private shipyards between 1983 and 1986.* To enable U.S. shipbuilders more efficiently to build these ships, the Navy has instituted a shipbuilding technology initiative within the Department of Defense's manufacturing technology program. The goal is to improve quality, decrease ship construction time, and increase productivity through the advancement of planning and production technologies in shipyards and supporting industries.

In 1981, the Navy requested that the National Research Council assist the shipbuilding technology initiative by identifying promising technology developments, including: industrial engineering and automation technologies available in other industries that have the potential for shipbuilding technology improvements; opportunities and strategies for developing the next generation of shipbuilding technologies and strategies for implementation; and management strategies for shipbuilding technology developments.

The Commission on Sociotechnical Systems of the National Research Council thereupon convened the Committee on Navy Shipbuilding Technology under its Maritime Transportation Research Board.+ Members of the committee were selected for their experience in the development and application of productivity improvements in a corporate environment, industrial engineering, manufacturing research, labor union management, manufacturing and engineering of ship components, naval architecture and marine engineering, industrial relations, research and development (R&D) management, computer science, industrial plant management, and merchant and naval ship construction. The principle guiding the constitution of the committee and its work, consistent with the policy of the National Research Council, was not to exclude the bias that might accompany expertise vital to the study but to seek balance and fair treatment.

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*For comparison, the U.S. Navy ordered 76 ships from 1977 through 1981.
+In a reorganization of the National Research Council in the spring of 1982, the Commission on Sociotechnical Systems was subsumed into the newly created Commission on Engineering and Technical Systems, and the Maritime Transportation Research Board was merged with the Marine Board.

Scope of the Study

The charge to the committee is to "provide an objective external review, analysis, and appraisal of the potential for shipyard productivity improvement gains through the introduction of technological, organizational, and management innovations." Productivity improvements include savings in time, cost and total effort, as well as improving the quality of the ships that are built and the safety of the personnel involved. The scope of the study is limited to new construction of both combatant and noncombatant Navy ships by domestic, private shipbuilders. Considerations of ship conversion and repair work, and naval shipyards are excluded; however, the committee recognized that productivity improvements in these other areas can possibly have application to shipbuilding (and vice versa), and, that in some technology areas, it is necessary to consider the requirements of conversion and repair work in order to optimize shipyard capabilities.

The committee has identified and appraised ways to improve the productivity of naval shipbuilding in the United States. It has sought means to build Navy ships faster and cheaper, to build higher quality ships, and to build them more safely. It has identified innovations that may lead to productivity improvements, and considered productivity improvement measures and how to implement them. It has also examined potential research and development to enhance shipyard productivity. The committee has identified financial, regulatory, institutional, technical, and social incentives and constraints on the improvement of shipbuilding productivity. The committee has not assessed the implementation of the Navy's shipbuilding technology initiative in this report.

Organization of the Study

The technical basis for the committee's assessment was provided by the Industrial Advisory Committee (Appendix A) convened by the National Research Council to assist the committee. The Industrial Advisory Committee planned and conducted the National Confererence on Naval Shipbuilding Technology and a public symposium on computer-aided design and computer-aided manufacture (CAD/CAM) applications in the construction of naval vessels.

The National Conference on Naval Shipbuilding Technology was convened to examine means for improving productivity, reducing construction time, and improving quality and safety in naval ship construction. Papers on many aspects of shipbuilding productivity were presented at the conference. Workshops were convened on: design, planning and advanced technology; industrial engineering; institutional factors; and human resources. Issue papers developed at the workshops were provided to the committee for their consideration. The list of papers presented at the conference and of participants in the conference and workshops are shown in Appendix B.

Participants in the CAD/CAM symposium identified opportunities for the application to Navy shipbuilding of CAD/CAM systems currently in development, opportunities and strategies for developing the next generation of computer-aided systems for shipyards, and the role of computers in shipyard information management applications. Discussions at the workshop addressed the Navy's role in shipbuilding CAD/CAM development and utilization, the status of CAD/CAM standards, and organizational and human factors considerations in the application of CAD/CAM in shipyards. The papers presented at the public symposium are listed in Appendix C.

The committee participated in the conference and the symposium and reviewed the technical information developed to identify and explore shipbuilding productivity issues (Chapter 3 of this report). The committee then initiated the assessment of shipbuilding productivity issues, a task which occupied the committee for some time and is still continuing.

To date, the committee has completed technical assessments in three areas: opportunities for improving productivity through the use of computers in shipbuilding, increased development and use of standards, and the potential contribution of industrial worker participation and organizational change programs to shipbuilding productivity improvement. These were chosen because of their significance and because the committee considered it had enough time and information to make initial assessments, and in some cases, recommendations for improvement.

The report also describes many other issues that warrant further comprehensive assessment and study. Time and information was not available to explore these additional issues in this initial report.

The committee is continuing its assessment of shipbuilding productivity issues, and additional issues will be assessed and reported on in the future. Some issues that have been identified are not appropriate for study by this committee. Where this is the case, other investigative avenues are recommended.

The committee's identification of issues, assessments, conclusions, and recommendations are based on analysis of the information provided by the Industrial Advisory Committee through the conference and symposium it convened, on additional information developed by the committee, and on the professional experience of committee members.

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SUMMARY

Scope of Report

To enhance national security, the U.S. Navy is interested in improving the capability of the U.S. shipbuilding industry, including shipbuilding companies, their suppliers, and ship design agents, to build naval ships. The Navy is seeking to improve the quality of ship construction, to decrease ship construction time, and to increase productivity through the advancement of planning and production technologies. As an element of this shipbuilding technology initiative, the Navy requested in 1981 that the National Research Council identify promising technology and strategies for developing and implementing advances in shipbuilding. The National Research Council convened the Committee on Navy Shipbuilding Technology to undertake the study.

This report is the first of a multi-year effort and is therefore introductory in nature. Its objectives are limited: to describe the status of shipbuilding productivity in the U.S., to acknowledge and describe the substantial industrial activity that is directed towards productivity improvement, and to identify and appraise a number of issues for subsequent technical assessment. The committee is continuing its work and will present detailed assessments in future reports.

The Basics of Productivity

The history of shipbuilding clearly demonstrates that the productivity of shipbuilding is greatly affected by the status of certain fundamental aspects of industry. The purpose of this report is less to measure and evaluate productivity than to recommend how it may be improved. Toward this objective, the committee's analysis indicates that shipbuilding productivity is enhanced and improved when certain conditions are present and positive:

- Ships are built in volume and on long-term contractual commitments.

- Designs are standardized and explicitly directed toward ease of manufacturing.

- Shipbuilders individually and as an industry invest in and employ technologies and facilities which improve productivity and constantly seek to improve their equipment and production processes via innovation and application of human and financial resources.

- Management systems and personnel do an aggressive and effective job in production planning, contracts, information systems, and project management, taking advantage of continuing developments in management science and techniques.

- Managers place consistent and substantial emphasis on the development of superior human resources, focusing on effective communications, employee training and development, and participative organizations, all with genuine concern for the welfare of employees.

Another fundamental requiring attention is the documentation of the productivity of the U.S. shipbuilding industry in constructing naval ships. The committee recommends that the Navy conduct studies to analyze and evaluate the productivity of the U.S. shipbuilding industry in constructing naval vessels so that efforts to improve productivity can be focused on problems and opportunities. It is also necessary to consider the productivity of shipbuilding supplier industries because procuring, assembling, and installing supplier-built systems represents the largest single cost area in naval shipbuilding.

Productivity-related research and development is central to the advancement of shipbuilding technologies. Productivity-related research and development exists in shipyards today largely as the result of the National Shipbuilding Research Program, which is funded by the Maritime Administration (MarAd) and the Navy. Because of the benefits that result from the process of technical interaction among shipbuilder representatives in the program as much as from the substance of the activities undertaken, the committee recommends that the Navy and MarAd continue to participate in and support the National Shipbuilding Research Program.

Shipbuilding Productivity Issues

With the understanding that productivity improvements in naval shipbuilding will not be forthcoming through the development and application of technologies unless and until the fundamentals of industrial health are attended to, the committee identified areas where substantial productivity improvement appears to be possible. (Some areas are the subject of substantial industry or government programs; other areas have not as yet been targeted by industry or government for development.)

Shipbuilding Industry and Supplier Productivity

To effect substantial improvement in naval shipbuilding productivity, it will be necessary to investigate problems and opportunities in the supplier industries as well as shipyards. The suppliers and the shipyards also need to be assessed as a system, since the interface between them complicates production planning and the quality of supplied materials affects the quality of the product and the necessity of rework.

Industrial Factors

Integration of Design and Production The degree of integration of the engineering phases of ship production -- ship design, production planning, early material ordering, and production engineering and employee training -- is a major determinant of production efficiency. These engineering phases are segregated in U.S. shipbuilding to a greater degree than in some other countries. Further, such separation of engineering phases does not occur in many other American industries. Assessments are needed of how the lack of integration affects productivity, the extent to which it is difficult to introduce productivity innovation and how more complete integration of the engineering phases of ship production can be achieved.

Work Flow in Shipyards The scheduling and flow of materials and work in shipyards bear on productivity. The extent to which improvements in facility layouts, production processes, and materials handling can improve the efficiency of materials and work flow needs to be assessed in each shipyard. Opportunities for improvements need to be identified and pursued.

Modern Production Control Techniques The potential of product-oriented work breakdown structures to produce significant productivity gains in Navy shipbuilding needs to be determined. Impediments to the introduction of product-oriented work breakdown structures need to be identified.

Management System Modernization and Computerization The extent to which significant Navy shipbuilding productivity improvements can be made through shipyard management system modernization and computerization needs to be determined. Specific actions to this end need to be identified.

Computer-Aided Design and Manufacture (CAD/CAM) The use of computers in ship design and manufacture has the potential to improve productivity significantly. However, the successful integration of computers into and between shipyards, the design agent, and the Navy requires organizational and procedural changes. Ways to harness the potential of computers in shipyards need to be outlined and pursued.

Human Resources Issues

<u>Quality of Engineering and Management Personnel</u> The implementation of new technologies and productivity innovations in shipbuilding will require basic strengthening in engineering and management functions and personnel. Needing identification are the means to attract engineering and management personnel to the field, to improve the adaptability of existing personnel to new technologies and innovations, and to train them.

<u>Labor-Management Relations</u> Improvements in labor-management relations are needed to pave the way for the implementation of new technologies and productivity innovations in shipbuilding.

<u>Training and Retention of Skilled Labor</u> As shipyard production processes become more sophisticated, it will be necessary to attract, train, and retain skilled shipyard workers. Problems and opportunities in skilled worker training and retention need to be identified and developed.

<u>Participatory Management/Organization of Work</u> The potential for productivity improvement through reorganizing shipbuilding work to better utilize human resources needs to be established. The nature and extent of alternative approaches and their potential contribution and applicability to Navy shipbuilding need to be explored.

Institutional Factors

<u>Capital Formation</u> The importance of financial stability to capital formation and productivity innovation needs to be established, as does the extent to which the Navy can or should assist U.S. shipbuilders and their suppliers in developing a healthy financial climate suitable for productivity innovations. Aspects of this include the degree to which the government can share financial risks of production technology advancement, whether the shipbuilding workload can be stabilized over the long term, the financing of capital improvements, and whether U.S. shipbuilders are competitive in warship production.

<u>Contracts</u> The effects of the scope and duration of ship procurement contracts on shipbuilding need to be assessed. In addition, opportunities need to be investigated for reducing the complexity of Navy contracts and speeding up decision making.

<u>Material and Equipment Standards</u> Areas in critical need of standardization (defined as the use of standards) need to be identified. The body of existing standards needs to be distilled into a usable base of information, to facilitate their implementation (for without use, standards themselves are of no consequence). The extent to which commercial marine standards meet military requirements, the potential benefits to the Navy from supporting the development and

application of commercial marine standards, the needs and implications of updating, deleting, and supplementing military standards, and the additional areas in which the development of material and equipment standards would contribute to productivity improvement all need to be assessed.

Quality Assurance Means to achieve and improve the ability to meet Navy shipbuilding quality standards in the initial installation of material, equipment, and systems need to be identified and evaluated.

Employee Safety and Health Means to improve the safety of Navy shipbuilding need to be identified and evaluated as well as the benefits of comprehensive safety and health programs. Yards and vendors need to be encouraged to provide such programs. The Navy needs to be aware of potential health and safety exposures.

Effects of Federal Laws and Regulations The impact of government laws and regulations on shipbuilders needs to be better understood, since the cost of regulatory compliance is added to the cost of building ships.

Technical Assessments

The above issues constitute an agenda for the committee in identifying and appraising ways to improve the productivity of U.S. commercial shipbuilding of Navy ships. The committee has already assessed three of the issues, the application of computer-aided design and manufacture, increased use of standards, and the potential of worker participation/organizational development programs. A summary of these assessments follows.

Foster Rapid Development and Application of Computer-Aided Design and Manufacture (CAD/CAM) for Navy Shipbuilding

The opportunity exists to utilize a systems approach for the design, specification, and construction of ships with computer-based tools and data bases that significantly reduce costs, errors, and lead times and improve product quality.

CAD/CAM technologies offer an opportunity to improve productivity not only by reducing the direct labor contribution to a number of technical tasks, but also by making possible and stimulating the coordination of engineering phases and management functions. The Navy, as the major shipbuilding customer in the United States, is in an outstanding position to cause or foster its rapid development in conjunction with the shipbuilding industry. The committee recommends that:

- The Navy should sponsor the development of an integrated product definition data base for establishing its shipbuilding requirements and communicating them among the shipbuilding industry. The Navy should encourage its use and the development of complementary, compatible data bases by ship designers, shipbuilders, and vendors.

- The Navy should participate in and support the development and application of graphic exchange specifications applicable to shipbuilding. Together with the shipbuilding industry, it should cause a shipbuilding interest group to be established within the Integrated Graphics Exchange Specifications Program being coordinated by the National Bureau of Standards.

- The Navy should sponsor a continuing forum in conjunction with the broader CAD/CAM industry to allow shipbuilding and design agent CAD/CAM managers to plan jointly for the Navy's development and use of computer technology.

Encourage Development and Use of Standards

Increased development and use of standards represents a very significant opportunity for productivity improvement in Navy shipbuilding. With increased support in terms of committed technical talent and also financial resources, the benefits of standardization can be realized. The committee recommends that:

- The Navy should accelerate and increase its support of the Military Specifications (Mil Specs) improvement program to eliminate the lag between the state of military standards and the state of technology so that standards can be used effectively in the accelerated Navy shipbuilding program. This step should include minimizing the number of Mil Specs where commercial standards will suffice.

- The Navy should accelerate and increase its financial support of and technical participation in the industrial standards activities conducted under the auspices of the Society of Naval Architects and Marine Engineers' Ship Production Committee and the American Society for Testing and Materials (ASTM) to be as effective as possible in the current accelerated Navy shipbuilding program.

- Both the Navy and the ASTM standards program procedures should be reviewed and revised to shorten the period needed to update their standards.

Improve Human Resources

The cultivation of human resources is essential to the productivity of organizations. It begins with management commitment and includes human relations, labor relations, personnel functions (i.e., recruitment, selection, training, and retention), and industrial engineering.

Perhaps the most essential human resources challenge in shipbuilding is to improve the physical and organizational conditions of shipbuilding work by altering the relationship between employees and management and between employees and tasks. Participatory management and small group/multiskill worker organizational innovations focusing on effectiveness, performance, quality, and safety have significant potential for improving the productivity of the commercial construction of U.S. Navy ships. The logic for this emphasis is that weaknesses in human resources--for example, manpower shortages--may, in fact, be occasioned by physical and organizational deficiencies, such as failure to provide satisfying and challenging jobs.

Increased attention to the physical and organizational conditions of shipbuilding work can strengthen an already sound human resources situation, but it cannot substitute or correct for basic deficiencies. Shipbuilding, in particular, is prey to unstable work load and consequent high personnel turnover as the result of variables outside industrial control, including the economic climate, government procurement policies, and national industrial policy.

Investment in human resources is not easily justified in an environment of uncertain long term industrial prospects and high personnel turnover. Yet, such an approach is self-fulfilling in the sense that minimal human resource investment erodes industrial capabilities and leads to greater voluntary turnover. Since the immediate and mid-term survival of the U.S. shipbuilding industry hinges very largely on Navy construction, the Navy needs to contract in such a fashion that a number of yards are able to sustain stable employment. In any other environment it is unlikely that management and the work force will commit themselves to improving human resources and, in particular, to experimenting with participatory management/organizational development programs.

The committee recommends that the Navy should encourage experiments with worker participation and organizational change by considering requests from industry (labor and management) to share in the costs of experimental programs. By means of a continuing periodic forum, the Navy should foster the transfer of information between companies and unions involved in or considering social technology projects. The forum would allow both the Navy and commercial yards to share their growing experience with productivity-related social technologies.

Committee Work in Progress

The committee is continuing its identification and appraisal of shipbuilding issues. It is conducting additional technical assessments of the importance of capital formation to productivity improvement and the status of the shipbuilding industry in this regard, the potential for productivity improvement through modernization and computerization of shipbuilding management systems, the impact of vendor and supplier productivity improvement on shipbuilding productivity, opportunities for closer integration of design and production, and the engineering phases of ship production. These assessments will be reported on at the end of 1983.

THE PRODUCTIVITY OF SHIPBUILDING IN THE UNITED STATES

The purpose of this introductory chapter is to review the history of the U.S. shipbuilding industry and set forth several perspectives of the productivity of the industry today. The chapter begins with a brief history of the industry since 1940. A number of insights concerning productivity emerge from analysis of this historical period. Next, a description is presented of the industry as it exists today, focusing on factors which affect not only its current productivity but its vitality in the future. The chapter concludes with discussion of five factors which appear to be especially significant determinants of shipbuilding productivity.

Shipbuilding in the United States since the Second World War

Shipbuilding in the United States has a long and varied history. Certain enduring features of the industry are significant. First is the relationship of economics and politics in shipbuilding. "Economics, as it is usually understood, is not the controlling factor in shipbuilding to the extent that it is in many other industries. The importance of shipbuilding to the nations of the world, both in their warmaking activities and in their economic development, has been so great that economics has been tempered by and at times supplanted by politics. At times, then, questions in shipbuilding that appear to be economic are answered with political answers" (Society of Naval Architects and Marine Engineers, 1948). The volume of shipbuilding fluctuates widely in response to economic and political stimulii. Another feature is the nature of shipyard membership. There are both government-owned and privately owned shipyards. While the government-owned shipyards have engaged exclusively in ship repair in recent years, they draw supplies, equipment, and personnel from the same sources as private yards. They train and develop the same general skills, utilize similar facilities, and apply some similar work techniques. Lastly, periods of high shipbuilding activity can create a future surplus of ships, because of the relatively long service life of ships.

World War II

Since the shipbuilding industry has always had to respond to changing requirements for new construction of vessels of varying types and complexity, historical comparisons must be approached cautiously. During World War II, the U.S. shipbuilding industry demonstrated that extraordinary accomplishments can be achieved when national policies and resources are directed to building as many ships as possible, as quickly as possible. The record of accomplishment, which is summarized in this section, was compiled after the war by the U.S. Maritime Commission (Fisher, 1949).

As of January 1, 1941, there were 19 private shipyards with 75 shipways in the United States capable of building a ship at least 400 feet in length. Wartime shipbuilding requirements resulted in expansion to 40 shipyards with 313 shipways of this size by August, 1945.

During the war years, 5,777 commercial vessels of 126 different designs were constructed (see Table 1).

TABLE 1 U. S. Commercial Shipbuilding in World War II

Vessel Type	Number Delivered
Dry Cargo (Liberty, Victory ships)	3,663
Tankers	705
Minor (tugs, barges, coastal vessels)	727
Military (troop transports, other auxiliary vessels)	682
TOTAL	5,777

SOURCE: Gerald J. Fisher, Statistical Summary of Shipbuilding Under the U.S. Maritime Commission during World War II (1949).

While none of the shipyards was dedicated to construction of ships of a single design during the war, many did concentrate their effort. For example, 384 out of 508 vessels constructed by Bethlehem-Fairfield Shipyard were Liberty cargo ships; all 414 Victory Cargo ships were constructed in only five shipyards; and, 249 out of 328 vessels constructed by Sun Shipbuilding and Drydock Company were tankers. As would be expected, the speed of ship construction accelerated with repetition of the production of standard ships. Table 2 provides examples of construction period improvements achieved for selected ship types.

It can be seen in Table 2 that both the Victory Cargo Ship and the Victory Transport programs were not initiated until 1944. The much shorter initial (also minimum) keel-to-launch and initial keel-to-delivery periods were the result of design standardization, improved production and facilities capabilities available toward the end of the war, standardized components from vendors, and a considerable learning curve.

TABLE 2 Construction Period Improvements for Selected Ship Types in World War II

Vessel Types	Total Constructed	Initial Monthly Avg. Days (Keel-to Del.)	Minimum Monthly Avg. Days (Keel-to Del.)	Initial Monthly Avg. Days (Keel-to-Launch)	Minimum Monthly Avg. Days (Keel-to-launch)
Liberty	2,708	226	41	158	28
Victory Cargo[1]	414	102	73	54	45
C2 Cargo	1,041	252	113	171	44
T2 Tanker	2,852	228	82	202	64
Victory Transport[1]	683	118	88	58	41

[1]Program commenced in 1944.

SOURCE: Gerald J. Fisher, Statistical Summary of Shipbuilding Under the U.S. Maritime Commission during World War II (1949).

The extraordinary keel-to-launch learning curve improvements are illustrated by the experience of Oregon Shipbuilding Corporation in the construction of Liberty ships. The average duration for the first vessel on each shipway was 138.1 days. The duration for the twenty-fourth vessel on each shipway was 15.1 days, a reduction of 89.1 percent.

Shipbuilding productivity during World War II also has been documented (see Table 3). Oregon Shipbuilding Corporation experience

TABLE 3 Shipbuilding Productivity in World War II

Vessel Type	Man-Hours/Ship: Minimum Annual Avg.	Man-Hours/Ship: Overall Wartime Average	Man-Hours/Ton: Minimum Annual Avg.	Man-Hours/Ton: Overall Wartime Average
Standard Cargo	687,000	954,000	151	221
Liberty	512,000	601,000	147	173
Victory Cargo	590,000	670,000	132	150
Standard Tankers	671,000	898,000	123	164
Emergency Tankers	665,000	671,000	180	182
All Types	678,000	740,000	164	194

SOURCE: Gerald J. Fisher, Statistical Summary of Shipbuilding under the U. S. Maritime Commission during World War II (1949).

may again be used as an example. At its most productive, Oregon was able to build better than nine vessels on a shipway in the same period of time that it took to build the first vessel. For Liberty ships, the average for the first vessel on each shipway was 1,064,000 man-hours per ship. The average for the twenty-fourth vessel on each shipway was 313,000 man-hours per ship, an improvement in productivity of 70.6 percent.

U. S. Shipbuilding since the War

Figure 1 shows trends in shipbuilding employment and production from 1948 to 1981. It is difficult to show comparable data on productivity for this period because ships have changed drastically in size, diversity, and complexity over the decades. Landmark ship types include the *Mariner* class in the 1950s, and the later development of container ships, roll-on roll-off ships, and tankers and bulk carriers of increased size and types. The evolution in military vessels includes nuclear submarines of various types, nuclear aircraft carriers, amphibious assault ships, destroyers, guided missile frigates, and nuclear-powered guided missile cruisers.

Some generalizations can be made about productivity in this period. As ships have become larger, more complex, and more specialized, the length of time of construction has increased. The number of man-hours required to build a ship also has risen substantially.

Current Status

The active U.S. industrial shipbuilding base for new construction of large ships, as defined by the Navy and the Maritime Administration, consists of 27 shipyards that have indicated they are building or are interested in building oceangoing naval or merchant ships. The industry has grown steadily, if erratically, since 1950 in terms of total employment. Orders for new Navy vessels and for new merchant vessels determine the industry's health and vitality. A low level of Navy orders in the past was normally offset by a high level of commercial orders and vice versa (see Figure 1).

The current environment, however, is uncertain as a result of the overall economic climate in which corporations have found it difficult to capitalize on new ventures, such as new ship construction. There will soon be a predominance of naval ship construction with the cessation of construction differential subsidies for merchant ship construction.

Whenever there is a slump in shipyard activity, as at present, skilled workers go elsewhere for employment. There is also a concomitant decline of the industrial support base of vendors who provide shipbuilders with systems and components. These items represent roughly half the cost of building a merchant ship, and a greater percentage of the cost of a warship. Because of reduced demand, some vendors have ceased to produce items specifically

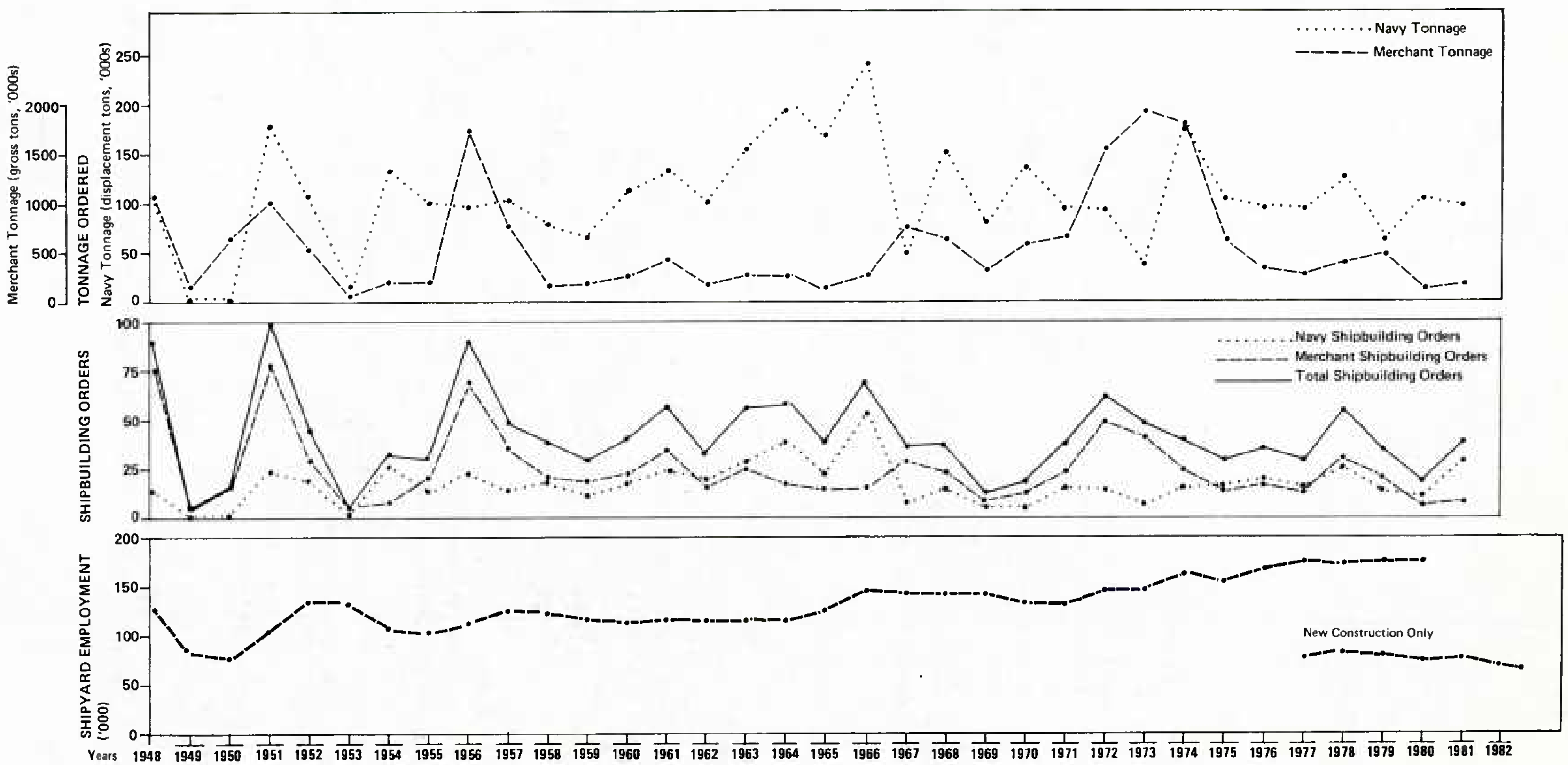

FIGURE 1 Shipyard Employment and Shipbuilding Orders 1948 - 1982

SOURCE: Employment Data from Bureau of Labor Statistics (SIC Code 3731)
Order and Tonnage Data from Shipbuilders Council of America (data for vessels, 1000 tons and larger)

designed for a marine environment. Likewise, these allied industries must now rely on a single source of second-tier suppliers for certain materials and parts.

Not all of the 27 shipyards in the active U.S. industrial shipbuilding base are capable of the highly specialized work involved in constructing major combatants. Only two shipyards currently are capable of nuclear construction. Nine yards (out of 27) can handle the construction of major combatants. As might be expected, the shipyards that are capable of major combatant construction (which is the most costly) will reap the lion's share of business from the planned naval construction program.

Prognosis for the Future

Recent changes in U.S. maritime policies, notably the curtailing of construction subsidies for new ship construction and the extension of operating differential subsidies to foreign-built, U.S.-flag ships, will affect the level of future large commercial ship construction in the United States. For its part, the Navy plans to authorize construction of 133 new ships in private yards between fiscal years 1983 and 1987, at a cost of nearly $100 billion (see Table 4). By comparison, the U.S. Navy ordered 76 ships from 1977 through 1981. The complete implementation of this program would represent a significant amount of shipbuilding activity.

Comparisons of Productivity

Navy and Merchant Ship Construction

In much of the discussions so far, no distinction has been drawn between naval and merchant ship construction. There are, of course, many similarities. The fundamental naval architectural and marine engineering principles apply equally to both. However, in terms of ease or difficulty of design and construction, the job of assembling all the parts into a working whole is significantly different from both a technical and administrative standpoint.

A naval ship is a totally integrated system packed solid with equipment, systems, and personnel for propulsion, navigation, accommodations, command, control, communication, and combat to accomplish its military missions. These each have installation and maintenance requirements. They compete for space, their weights must be minimized, and they must operate in a hostile environment, actually going in harm's way and increasing the possibilities of damage.

A commercial ship on the other hand, which is intended to carry cargo, has large volumes of (otherwise empty) spaces for cargo. Crews are smaller, the systems and equipment are simpler, and the conflict for space is less intense.

In administrative areas, contracting requirements, monitoring of work in progress, and requirements for specific customer approvals or

TABLE 4 Proposed Five-Year Naval Shipbuilding Plan

New Construction	Number	Percent
Strategic Ships		37
Trident Fleet Ballistic Missile Submarine	6	
Nuclear Aircraft Carrier (CVN)	2	
Nuclear Attack Submarine (SSN-688)	17	
Guided Missile Cruiser (CG-47)	17	
Guided Missile Destroyer (DDGX)	4	
Nuclear Guided Missile Cruiser (CGN-42)	1	
Destroyer (DD-963)	3	
Total	50	
All Others		63
Landing Ship Dock (LSD-41)	8	
Amphibious Assault Ship (LHD-1)	2	
Guided Missile Frigate (FFG-7)	12	
Mine Countermeasures Ship (MCM)	13	
Coastal Mine Sweeper Ship (MSH-1)	11	
Destroyer Tender (AD)	2	
Fleet Oiler (TAO)	18	
Ocean Surveillance Ship (AGOS)	6	
Ammunition Ship (AE)	4	
Cable Laying and Repair Ship (TARC)	1	
Salvage Ship (ARS)	2	
Fast Combat Support Ship (AOE)	4	
Total	83	
Conversions/Acquisitions/Reactivation		
Aircraft Carrier (CV Slep)	3	
Battleship (BB) (React)	3	
Ocean Survey Ship (TAGS) (Conv)	2	
Range Instrumentation Ship (TAGM) (Conv)	1	
Hospital Ship (TAHX) (C) (Acq)	2	
Fast Logistics Support Ship (TAKRX)	4	
FBM Resupply Ship (TAK) (FBM) (C)	1	
Total	16	

SOURCE: U.S. Department of Defense, 1982. Annual Report on the Status of Shipbuilding and Ship Repair Industry of the United States. Washington, D.C. Table 1-6.

acceptances are much more extensive in Navy than commercial work. Considerable time and expense are expended by both the Navy and the shipbuilder as a result.

The complexity of Navy shipbuilding renders Navy ships far more time consuming to produce when compared to merchant ships. Even though many current merchant ships are much more complex than their predecessors, they do not approach the complexity of Navy combatants.

The complexity of Navy ships bears directly on the cost of ship construction. The fact that Navy ships are far more costly than commercial ships is not surprising, however, nor is it especially germane (Kaitz and Associates, 1980). What is interesting is the fact that only about one-fifth of the cost of a sophisticated naval vessel is attributable to construction of the platform (Ramcar, Inc., 1982). Equally revealing is that combat system costs have grown over the years to the point where they represent more than 50 percent of total cost (Bennett, 1982). One can easily conclude that addressing shipbuilding productivity in its traditional sense as strictly a shipyard ship construction issue will only address a part of the problem.

Merchant Ship Construction in U.S. and Foreign Shipyards

A 1980 study of merchant ship construction sponsored by the Maritime Administration concluded that: "Productivity in the best Japanese and Scandinavian yards is of the order of 100 percent better than in good U.S. or U.K. shipyards. Thus, whereas a typical U.S. yard might be able to produce four medium size ships per year, it can be shown that a good foreign yard could produce of the order of eight ships per year with a labor force the size of the U.S. yards" (Appledore, 1980). This statement was based on a comparative productivity study of commercial shipbuilding completed in 1979 (Marine Equipment Leasing, Inc., 1978). The 1979 study determined that 25 to 30 percent of the productivity difference is attributable to superior design for production in foreign shipyards; 35 to 40 percent to better layout, facilities, and techniques; and 30 to 35 percent to better organization and systems, and a more effective work force.

The generalization that commercial ships can be built approximately twice as fast for about half the cost in foreign yards is supported by another MarAd study, completed in 1982, which compared the construction of a MarAd-designed multipurpose mobilization ship in a U.S. and a Japanese shipyard (Kiss, 1982). The Japanese yard would be able to deliver the first ship in 15 months as compared with 30 months for the U.S. yard. However, the U.S. delivery under emergency conditions (presumably with top priority assigned to component procurements and some federal regulations suspended) would be 17 months. In terms of man-hours, the U.S. shipyard would require nearly three times the labor input that would be required in the Japanese yard. The substantial difference is the result of fundamental differences that relate to shipbuilding management, vendor supply, the labor market, and sociological/organizational systems.

While the two-to-one difference in commercial shipbuilding productivity persists, it must be recognized that the best foreign productivity rates have been achieved on multiple, almost identical ship construction programs. The recent trend towards fewer, more complex ships may have shaved a bit off the foreign productivity edge. Also, as a result of changing requirements for different ship types and sizes, U.S. shipbuilders invested $2.0 billion in the 1970s to upgrade facilities, equipment, techniques, and procedures to be able to construct large, complex, modern ships more competitively. This upgrading of facilities has, in some cases, included the transfer of foreign technology to U.S. shipyards. Under MarAd sponsorship, for example, some U.S. shipyards have adopted Japanese production systems. Significant productivity improvements are anticipated as a result.

Military Construction in U.S. and Foreign Yards

While U.S. shipbuilding productivity in the construction of commercial vessels in comparison with foreign productivity has been studied extensively, the committee is not aware of any substantial published study comparing productivity in the construction of naval vessels. This may be the result of security considerations attendant to Navy ships, as well as the lack of numbers of comparable naval vessels built elsewhere. Nonetheless, some limited information is available.

A recent contract with a major Japanese shipbuilder for a 5,200-ton self-defense ship (DDH class) was completed in 48 months (Kiss, 1982). A slightly smaller self-defense ship (DD) was scheduled for 46 months. (These times include approximately six months of operational evaluation and testing which exceed U.S. practice.) For comparison, typical construction times for follow-ships of the U.S. 3,605-ton FFG-7 class (in between DDH and DD in size) at Bath Iron Works has been 42 to 44 months. The Japanese man-hours input for the DDH amounts to about two million man-hours--not unlike American hours for similar construction. A comparison of foreign versus U.S. naval construction is provided in Table 5. (While the comparison is informative, it is neither rigorous nor definitive because the two ships in the table are not directly parallel; they are not like ships under like circumstances.) A NATO task group has recently concluded that there is essentially no difference in cost between U.S.-built and European-built frigates (NATO, 1982).

From this very limited data it is difficult to reach any definitive conclusions. However, the very significant time and cost differences which are so widely advertised in U.S. and foreign merchant shipbuilding comparisons may not be the case in U.S. versus foreign naval shipbuilding. The lack of volume, the great complexity, and the higher technology implicit in naval shipbuilding appear not to put foreign shipbuilders in anywhere near the superior position they enjoy in merchant ship construction. This is due, in the main, to the fact that because of the small number of orders and their complexity, foreign shipbuilders may not have the opportunity to be as productive as they are on commercial building.

TABLE 5 Comparison of U.S. and Japanese Military Shipbuilding

	JDA Destroyer[1] Sawayuki (DD) (4th of Class first constructed by IHI)	FFG-8 (2nd of Class)
Displacement	2950T	3605T
Length Overall	130M (416 ft.)	135.6M (445 ft.)
Beam	13.6M (43.5 ft.)	13.7M (45 ft.)
Draft	8.5M (27.2 ft.)	7.5M (24.5 ft.)
HP	45,000	41,000
Speed	30 knots	29 knots
Contract Award (A)	4/80	2/76
Launch (L)	6/82	11/78
Delivery (D)	2/84	11/79
A to D	46 months[2]	45 months
L to D	20 months[2]	12 months
Building Yard	IHI, Tokyo	Bath Iron Works

1 IHI Bulletin, June, 1982.
2 Includes approximately six months of operational test and evaluation which exceeds U.S. practice.

Another factor is the relatively small role (20 to 25 percent of total effort) that construction (i.e., erecting steel, painting) plays in the total procurement, to distinguish from shipyard outfitting, installing, and assembling systems, for example. From the standpoint of cost, the majority of a naval ship procurement involves systems which the shipbuilder simply assembles. Statistically, a 50 percent increase in shipyard construction productivity may only mean a 5 to 7 percent reduction in ship costs (Bennett, 1982).

National Activity in Shipbuilding Research and Productivity

The end of World War II certainly found the national shipbuilding industrial capacity at its greatest. In the period from 1945 to 1970, however, U.S. shipbuilders did little to improve their technical capability to produce ships. Most yards by 1970 had abandoned all pretense of carrying on research and development activities for improved shipbuilding productivity, and the few active shipyards left in 1970 capable of building a major ship were desperately trying to survive. The health of the U.S. shipbuilding industry received presidential and congressional attention with the passage of the Merchant Marine Act of 1970. The Act authorized the Maritime Administration to collaborate with the shipbuilding industry to improve shipbuilding in the United States.

The Act, and concerns and actions leading to its passage, spawned long-term, fundamental, continuing industry and government activities that have demonstrated the importance of technology transfer, research and development, and their role in productivity improvement. These activities continue to advance U.S. shipyard production capabilities and practices to some degree. Principal among these programs are the:

- o Ship Production Committee of the Society of Naval Architects and Marine Engineers;
- o National Shipbuilding Research Program; and
- o Institute for Research and Engineering for Automation and Productivity in Shipbuilding (IREAPS).

These activities, and the ways they coalesce, are described in this section. A newer federal initiative, also described in this section, is the Navy Manufacturing Technology/Shipbuilding Technology initiative, which is directed at improving productivity of Navy ship construction.

Ship Production Committee (SPC)

Responding to the same concerns and actions that called attention to shipbuilding in the Merchant Marine Act of 1970, shipbuilding industry leaders established in 1970, within the Society of Naval Architects and Marine Engineers (SNAME), a Ship Production Committee (SPC) to address the technology of shipbuilding. Since its inception, the SPC has coordinated shipbuilders' technical activities, including research and development, and exchange of production information on the premise that technical cooperation will contribute to the health of the industry and improve its cost performance. SNAME provides a neutral, professional forum in which shipbuilding personnel can work together. The technical activities of the SPC (described under the National Shipbuilding Research Program) are conducted by its panels, currently 10 in number. Nearly 400 shipbuilding technical and management personnel, including some Navy personnel, participate in the SPC.

National Shipbuilding Research Program

Authorized by the Merchant Marine Act of 1970, the National Shipbuilding Research Program is a cooperative venture between the shipbuilding industry and the Maritime Administration (MarAd). It provides financing and management of research projects to improve the productivity of U.S. shipyards and their competitiveness in the world shipbuilding market. The program, initiated in 1971, is financed by both industry and government and provides for industry involvement in technical management and execution through involvement of SNAME's Ship Production Committee (SPC). The SPC collaborates with MarAd in the management of the program, especially to set program priorities, assign responsibilities for projects, provide technical direction, and assist in demonstrating program results.

The development of projects is carried out by the panels of the SPC (see Figure 2). The panel structure is flexible -- panels are added or abolished as the SPC determines the need. As shown in Figure 2, lead shipyards provide an administrative and technical base for each panel's activities. Panel activities are overseen by a full-time project manager, an employee of the base shipyard. The salaries and expenses of the project managers are paid jointly by the lead yard, MarAd, and the Navy (commencing in fiscal year 1982).

The panels work closely to exchange technical information, identify new problems and recommend opportunities for research and development, oversee ongoing projects, and demonstrate completed work. The costs of research projects are shared by the lead shipyard and the government, often on a fifty-fifty basis. In addition, the shipbuilders pay all employee expenses associated with panel activities.

The industry program manager is the catalyst in the panel's activities. The program manager, with his panel members, identifies problems and opportunities, scopes projects for research and development, advocates projects as they are reviewed by SPC/MarAd/Navy for funding, oversees the research work, and disseminates the final results.

Over the 12 years since inception, the collaboration of the National Shipbuilding Research Program and the SPC has resulted in completion of 76 major projects, with 18 more in progress and others in planning.

While the research projects are the substance of the collaboration, as important is the process that has evolved and endured -- the regeneration of productivity related R&D in the shipyards and a growing awareness on the part of management of the value of such activities. All of the major shipyards now participate in the program. The program has stimulated pragmatic, results-oriented projects, fostered technical communication and exchange among shipyards, enhanced the incorporation of productivity improvements into shipyards, and promoted communication of shipbuilding industry requirements to industrial suppliers.

Institute for Research and Engineering for Automation and Productivity in Shipbuilding

In the early 1970s, MarAd and the shipbuilding industry recognized the imperative of introducing computer aids into ship construction. In 1974, the MarAd commenced an effort to stimulate the introduction of computer-aided manufacturing into U.S. shipbuilding.

Because of the lack of technical depth of U.S. shipyards in computer-aided manufacturing, MarAd contracted for continuing

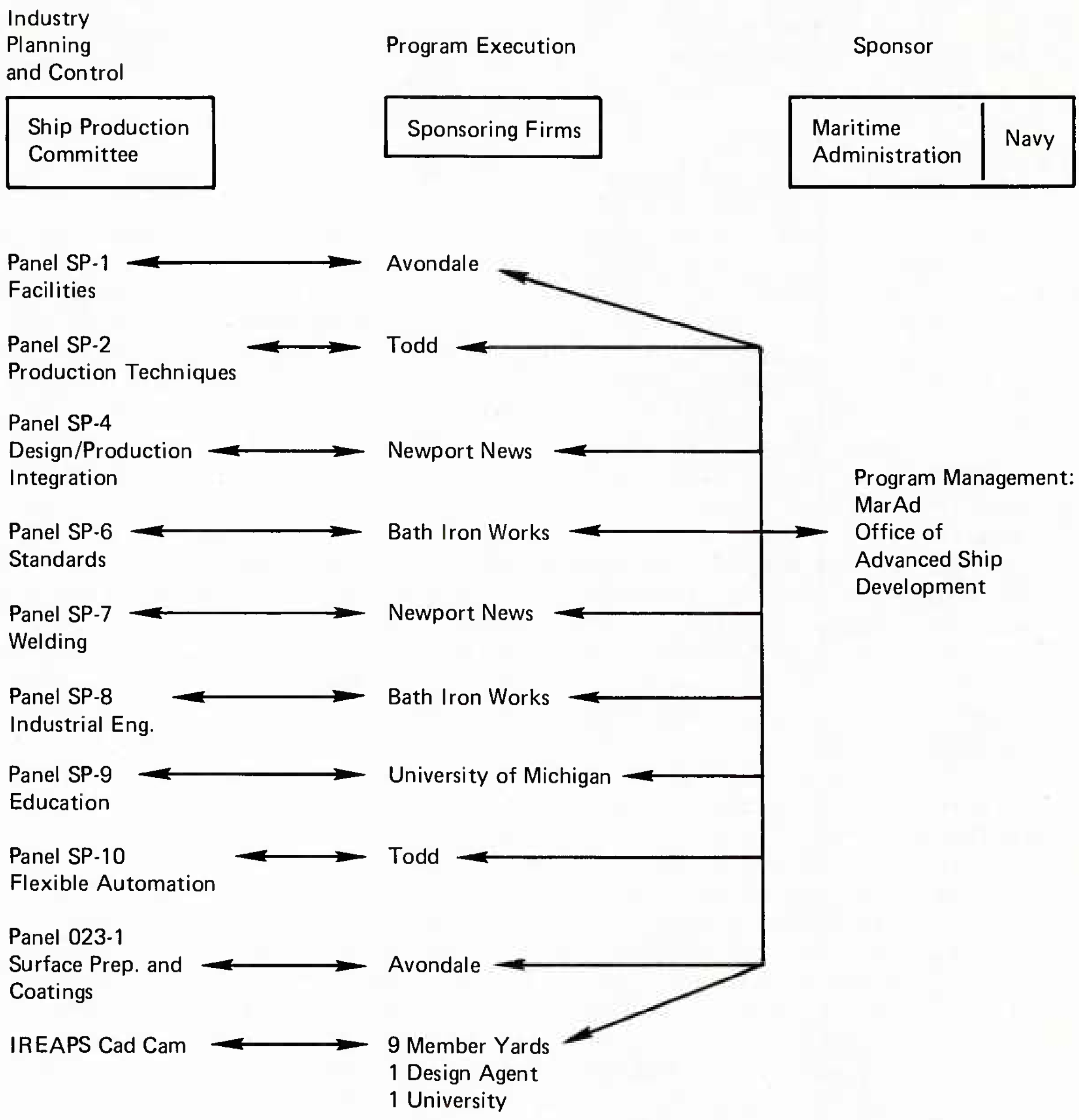

FIGURE 2 National Shipbuilding Research Program

coordinating and expert assistance to aid in the introduction of computers into shipbuilding. (The Illinois Institute of Technology Research Institute was selected.) This contracted service has grown since its inception. As with the MarAd/SPC collaborations, IREAPS is now funded jointly by shipbuilders and the government. In November, 1982 IREAPS joined forces with the SPC to establish a focal point for the coordination of shipbuilding research, production, and the range of technical interests of the shipbuilding community.

Navy Manufacturing and Shipbuilding Technology (MT/ST) Program

To reduce the cost and delivery time for acquired military systems and to improve their quality, the Department of Defense maintains a manufacturing technology program. The focus of the program is the development and execution of projects whose objectives are advancing manufacturing technology and providing first-of-a-kind applications to industrial operations. The majority of the projects sponsored involve government indemnification of manufacturers' innovations. The manufacturing technology program is overseen by the Manufacturing Technology Advisory Group, which sets program priorities, reviews, coordinates, and assesses projects, and provides project liaison to industry.

Within the Navy, major emphasis has recently (1981) been placed on production technology advancement in shipbuilding, including shipyards and supporting industries. The rationale for this emphasis is that all Department of Defense manufacturing technology program components contribute to technology improvements in the manufacture of Navy electronics, aircraft and weapons systems, but only the Navy has the mission to address Navy shipbuilding productivity. The Navy manufacturing technology/shipbuilding technology initiative is housed within the Ship Acquisition and Logistics Directorate of the Naval Sea Systems Command.

The main thrust of the shipbuilding technology initiative is to transfer to Navy shipbuilding applicable advanced production technologies already proven in shipbuilding and other industries. In fiscal year 1982 the MT/ST Program supported a series of shipyard self-assessment surveys in yards building Navy ships to identify future manufacturing technology projects for consideration in the Industrial Modernization Incentive Program (IMIP). The IMIP is directed at motivating industry (contractors and subcontractors) through contractual incentives to increase substantially capital investments in productivity enhancing technology, processes and modern plants and equipment. Primary incentives include rewards which permit industry to share in the savings (cost reductions) on programs resulting from productivity enhancing capital investments and contractor investment protection through contingent liability guarantees. IMIP projects are to be proposed by shipbuilders and identified with a specific procurement.

In fiscal year 1982, the MT/ST program contributed $2.2 million to the National Shipbuilding Research Program, an amount equal to the

MarAd and shipbuilders' contributions. Continuing Navy support for the program is planned in recognition of its importance relative to the expanded naval shipbuilding program.

The MT/ST program addresses all elements of shipbuilding, which is a subject much larger than shipyards alone. It includes the productivity of major suppliers and vendors, in addition to the assembly and fitting out of the final product, the U.S. Navy ship. This wider scope is made necessary by the modest percentage of procurement cost represented by the assembly of the platform, relative to the manufacturing costs of systems, equipment, and components which are integrated therein (see previous discussions and tables 6 and 7).

TABLE 6 Ship Construction Costs, 1980 - Generic Destroyer Class

	Millions	Percentage
Hull and Machinery	$115	26
Combat Systems	265	60
Reserve & Contingencies	38	09
Program Cost*	21	05
Total	$439	100

*Does not include government program costs.

SOURCE: Naval Sea Systems Command, 1980.

TABLE 7 Shipyard Construction Costs, 1980 - Generic Destroyer Class

	Millions	Percentage
Manufacturing	$ 38.5	33.4
Program Management	7.2	6.3
Engineering	5.3	4.6
Other Functions	1.0	0.8
Material Costs	63.2	54.9
Total	$115.2	100.0

SOURCE: Naval Sea Systems Command, 1980.

The MT/ST Program currently assesses the broad scope of the shipbuilding productivity problem, and identifies additional courses of action to improve productivity in the construction of Navy ships.

Determinants of Shipbuilding Productivity

Productivity is a complex subject for it includes not only unit costs and outputs per various inputs but also is measured by lead times, delivery reliability, and quality of product. However productivity is defined and measured, the history of the shipbuilding industry clearly demonstrates certain critical factors which substantially affect shipbuilding productivity.

The purpose of this report is less to measure and evaluate productivity in any absolute sense than to recommend how it may be improved. Toward this objective, this review of shipbuilding productivity in the United States indicates that shipbuilding productivity is enhanced and improved when certain conditions are present and positive:

- Ships are built in volume, and on long-term contractual commitments.

- Designs are standardized and explicitly directed toward ease of manufacturing.

- Shipbuilders individually and as an industry invest in and employ technologies and facilities which improve productivity, and constantly seek to improve their equipment and production processes via innovation and application of human and financial resources.

- Management systems and personnel do an aggressive and effective job in production planning, controls, information systems, and project management, taking advantage of continuing developments in management science and techniques.

- Managers place consistent and substantial emphasis on the development of superior human resources, focusing on effective communication, training and development, and participative organizations. All with genuine concern for the welfare of employees.

The report now proceeds to a discussion of these five areas. The logical sequence of these discussions is as follows:

- What the present situation is in the industry concerning each set of productivity factors, i.e., identification and appraisal of issues

- Why certain factors are now less than ideal, i.e., technical assessment of issues.

- What needs to be done to improve these factors and how such improvements could take place, i.e., conclusions and recommendations.

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SHIPBUILDING PRODUCTIVITY ISSUES

This chapter identifies areas where substantial productivity improvement in naval shipbuilding appears to be possible. It describes factors affecting shipbuilding productivity and identifies a number of issues for subsequent detailed assessment.

Productivity: A Parameter that Can Be Measured and Managed

Productivity is frequently expressed as the value of goods and services produced divided by the number of man-hours necessary for producing them. This approach is useful to the extent that labor efficiency reflects the application of capital and resources to a production process. Comparing the value of output to the level of only one input, direct production labor, however, obscures efficiencies that may be realized through the introduction and management of other factors of production. For example, if the manager of a shipyard makes a poor investment in a piece of capital equipment, the damaging effect on efficiency may appear in conventional productivity reports to look like a deterioration in the effectiveness of labor.

The measurement of productivity can be manipulated either by changing the output used or the input. For example, in shipbuilding productivity, the cost of the Longshoreman's and Harborworker's Compensation Act shows up as a productivity improvement because it raises costs without a corresponding change in labor input. In a similar manner, increasing profit increases productivity.

An especially difficult problem in measuring productivity involves improvements in production that are not measurable or do not directly affect the product, such as changes in processes undertaken for safety or health reasons. While expenditures for such improvements are a cost of production, the benefits are seldom taken into account in gauging productivity.

Higher productivity is beneficial because it increases value added during an hour of work. The increased return to society from higher productivity can be seen in the form of higher wages, higher return on investment, increased capital investment in equipment, processes, and management, or higher prices paid for raw materials. Or, increased efficiency can benefit the customer in the form of lower prices, better service, faster delivery, or higher quality products. The U.S. Navy reaps the benefits of productivity gains in private shipyards in terms of savings in time and cost of construction, improvements in the quality of the ships that are built, and the safety of the industrial processes that are used.

From a management standpoint, some kinds of investment have a record of contributing more to productivity improvements than others. In manufacturing and other industries, innovation and new technology account for the largest productivity gains (Kendrick and Vaccara, 1980). These can come either through R&D or the adoption of existing technologies from other places. Investment in R&D, especially, has a considerable multiplier effect. By encouraging vendors, and shipbuilders' R&D, the Navy obtains substantial benefits as the customer.

Some "improvements" can be made without "investment" as such -- they require only that a problem or opportunity be recognized and acted upon. Such areas as management techniques, quality assurance, training, management-union accommodations, and materials management are fertile grounds for productivity improvements.

Some factors affecting shipbuilding productivity can be managed directly by the shipbuilder; for example, the composition and utilization of the work force, the planning of production and processes employed, the introduction and application of technologies, and management methods. Other factors, such as requirements for procurement and documentation, and test and evaluation, are under the control of the customer. In the context of Navy ship procurements, the U.S. Navy Manufacturing Technology/Shipbuilding Technology Program has potential to foster some shipbuilding productivity innovations, while the U.S. Navy, as a customer, can foster other innovations.

Status of U.S. Naval Shipbuilding Productivity

Shipbuilding Industry and Supplier Productivity

The preceding chapter established that shipyard construction tasks such as erecting steel and coating surfaces, account for only 20-25 percent of the total cost of a naval ship. The majority of the procurement is directed to procuring and assembling systems, and installing them on the ship (outfitting). The productivity of suppliers and the integration of supplier deliveries into shipyard production planning is more critical in Navy than commercial construction because a larger share of Navy construction involves materials or equipment from outside the shipyard. Supplier productivity and the interface of suppliers with shipyards will become more critical as more sophisticated production and planning methods take hold.

The problem of supplier productivity is made more complex by the fact that Navy sales represent a relatively small percentage of many suppliers' total sales. When the Navy does not command a dominant market share, it is treated accordingly. This causes particular problems in terms of added costs and delays when Navy requirements differ from commercial specifications because of unique design criteria (necessary for continued performance "in harm's way").

> ISSUE: To effect substantial improvement in naval shipbuilding productivity, it will be necessary to investigate problems and opportunities in the supplier industries as well as shipyards. The suppliers and the shipyards also need to be assessed as a system since, the interface between them complicates production planning, and the quality of supplied materials affects the quality of the product and the necessity of rework.

U.S. Versus Foreign Naval Shipbuilding Productivity

The preceding chapter noted that the productivity of the U.S. shipbuilding industry in constructing merchant vessels has been studied extensively and has been established as approximately half that of the leading foreign competitors in series production. In contrast, the productivity of the U.S. shipbuilding industry in constructing naval vessels has not been well documented. It needs to be analyzed and evaluated so that efforts to improve productivity can be focused on problems and opportunities.

> ISSUE: The productivity of U.S. naval shipbuilding versus comparable foreign construction should be studied. The primary factors for any productivity differences should be identified and their implications explored.

Industrial Factors

Integration of Design and Production

United States naval ships are designed by the Navy (usually by consulting design agents under contract to the Navy), and then the designs are provided to the selected shipbuilder for detailed design work, production planning, and ship production. The consulting naval architects that undertake preliminary and contract design tend to be oriented more in the direction of ship design-for- performance, as opposed to design-for-production, because production planning is generally undertaken by U.S. shipyards, after a contract for ship construction has been awarded. Even where some integration of design and production has been accomplished during contract design, little information is generally available to designers on how design changes affect production planning and cost.

Designers need to develop a better understanding of shipyard facilities and their capabilities and how to design for better producibility. They also need a better understanding of how to make drawings more meaningful and easier to comprehend at the shipyard. Closer integration of design and production becomes more critical as shipbuilders adapt proven productivity enhancing techniques such as zone construction,* which are regularly used in many foreign shipyards, the U.S. airframe industry, and the U.S. civil construction industry.

> ISSUE: The degree of integration of the engineering phases of ship production -- ship design, production planning, early material ordering, and production engineering and employee training -- is a major determinant of production efficiency. These engineering phases are segregated in U.S. shipbuilding to a greater degree than in some other countries. Further, such separation of engineering phases does not occur in many other American industries. How the lack of integration affects productivity, the extent to which it makes it difficult to introduce productivity innovations, and how more complete integration of the engineering phases of ship production can be achieved all need to be assessed.

Work Flow in Shipyards

Improved facility layouts and work flow can decrease costs and completion time and contribute to higher quality. For example, the mechanization of the panel assembly shop at Bethlehem Steel's Sparrows Point Shipyard resulted in a savings of 35 percent in man-hours.+ Another example, a potential opportunity that has not as yet been seized by U.S. shipbuilders (and steelmakers) is the use of larger steel plates in ship construction. The pattern of the work flow in the shipyard must be recognized throughout the engineering phases of ship production for the best use of production facilities.

Designs must facilitate the incorporation of the most efficient production processes, outfitting, and materials handling equipment. During the preliminary and contract design work undertaken by the Navy and consultants, and then in the detailed design, production planning and engineering undertaken by the shipbuilder, specific shipyard unless facility characteristics and capabilities need to be communicated to designers and planners. They then must be incorporated into plans, procedures, and schedules to make the best

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*Zone construction refers to the concept and practice of integrated hull and outfit construction based upon defined production products. It involves construction and outfitting of a series of modules comprising portions of a number of systems which are then assembled to complete a ship.

+Dave Watson, Sparrows Point Shipyard, Bethlehem Steel Corporation, personal communication, October 12, 1982.

use of, and fit in with, production facilities. To the extent that shipyards seek multiple customers, including both naval and commercial work, their facility lay-outs represent trade-offs between competing requirements. It is not feasible to optimize the lay-out and work flow of a shipyard unless the yard has a long-term, multiple-ship project in hand that justifies the investment and resulting specialization in capability.

> ISSUE: The scheduling and flow of materials and work in shipyards bear on productivity. The extent to which improvements in facility layouts, production processes, and materials handling can improve the efficiency of materials and work flow needs to be assessed in each shipyard. Opportunities for improvements need to be identified and pursued.

Modern Production Control Techniques

The adoption of product-oriented production systems, such as zone construction, in place of traditional systems-oriented ship construction is credited with major productivity advances in commercial ship construction. Greater knowledge of the effects on productivity of alternative outfitting and production procedures would facilitate the making of changes in work organization to accommodate new production processes.

> ISSUE: The potential of product-oriented work breakdown structures to produce significant productivity gains in Navy shipbuilding needs to be determined. Impediments to the introduction of product-oriented work breakdown structures need to be identified.

Management System Modernization and Computerizatiion

Unnecessary delays in production can be caused by inadequate management information, for example, inability to locate specific materials quickly and accurately. Management information systems that enable the control of manufacturing systems have been central to achievement of higher productivity in some commercial shipyards and in other industries such as airplane construction. Their applicability to shipbuilding needs to be assessed. Because every shipyard is unique, however, management systems need to be tailored to fit unique characteristics.

> ISSUE: The extent to which significant Navy shipbuilding productivity improvements can be made through shipyard management system modernization and computerization needs to be determined. Specific actions to this end must be identified.

Computer-Aided Design and Manufacture (CAD/CAM)

The use of computers in design and manufacture offers the potential of an integrated information system that encompasses product planning, designing, manufactural engineering, purchasing, materials requirements planning, manufacturing, quality assurance, and customer acceptance. A single product definition data base containing an electronic description of the designed products that are being constructed or manufactured is a keystone to the successful utilization of CAD/CAM technology.

Also broadly applicable in all aspects of shipbuilding (and supplier industries) are the principles of group technology. The techniques of grouping similar but nonidentical components based on similar geometry and machining processes can be applied to operations such as design, drafting, and purchasing to reduce production costs. Group technology is essential to the efficient use of computers in design and manufacture.

CAD/CAM technologies have been incorporated in design, management, and manufacture/production to a considerable degree in many industries. In some industries, notably aerospace, CAD/CAM technologies are totally integrated with, and central to, all aspects of design, management, and production.

CAD/CAM technologies have been incorporated into shipbuilding and different shipyards to varying degrees. Nearly every shipyard employs computer-aided design techniques for faster, better, and cheaper drafting. The most complete integration of CAD/CAM technologies in a shipyard in the U.S. may be the Boeing shipyard that constructs hydrofoils.* With just one customer, naval shipbuilding would appear to present an opportunity for incorporation of CAD/CAM technologies, and reliance on them to further integrate, coordinate, and plan ship design, shipbuilding management, and ship production.

> ISSUE: The use of computers in ship design and also manufacturing has the potential to improve significantly productivity. However, the successful integration of computers into and between shipyards, the design agent, and the Navy requires organizational and procedural changes. The steps that need to be taken to harness the potential of computers in shipyards need to be identified and pursued.

Human Resources Issues

Quality of Engineering and Management Personnel

Engineers and managers play a key role in productivity innovation by making decisions to innovate and then planning and committing the organization to implementation. The more sophisticated the engineers

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*Harvey Buffum, Boeing Company (retired), personal communication, August, 1982.

and managers, the more likely they are to understand the direct links between their skills and productivity.

Many shipyard engineers and managers have worked their way up through the skilled trades.* Such employees are likely to have intimate knowledge of that shipyard's practices and procedures, but only limited familiarity with broader engineering and management principles. That kind of background also may not be the best for overseeing the introduction of new technologies.

> ISSUE: The implementation of new technologies and productivity innovations in shipbuilding will require basic strengthening in engineering and management functions and personnel. Means to attract engineering and management personnel to the field, to improve the adaptability of existing personnel to new technologies and innovations, and to train them need to be identified.

Labor-Management Relations

Good labor-management relations are a prerequisite to innovation in the workplace. When the two parties are able to exchange information and views in an atmosphere of mutual respect, support, and cooperation, it is a straightforward matter to pave the way for the introduction of new technologies and work practices through the realignment of craft structures and other innovations.

> ISSUE: Improvements in labor-management relations are needed to pave the way for the implementation of new technologies and productivity innovations in shipbuilding.

Training and Retaining Skilled Labor

The majority of skilled workers in shipyards learn their craft in the shipyard. Such training has been well suited to shipbuilding, where the production processes of each shipyard are unique. With peaks and valleys in the demand for ship construction in the U.S., skilled workers may be laid off at any time, and the trained shipyard worker may seek employment elsewhere. When the demand for shipyard workers rises, the once-laid-off worker may no longer be interested in rejoining the shipyard work force. The investment in training may be lost to the shipbuilding industry and will have to be repeated. Competition from construction and other industries for skilled tradesmen further complicates the retention of skilled labor.

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*Frank J. Long, General Manager, Human Resources Division, Shipbuilding Department, Bethlehem Steel Corporation, personal communication, December 21, 1982.

ISSUE: As shipyard production processes become more sophisticated, it will be necessary to more adequately attract, train, and retain skilled shipyard workers. Problems and opportunities in skilled worker training and retention need to be identified and developed.

Participatory Management/Organization of Work

Advances are being made in "people technologies" -- the organization of work and the work force, the attitude and training of workers, workers' involvement in production decision-making, and the productivity and quality of work life -- that provide an opportunity and may be essential for capturing the benefits of some technology advances and productivity innovations. Similarly, as workers become better educated, they have more to contribute to production decision-making. At the same time, they are more demanding. Many seek to play a thinking role in their organization. The challenge to management is to reorganize shipbuilding work to facilitate production innovations and to get the benefit of production-worker input.

ISSUE: The potential contribution to productivity improvement of reorganizing shipbuilding work to make better use of human resources needs to be established. The nature and extent of alternative approaches and their potential contribution and applicability to Navy shipbuilding need to be explored.

Institutional Factors

The term "institutional factors" refers to the ways of doing business. This includes technical rules and procedures of shipyards as well as those of the U. S. Navy, suppliers, and the shipyard's labor force. It encompasses capital formation, contracts, standards, questions of quality, safety and health, and regulations. Institutional factors can slow production and add to costs. They can facilitate or discourage the introduction of technology and productivity innovations in shipbuilding.

Capital Formation

New technologies, upgraded physical plant, and experiments with restructuring the organization of ship construction all require a climate of financial stability, investment, and growth if they are to be introduced to improve productivity. While more than $2 billion was invested by shipbuilders in the 1970s to improve their production capability, it remains to be established whether sufficient investment has been made. Certainly, many U.S. shipbuilding companies continue to employ outdated technology, physical plant, and production processes. Long-term business trends and conditions, including the constancy of frequent changes in naval procurement practices and shipbuilding policies, the decline of commercial building of large ships in the United States, corresponding overcapacity in shipbuilding, and the acquisition of shipyards by larger diversified corporations with competing priorities for capital investment, highlight the need for financial stability to provide a climate for innovation.

> ISSUE: The importance of financial stability in Navy shipbuilding to capital formation and productivity innovation needs to be established, as does the extent to which the Navy can or should assist U.S. shipbuilders and their suppliers in developing a healthy financial climate suitable for productivity innovations. Aspects of this include the degree to which the government can share financial risks of production technology advancement, whether the shipbuilding workload can be stabilized over the long term, the financing of capital improvements, and whether U.S. shipbuilders are competitive in warship production.

Contracts

Navy contracts are the primary means by which the Navy communicates its shipbuilding requirements to the shipbuilder. The contract defines the product and sets its terms and pace.

The contract is the basic instrument that enables the shipbuilder to accumulate capital and to produce the ship. The scope and duration of contracts govern the shipbuilder's planning cycle; major capital improvements or other fundamental investments won't be made unless they are justified on the basis of the current contract(s). The majority of U.S. Navy contracts are funded on an annual, fiscal year, basis. This constrains shipbuilders to plan production and justify investments on an annual basis. In the few instances when naval ships have been procured on multi-year, multiple-procurement contracts, shipbuilders have benefited from the ability to make capital investments and the assurance of sufficient business to generate an acceptable return on investment.

Savings are realized from more efficient use of existing facilities, preparing and issuing documentation once and to the same base line, efficiencies in volume purchasing and production, and a shorter total construction period. Still other efficiencies are gained from keeping work teams intact and assembly lines full, and in improved planning and scheduling.

The complexity and magnitude of contracts lead to many differences of interpretation on questions ranging from the specifications and technology to be employed, to the sharing of risks, to financial compensation that require negotiation and resolution, both prior to contract award and during the life of the contract. Throughout the negotiation and administration of contracts there is potential for misunderstandings and delays that can affect productivity. For example, the contract specifies the materials and equipment to be furnished the shipbuilder by the government and its availability; and, the materials and equipment to be furnished by the shipbuilder. The particulars of the contract set the parameters for the planning of detailed ship design and production. Deviations from the terms of the contract, such as delays in obtaining government furnished items often have scheduling and cost implications.

> ISSUE: The effects of the scope and duration of ship procurement contracts on shipbuilding need to be assessed. In addition, opportunities need to be investigated for reducing the complexity of Navy contracts and speeding up decision making.

Shipbuilding Standards

The need for standardization, which is the use of standards, in shipbuilding is becoming increasingly apparent. Recent attempts of several U.S. shipbuilders to implement advanced design and production techniques used by some foreign shipyards have accentuated the fact that our shipbuilding standards, and our reliance on standards, must be expanded to permit incorporation of these techniques to their maximum extent.

Historically, shipbuilding standards have been thought of as being limited to specifications for materials and equipment. However, the potential use of standards in shipbuilding goes far beyond the material and equipment area into the design, production, procurement, and inspection areas. For example:

- Product standards provide a basis for outfit module design.
- Design standards define the optimum scope and size of outfit modules and ensure a producible product that is within the capability of the production trades.
- Planning standards establish guidelines for the proper application of the product work breakdown structure.
- Scheduling standards establish guides for the efficient use of facilities.
- Product standards, stored in a data bank, facilitate the application of CAD/CAM by simplifying programming and processing.
- Functional performance standards and testing/inspection standards, provide a basis for common understanding between buyer and suppliers and, if used, can simplify the approval/testing process.

- o Use of manufacturer's standard items where possible will reduce lead times and free critical engineering/procurement manpower to address priority areas.

- o Accuracy and tolerance standards address quality of workmanship.

- o A computerized material control system which interrelates design, material procurement, production, scheduling and accounting depends heavily on the use of standards in all of these areas.

The use of standards facilitates the implementation of advanced shipbuilding techniques such as zone oriented outfitting and product work breakdown structure, broad application of CAD/CAM, rationalization of the procurement process, increased accuracy control, and computerized material control. By eliminating repetitive or routine tasks, the use of standards can accelerate design and production and allow more efficient allocation of resources.

A myriad of standards are necessary for the efficient construction of Navy ships. Standards are developed and implemented on an industry-wide basis, and by individual companies and the military.

In the area of military standards, a five-year program is underway within the Navy to update, delete, and supplement military standards. The Navy also has established a policy of relying, wherever possible, on commercial standards.

Currently, a large number of military standards are out-of-date and require consolidation and updating. Occasionally, military standards overlap or conflict with commercial standards with inadequate or at least poorly understood (by private shipbuilders and equipment/material suppliers) justification. Nevertheless, in mission critical areas, Navy standards are an essential requirement.

The National Shipbuilding Standards Program, presently comprised of SNAME Panel SP-6 and ASTM Committee F-25, is continuing efforts to establish industry standards for design, equipment, procurement, and production areas. Its member organizations constitute a cross section of the industry and newly developed standards will have the potential for widespread applicability in Navy construction and repair activities.

> ISSUE: Areas in critical need of standardization need to be identified. The body of existing standards needs to be distilled into a usable base of information, to facilitate their implementation (for without use, standards themselves are of no consequence). The extent to which existing commercial standards meet the Navy's requirements must be established, as do the potential benefits to the Navy from supporting the development and administration of commercial standards. The needs and implications of updating and supplementing military standards require assessment. The role of the Navy in fostering the development of industry standards via the National Shipbuilding Standards Program also requires definition.

Quality Assurance

Quality assurance encompasses the acquisition of data with respect to the quality of production, analysis of data to discern that components meet standards, and the feedback of the analytical results to ship designers and builders so that remedial measures can be taken and similar problems avoided in the future.

Navy contracts invoke quality standards with respect to shipbuilding equipment, material, and systems. There are, within most shipyards, quality assurance programs that are separate from production departments. The major function of shipbuilder quality assurance programs is to assure compliance with the quality standards invoked in contracts. Regardless of the efforts of shipbuilder quality assurance programs, the primary assurance of meeting quality standards lies in the hands of the workers who actually perform the shipbuilding work. Good performance initially precludes the need for rework or repair. Rework and repair, in addition to adding to costs, usually must be done in a less efficient manner than was done in the first place. This in itself can lead to further rework and repair or replacement.

> ISSUE: Means to achieve and improve the ability to meet Navy shipbuilding quality standards in the initial installation of material, equipment, and systems need to be identified and evaluated.

Employee Safety and Health

Like all industries, shipbuilders have a legal and moral obligation to protect their employees from on-the-job injury and unhealthy working conditions. Typically, this obligation is met by supporting professional safety departments manned by safety engineers, industrial hygienists, and other qualified personnel. Safety departments conduct regular safety audits, provide safety rules and procedures, hold meetings with employees to discuss safety and health issues, keep records of safety performance, and provide safety equipment requiring or encouraging its use. To promote safety and health, shipbuilders also train employees and publicize and alert employees to potentially dangerous conditions.

The benefits of promoting industrial safety and health are easily measurable in human terms by comparing the statistics associated with lost time, accident severity, and frequency from one period to another. However, comprehensive safety and health programs are expensive, and their economic benefits may not be so easily determined. In the short term, the benefits may not cover program costs. For the longer term, reduced compensation costs, medical expenses, legal costs, and keeping healthy employees on-the-job provide substantial economic returns. Without comprehensive safety and health programs, the Navy, shipbuilders, and suppliers would be subject to long-term risks such as those associated with asbestosis, a problem that originated 40 years ago but only recently has been recognized.

> ISSUE: Means to improve the safety and health of naval shipbuilding need to be identified and applied. The benefits of comprehensive safety and health programs also need to be identified and evaluated. Yards and vendors need to be encouraged to provide such programs. The Navy needs to be aware of potential health and safety exposures.

Effects of Federal Laws and Regulations

Shipbuilders constructing naval vessels are subject to a variety of federal laws and regulations that apply to all places of employment, to government contractors, and to the shipbuilding industry.

Many of these apply to the safety of the workplace. Since shipyard work is largely done outside in confined spaces, at heights, is noisy, uses open flame sources such as welding and burining tools, and requires the lifting of heavy loads over and among workers, shipyard safety practices are vigorously inspected and enforced. While this is important and necessary, it must be recognized that it can have an uneven cost and productivity impact should enforcement be sporadic and nonuniform.

When shipyards are affected by broadly applicable laws and regulations, the cost of compliance is added to the cost of building ships. Newly enacted requirements, with significant cost impact, can be and are occasionally invoked after the contract price has been agreed to. This reduces the shipbuilder's margin of profit and is not compensated, as a practical matter, through Navy contracts. The impact of such regulatory developments on the shipbuilding industry does not appear to be reviewed by the Navy in any meaningful way. For their part, shipbuilders can do little to see that their concerns are addressed, unless the Navy takes the lead.

> ISSUE: The impacts of government regulations on shipbuilders need to be better understood since the cost of regulatory compliance is added to the cost of building ships.

Agenda for Assessment

The committee views the issues it has identified as an agenda for its work in identifying and appraising ways to improve the productivity of U.S. commercial shipbuilding of Navy ships. The remainder of this report is devoted to the assessment of four of the issues: capital formation, CAD/CAM, standards, and worker participation and organizational change. Three of these assessments are complete. The fourth, capital formation, consists of a short statement of the importance of the problem because the committee is continuing its assessment. The committee's technical assessment of issues is not being undertaken in priority order. Rather, the order of assessment is the result of the availability of appropriate expertise to the committee, the existence, for each issue, of sufficient data or adequate logic as a basis for assessment, and time and budgetary considerations.

Notes

Kendrick, John W., and Beatrice N. Vaccara. 1980. New Developments in Productivity Measurement and Analysis. Chicago, Illinois: University of Chicago Press.

CAPITAL FORMATION

One of the most important factors affecting shipbuilding productivity concerns the overall health of the industry, and particularly its attractiveness to sources of investment capital. When an industry is healthy in terms of profitability, growth, and stability, it will attract the financial and human resources it needs. When an industry consists of a sufficient number of firms to be competitive, industrial history demonstrates that owners and managers will invest, innovate, and take risks to gain competitive advantage. Consequently, productivity gains result that benefit not only the company but also its customers and the public.

Because of the importance of capital formation, the committee undertook preliminary work to describe and understand the shipbuilding industry and to appraise it as an industry in terms of its ability to attract superior financial and human resources. Questions have been raised about the health of the industry and the factors that influence its health. There are indications of unsatisfactory profit levels in many firms, a general state of over capacity leading to destructive competition, and serious problems not only in a lack of industrial growth but in excessive instability of orders and production levels. These problems are complex for they involve issues of national maritime policy, government procurement policies, political pressures affecting the allocation of available shipbuilding volume, the U.S. defense base and posture, the internal resource allocation policies of a number of large diversified corporations, and more.

The committee continues to explore these issues. It is gathering and analyzing data on the status of the industry, the market, and government policies and procedures to determine the attractiveness of the industry for financial and human resources, to identify positive and negative factors and what can be done by the industry itself, by the Navy, or by the Congress to improve its basic health and attract the resources necessary to improve productivity, product quality, and value received by the Navy and the American public. The next report of the committee will offer an analysis of capital formation in the shipbuilding industry and its problems and opportunities, as well as recommendations.

COMPUTER-AIDED DESIGN AND MANUFACTURE (CAD/CAM)

Although the acronym CAD/CAM is translated literally as "computer-aided design, computer-aided manufacture," the term is broadly and commonly used to refer to the use of computers in industrial manufacturing, in applications ranging from design to production and encompassing all peripheral information processing tasks associated with a common engineering data base.

CAD/CAM technology has developed from initial, narrowly defined applications such as drafting and numerical control of machines. Today, the most sophisticated CAD/CAM applications are integrated information systems that encompass product definition data, engineering configuration control, manufactural engineering, production planning, purchasing, materials requirements planning, manufacturing, quality assurance, and customer acceptance. A keystone to the full and successful utilization of CAD/CAM technology is a single product definition data base containing an electronic description of the designed products that are being constructed or manufactured, with the ability to interface with other data bases.

Internationally, applications of CAD/CAM have multiplied in the last 10 years in a broad range of industries: aerospace, automotive, heavy machinery, electrical, electronic, architectural, engineering, construction, and shipbuilding. While over 25,000 CAD/CAM workstations are in use today, the committee estimates that fewer than 500 CAD/CAM workstations are used in the Navy and in U.S. shipbuilding industries.

Problems and Opportunities

The Navy, through design agents, creates thousands of drawings and performs many more thousands of engineering calculations in designing a ship and establishing its specifications. These drawings, calculations, and specifications are provided to shipbuilders and suppliers in paper form. The shipbuilder then adds to the paper information package in submitting a ship construction bid to the Navy and in designing for production.

Throughout this process, many additional drawings and thousands of calculations are completed. The same geometries are drawn and redrawn again and again. Each time that a previously drawn geometry is redrawn or manually manipulated for any reason, or calculations have to be made based upon data extracted from a drawing, there are opportunities for additional costs and errors. Subsequently, for ship construction, the information that has been developed has to be laboriously translated into material and equipment requirements for ordering and scheduling as well as information for numerical control machines such as flame cutters, construction planning, and other activities.

The opportunity exists to use a systems-oriented approach for the design, specification, and construction of ships with computer-based tools and data bases that significantly reduce costs, errors, and lead times and improve product quality. Yet, the application of CAD/CAM in naval shipbuilding must await resolution of a number of far-reaching and complex legal and technical issues.

Transfer of Data Bases and Software

Application of CAD/CAM will hinge on the transfer of data-bases and software between users, including the Navy, ship design agents, lead and follow shipbuilders, and equipment suppliers. The possession and transfer of data and software have both antitrust and liability implications. Antitrust implications come to the fore in the transfer of data or software between design agents, between shipbuilders, as from a lead to a follow shipyard, or between shipbuilders and their suppliers. If the data and/or the software are considered proprietary, then on what basis does the government order that data or software be transferred, even though the transfer may be essential to the procurement? The matter of liability for omissions, errors or damage of data-bases or software is present when data or software are transferred. These legal issues are paramount and need to be addressed in Navy contracts.*

Product Definition Data Base

The means of electronic transfer of information will be through controlled architecture, application, and management of data bases and

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*The committee recognized the importance of the legal issues, but did not consider them in depth, because it considered their resolution to be both outside its expertise and outside the scope of the study. Nevertheless, resolution of the legal issues is perhaps the major impediment to the application of CAD/CAM. The technical discussion below should be viewed in light of the unresolved legal issues, which will control CAD/CAM applications as much as the technical issues which are discussed.

software, including the establishment of a control library forcontrolling data base format and computer language. Whether an integrated data base or other approach is best suited to naval shipbuilding needs to be established. The respective roles of the Navy, shipbuilders, marine equipment suppliers and ship designers in this process need to be defined. An important element of this will be equitable assignment of development and application costs among users (the technical problems themselves are manageable).

People

The shipbuilding industry needs to attract, recruit, train and retain the necessary people to plan, acquire, operate, and manage CAD/CAM technology in the face of rising costs and critical skill shortages. Shipbuilding career paths need to be restructured to accommodate CAD/CAM technology specialists; in this, the shipbuilding industry may be able to profit from lessons learned in other industries in the deployment of CAD/CAM technology. The Navy role in recruiting and training personnel in CAD/CAM technology for deployment in the shipbuilding industry needs to be determined.

Planning

The management of machine readable information in an industry that traditionally has used an information data base stored on paper needs to be assessed from a systems viewpoint. The Navy and the shipbuilding industry need to evaluate CAD/CAM technology and plan for its utilization. Whether the Navy should insist that individual shipbuilders and design agents use CAD/CAM technology needs to be determined, as does the matter of Navy assistance to industry in planning for an integrated systems approach to CAD/CAM technology.

Status and Applications of CAD/CAM Technology in Shipbuilding

In any industry, the introduction of CAD/CAM technology can reduce costs by reducing new product development time, minimizing product support and manufacturing costs, and improving quality of design and manufacture. Those companies that lay a solid foundation for the introduction of CAD/CAM technologies typically are able to obtain cost reductions or cost avoidances representing three to four times the implementation cost.

CAD/CAM is a reality today in manufacturing because computer technology has expanded , the cost of hardware has decreased, applications software has become more functional, and the benefits of an integrated data base have been identified. Hardware costs are on a 35-year downward trend that is forecast to continue for the next 10 to 15 years. The development of commercial computer technology in the last two decades, has trended toward the development of families of computers and peripherals that use similar applications software. The continuance of this trend permits an evolutionary enrichment of software. It is a fact that any CAD/CAM technology purchase can be replaced at a later date with less expensive, more powerful products. Rather than delaying purchase or applications on these grounds, the user needs to ensure that suppliers and purchases have adequate expansion and growth capabilities to support both present and future needs and requirements.

The potential contribution of computers to improving shipbuilding productivity varies with the application. For example, the detailed design of a particular ship may consume twenty to thirty times as much design and engineering effort as all of the preceding feasibility, preliminary, and contract design phases. For this reason, computer-aided design, especially as a replacement for manual drafting, can make an especially strong contribution to detailed design.

Computer-Aided Design Technology

With a suitable product definition data base, state-of-the-art CAD technology is capable of performing the drafting function and assisting in numerous design and engineering tasks. These include geometrical manipulations necessary for designing structures, layouts, piping and wiring systems, and other elements. CAD data can be used to produce tool path instructions for numerically controlled devices such as machine tools, pipe benders, and burning machines. Since the computer executes geometric calculations to several decimal places, great accuracy can be obtained in tool plotting and in burning. The results, particularly for structural and piping parts, are less material waste and improved fit-up with corresponding savings in fitter and welder labor.

Computer technology companies in the United States have developed state-of-the-art computer-aided design systems that command an important share of the world market. U.S. commercial shipyards are aware of and utilize these technologies to some extent. Perhaps 1 to 5 percent of shipbuilder design and drafting tasks are conducted with CAD assistance. Additional CAD work stations are being rapidly introduced by shipbuilders. The percentage of design and drafting tasks conducted with CAD assistance is destined to increase in the future, especially as the data bases necessary for efficient utilization of their potential are developed.

Computer-Aided Manufacture Technology

Numerical control machinery technology is directed primarily to fabrication operations. Although these operations favorably impact module assembly and outfitting through improved accuracy, most of the savings realized are not in high cost areas. State-of-the-art numerical control devices and robotics in shipbuilding are most suited to applications, such as plate and pipe shops, which resemble manufacturing more than construction. In the future, developments in robotics will lead to a larger variety of operations.

An area of computer-based potential for productivity gains is the increased use of management information systems. This makes it possible to collect and forward automatically the design data to all the complementary planning, material ordering, production tracking, and completion tasks.

Real productivity improvement involves more than producing greater amounts of quality work in less time. It entails more efficient planning, scheduling, and sequencing of the work processes--manufacture, inspection, and testing of the parts that make up the total product. Computers used for data management can have a potentially greater impact on production than numerical control machinery because they can assist in controlling the work breakdown structure in all areas of ship construction.

Integrated Data Base/Planning

Early implementations of CAD/CAM technology focused on narrowly defined tasks such as drafting, finite element mesh generation, and numerical control of machine tools. These applications had potential direct savings that could be made and measured. Once these savings were made, people realized there was an even larger potential for savings by using the same data base and software for other applications that could be identified such as lofting, mass properties, vibration analysis, material requirements planning, and construction management. Productivity gains would accrue through creation of one common data base and then using it in several different applications.

Major companies, such as General Electric, Boeing, and General Motors, in recent years have committed to moving from product definition on paper to product definition in electrically readable form. Today, the most advanced CAD/CAM technology installations are part of integrated information systems that encompass product definition, engineering configuration control, manufacturing engineering, purchasing, materials requirements planning, manufacturing, quality assurance, and customer acceptance.

The availability of a product definition data base can provide a means of recording modifications to a given ship over its service life, provided that a system is in place to enter in the data base modifications reflecting changes made to the ship during its service life. Repair of malfunctions, logistic support, and preparation for overhauls and alterations would be greatly facilitated by such an arrangement.

<u>Standards for the Establishment and Interface of Data Bases</u> If a data base is to be transferable and usable in numerous applications undertaken by different entities--for example, naval design tasks undertaken by the Navy and design agents--and detailed design,

production planning, and production undertaken by shipbuilders, then a standard for transfer of data is necessary to ensure compatibility and usefulness on different computer systems. This need for graphic exchange specifications has been recognized across the board in manufacturing industries. In 1979, 20 government and industry CAD/CAM technology users and vendors joined forces under the stewardship of the National Bureau of Standards to develop graphics exchange specifications. The activity, known as the Initial Graphics Exchange Specifications (IGES) program has as its objective the development of comprehensive national standards for the use of vendors and users.

IGES standards have been developed in a number of areas. At least eight CAD/CAM vendors already sell IGES conversion software, and major procurements of CAD/CAM equipment are being made with the requirement that the vendor supply IGES conversion software. IGES programs are most widely used by suppliers of mechnical parts, but the programs are rapidly gaining acceptance in a broad range of industries.

The IGES program has reached a critical level in terms of support by suppliers and users that indicates it will be increasingly relevant to all ongoing activities in CAD/CAM technology. Some shipbuilders have participated in some IGES standards development activities, for example, in the development of piping graphics exchange specifications. However, shipbuilders' participation in the IGES program has been limited in comparison with other industries' participation. The degree to which such broad-based industrial activities are relevant to the problems of a specific industry is often a function of the level of that industry's participation in the activity. Thus, graphics exchange specifications would be made more applicable to shipbuilding if shipbuilders took a more active part in their development.

Navy Use of CAD

Computers are utilized extensively in naval ship design. Since the bulk of Navy preliminary and contract design work and all ship detail design is contracted out, however, the Navy has not to date played a major role in promoting or influencing the use of CAD/CAM by U.S. shipbuilders and design agents. In addition, there is significant duplication of effort by design agents and shipbuilders in developing software individually, with little opportunity for interchange with one another or with the Navy's programs.

The Navy, considering the benefits that will accrue, has a strong incentive to promote and consolidate the use of CAD/CAM. As the customer, the Navy has the option of providing its requirements to designers, shipbuilders, and supplier industries in paper form as at present or in machine readable form. Were the Navy to provide their requirements in machine readable form, designers and shipbuilders would be provided with a powerful new incentive to restructure their operations on the basis of an integrated common product data base. To be effective, however, the Navy needs designers', shipbuilders', and suppliers' participation in their CAD development work. Exchange of information among design agents and shipbuilders would result from a cooperative effort, and this would open the door for the reorganizations of shipbuilding work and resultant productivity improvements that have been described.

As the Navy applies CAD/CAM it needs to take care that its requirements are commercially practicable. For example, a requirement that the shipbuilding industry employ the Navy's new computer language, ADA, would be difficult and costly to implement.

Human Resources Aspects of CAD/CAM

People trained and experienced in any aspect of CAD/CAM technology are in very short supply. The rapid industry growth permits persons with relevant experience to get jobs easily at higher salaries and with better benefits. Colleges and universities are not training enough new graduates in the needed time frame. Large scale users of CAD/CAM technology have invested in significant training programs for employees to provide some of the necessary people.

In addition to problems of recruitment and retention, the introduction of computers to shipbuilding augurs some very signficant changes in the organization of the work force and work practices. These changes may, or may not, be anticipated or planned for by industry. In this regard, the social technologies of participatory management and organizational change (described subsequently) are relevant.

Assessment and Summary of Advice

Potential Contribution to Productivity Improvement

CAD/CAM technologies offer the shipbuilding industry a tool and an opportunity to improve productivity by reducing the direct labor contribution to a number of technical tasks and, by stimulating and facilitating the coordination of management functions, (for example, materials requirements planning and scheduling) and engineering phases (e.g., design, planning, and production). CAD/CAM also can aid information transfer between the Navy's design functions and the shipbuilders' production activities as well as improve ship service life logistic support. Reliance on a paper mode of product description slows down the flow of management and production information in shipbuilding; this increases costs and decreases management control of production. Technical as well as legal issues need to be resolved to pave the way for the application of CAD/CAM to naval shipbuilding.

Integrated Product Definition Data Base

An integrated standardized shipbuilding product definition data base has significant potential to improve productivity. The Navy, as the major shipbuilding customer in the United States, is in an outstanding position to resolve the legal and technical issues and to cause or foster its rapid development, in conjunction with the shipbuilding industry.

In some industrial applications, it is practical, because of data volume, to have one data base that can store data on product definition and operations data, such as scheduling and planning. In many cases, it is more economical to have two or more data bases, but always with one data base for the product definition data as the foundation for common engineering and operations usage. Other data bases could be developed to meet the need for data storage not appropriately a part of the product definition data. An example of this need could be the storage of detail manufacturing plans and optional plans for the production of parts where factory workload would dictate which facilities and associated plans would be most economical for production.

The most significant CAD/CAM technology-related cost savings are achieved when a single, integrated product definition data base is constructed, modified, and used for products as they are taken from product concept all the way to manufactured products. There are enormous potential cost savings to be realized when the integrated product definition data base is used as a common source of data in product planning, engineering, manufactural engineering, purchasing, material requirements planning, manufacturing, quality assurance, and customer acceptance.

For example, in manufacturing, numerically controlled machine tools can automatically cut steel parts to the designed shape according to design information that is entered into the integrated product definition data base when the engineering tasks are accomplished. In engineering, the design can be completed faster and with greater numerical accuracy and higher quality because the integrated product definition data base and related CAD/CAM technology tools support design tradeoffs, tolerancing, and space conflict analysis. A related opportunity that results from CAD/CAM application is the development of software that applies some standards. In material management, the integrated product definition data base permits more accurate material forecasts and better inventory control. The detail designer is able to make drawings faster, better, and cheaper.

Further, by working jointly with the shipbuilding industry, the Navy insures that the specification for the integrated product definition data base is adequate for present and future needs. Individual shipbuilders may adapt this integrated product definition data-base architecture for their own use. Shipbuilders can improve their ability to receive and use information from the outside in electrically readable form by adopting the Navy's proposal. An important requirement for the integrated data base specification is the ability to utilize the IGES format. It is clear that IGES compatibility is desirable if not mandatory.

Data bases increase in value as design work is conducted. A data base is very expensive to develop and load with valuable data. Once a data base is developed and fully implemented, it is very costly to make revisions to the data base management system. Over time, the cumulative cost of the labor to create the data is far greater than the hardware and software costs. Thus, expansion and growth in this area needs to be built on the value of existing data bases. Maximum efficiency results from using data bases in as many applications as possible and from building into the data base the capacity of interchange with other CAD/CAM installations. Furthermore, the establishment of an integrated data base for all ship design and shipbuilding functions will take considerable effort over a number of years. It is desirable, as an adjunct to such an effort, to establish the format and contents of computer readable information that the Navy will provide to design agents and shipbuilders.

Navy and Shipbuilders' Interaction with other CAD/CAM Users

The major difference in the application of CAD/CAM to naval shipbuilding, as contrasted with its application in other industries, is the predominant role of the Navy as customer. Resolution of both technical and legal issues possibly can be facilitated through active participation in CAD/CAM industry activities. As an element of this, it appears advantageous for the Navy and the shipbuilding industry to form a special interest group in the IGES effort to insure that the technical evolution of the IGES specification meets the requirements of the shipbuilding industry. A continuing forum for joint development and use of computer technologies in shipbuilding also would be useful.

STANDARDS

Standards are basic technical guidance used in the construction of ships, including standards, specifications, classifications, codes of practice, definitions, and test methods. The use of standards results in the manufacture of products based on the concept of a uniform specification, design, and production process. Taken in the aggregate, this process is termed standardization.

Standardization

Standardization plays an important part in industrial productivity. The degree to which standardization is applied to form, fit, or function depends largely upon the specifics of the industry, the elements of the product being produced, and the processes being employed. In recent years, for example, where advanced techniques have been utilized in shipbuilding for modular unit construction, interfaced material and production control, and zone-oriented production, standardization has been one of the key elements in the success achieved. Standardization can be applied to equipment, material, design, and the production process. It can range from a standard thread for bolts and nuts to building multiple copies of complete ships with different missions but with the same hull and machinery, altering only those features unique to the mission.

Standardization is usually thought of in terms of mass production. Shipbuilding, however, is not a mass-production industry because of the small number of units, their size, and their complexity in structure and systems, including combat and electronics systems in naval vessels. Therefore, standardization in shipbuilding usually applies to something less than a whole ship.

Standardization has positive and negative effects on shipbuilding systems (see Table 8). The use of standards also has benefits for lifetime logistics support and future overhauls. For logistic support, spare parts can be reduced in quantity and number. Technical publications can be fewer, and updating costs can be reduced. Crew training can be improved with fewer courses to be prepared and administered. Knowledge of systems by crew members can be carried from ship to ship. Overhauls, particularly for submarines, performed

TABLE 8 Effects of Standardization

POSITIVE	NEGATIVE
o Standardized/simplified design	o Technology freeze if standards not updated to incorporate technology developments
o Minimized documentation	o Resistance to change
o Interchangeability	o Need for suitability for new construction and back fit
o Simplified logistic support	o Effort required must be compatible with business volume and companies to be serviced
o Long-term stability in design, manufacturing, and logistic support	o Initial start-up waste (discard of nonstandard items) if initiating logistics are not adequately planned
o Worker familiarity	o Immediate cost impact to implement
o Reduced obsolescence	o Lengthy development cycles
o Increased interaction of design/production engineers	o Cost to maintain standards
o Advanced planning to achieve integration	
o Multiunit procurement	
o Simplified/shortened approval cycles	
o Improved product quality	
o Improved product reliability	
o Improved communications among designer/shipbuilder/supplier/owner	
o Reduction in life cycle cost	
o Improved maintainability	
o Reduced testing time	
o Support CAD/CAM	

late in the ship's service life are adversely affected by the unavailability of parts for critical components. The situation is made more difficult because ships of the same class from different builders have different components for similar functions.

During the life of a ship, substantial economies can be realized from reduced procurement costs, engineering requirements, and simplification of overhauls, provided attention is given to standardization during design and construction.

Logically, the use of appropriate standards will contribute to productivity by assuring required product quality, reducing procurement and production time, and minimizing cost. Standards, if established, adhered to, and maintained can assure increased service performance, decreased failure, and reduced ship maintenance. Standards assure ease of fabrication or fit, proper quality, and reduced rework and inspection for the builder.

Shipbuilding Standards Programs

Shipbuilders and suppliers rely on and use a profusion of design, material, and equipment standards in the construction of naval ships. Standards suitable for commercial and military applications are developed and maintained by a large number of professional and industrial organizations, both nationally and internationally.* Even so, there are no marine standards for some shipbuilding tasks and equipment. Organizational structures exist in the industry and the Navy that can, with full support, fulfill a significant portion of the Navy's standards needs. Recognizing that a large number of organizations develop and maintain standards and encourage their use, the committee confined its assessment of standards programs to the two that address shipbuilding (and within this naval shipbuilding) most directly.

The National Shipbuilding Standards Program

The National Shipbuilding Standrds Program was developed and is coordinated as an element of the National Shipbuilding Research Program. It consists of a steering committee, SNAME Panel SP-6, and a technical committee, The American Society for Testing and Materials (ASTM) Committee F-25, which undertakes shipbuilding standards development.

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*Certain international standards issues affect U.S. shipbuilding productivity. Examples are the degree to which U.S. shipbuilding will go metric, and the degree to which U.S. standards and standards practices are in conformance with international standards and practices. The committee recognized this but did not address international standards issues in its assessment because it considered the issues to be rather broader of focus than, and extraneous to, its charge to examine naval shipbuilding productivity in the U.S.

SNAME Panel SP-6, Standards and Specifications The principal role of the SNAME Panel SP-6 in the National Shipbuilding Standards Program is to set the technical community's plans and priorities for standards development, and through the SNAME Ship Production Committee, to recommend cooperative MarAd/Navy/industry cost-shared projects which will accelerate direct benefits to the industry. The panel's major contributions have been the publication of a long-range plan for the development of shipbuilding standards as well as the production of a large number of draft standards that are in various stages of processing within ASTM and the panel itself.

Since its activation in late 1977, membership on SNAME Panel SP-6 has increased from nine members representing five shipyards to 32 members representing shipyards, design agents, equipment suppliers, the Naval Sea Systems Command (NAVSEA), and the Maritime Administration. Many members are placing increased emphasis on standards development and use and still others plan to initiate internal (company) standards programs.

The benefits of participation on Panel SP-6 include keeping informed about progress and developments and also actively supporting projects (Navy/MarAd funded).

ASTM Committee F-25 Where SNAME Panel SP-6 serves in effect as an industrial advisory committee for setting standards development priorities, ASTM Committee F-25 actually undertakes shipbuilding standards development utilizing, in large measure, the same individuals who serve on SNAME Panel SP-6.

ASTM is a nonprofit management system for the development of voluntary consensus standards. It is the world's largest source of voluntary consensus standards. ASTM committee F-25 was organized in 1978.

The development of consensus standards within formal due process requirements of a recognized forum such as ASTM is often a slow process. However, the rate of standards promulgated is proportional to the degree of commitment and support provided by the industry for the development of the standards.

To summarize the normal procedure, a task group of two to five people is formed to do the required background work and prepare an initial draft, which is reviewed by its parent subcommittee through a balloting procedure. If the document is approved by two-thirds of those returning ballots (a minimum of 60 percent of the voting interests must return ballots), the document proceeds to the main committee ballot. Here, 90 percent of those returning ballots (again a 60 percent return is required) must approve the document.

It then advances to a Society ballot where a minimum return of 50 ballots is required, and 90 percent must vote affirmatively to make it an approved ASTM standard. A single negative ballot at any stage returns the proposed standard to the technical subcommittee for resolution. Maintenance of the technical content of ASTM standards is assured through a mandatory review procedure which stipulates that all standards under the jurisdiction of a committee be reviewed and formally acted upon at least once every five years.

The consensus standard system and ballot action process is a deliberate and time-consuming procedure. About 120 standards are currently under development. Thirteen of these have been approved and are in effect.

In the early stages of the program, significant efforts were expended to establish the organizational structure that would provide an effective system for standards development. This structure remains essentially intact and is used to process the previously mentioned 120 standards. Of the thirteen standards now available, a documented 70% have been fully implemented in several yards. Initial cost savings of $25,000 per hull have been documented in one shipyard through the use of just four of these standards on a new construction contract. Numerous others are being implemented in shipyards prior to their final adoption by ASTM.

A long-range plan for standards development has been developed through Panel SP-6 and is in place to establish the foundation for the future efforts of the program.

It is apparent that this program is at a most critical phase of its existence. The National Shipbuilding Standards Program has developed from an organizational phase into an implementation phase. The program needs substantial technical support and participation to achieve its objectives.

Military Standards for Shipbuilding

The Navy has a specification, standard, handbook, or standard drawing or type drawing for almost every requirement. In the words of Dr. John J. Bennett, former assistant secretary of the Navy for shipbuilding and logistics:

> Navy technical documentation is complex and costly. Typically, 1,000 pages of ship specifications, 2,500 references, accompanied by 1,500 Mil/Fed Specs (Military/Federal Specifications) and 250 industry references provide a shipbuilder with what he needs to know in order to build what is wanted. The shipbuilder in turn converts this material into as many as 5,000 procurement specifications, including every piece of equipment on board, and up to 8,000 construction drawings (Bennett, 1982).

The scale of this effort is impressive, especially when it's realized that the 1,500 cited Mil/Fed Specs also include as references within themselves, numerous other Mil/Fed specs. In addition, the amount of inspection and technical review that is required at various levels to assure compliance with standards is massive.

Burdened with such a volume of material concerning the status of technology, which evolves over time, it is quite understandable that some military standards are out-of-date and need to be deleted or updated; and, that needs for new standards often arise. Fully 35 percent of the standards for which the Navy has prime technical responsibility (9,000 Mil Specs and 2,500 standard and type drawings) are out of date. Occasionally, military standards are perceived to overlap or conflict with commercial standards, with inadequate or at least poorly understood (by commercial shipbuilders) justification. U.S. Navy requirements for surface coatings are a case in point. They differ considerably from, and result in substantially higher costs than, commercial practices. In still other areas, standards specific to Navy shipbuilding are urgently needed. An example is design standards for the form, fit, and function of ship components. Finally, in the past, some Mil Specs have been developed in the absence of any available specification where there is really no military requirement. Such standards (that are not militarily necessary) could be replaced by industrial standards, resulting in a less costly product.

The Navy has a program to improve the technical documentation used in ship acquisition, repair, overhaul, and maintenance. The program includes the maintenance of the general specifications for ships of the U.S. Navy, federal and military specifications/standards and handbooks, standard and type drawings, design data sheets, and increased use of industry standards. Approximately 9,000 specifications are scheduled for review and update. The current annual budget for this effort is about $5 milliion of which 50 percent is contracted out. It has been difficult in the past for the Navy to obtain adequate funds for this effort, hence the backlog of standards needing review and update.

Despite or because of the size of the military standards effort, the Navy is interested in the increased use of industry standards. Navy policy in this regard conforms with Offiice of Management and Budget Circular A-119. The Navy will:

- Rely on voluntary standards wherever possible.
- Participate in developing voluntary standards where needed.
- Review existing standards and cancel Navy standards where voluntary standards exist and will do.

To this end, the Navy participates in and supports the industrial standard activities that have been described. To the extent voluntary standards will suffice, the Navy will be that much farther ahead. Due to the mission-unique requirements of certain systems and equipment such as weapons systems, communications systems, and others, military specifications will continue to be a necessary component of naval ship construction.

U.S. Navy ship specifications for an individual ship or class of ships are all based on and extracted from the general specifications for ships of the U.S. Navy (known as the Gen Specs). The Gen Specs have built into them a long history of ship design, construction, operation and maintenance experience.

Individual ship or ship class specifications which are extracted from the Gen Specs, together with a package of some 20 to 150 contract drawings, form the technical requirements for the entiire ship acquisition contract. It is in the individual ship specifications, along with the related drawings, where the unique characteristics of the individual ship are delineated.

Essentially the same acquisition methodology is used in merchant work and naval combatants. It is normal practice in both areas that most material, components, equipment, and machinery are furnished by the shipbuilder. Weaponry and sophisticated electronics are generally acquired separately by the government and furnished to the shipbuilder. The hull, mechanical, and electrical equipment is normally supplied by the shipbuilder. About half the cost of a ship derives from items provided by vendors.

Because the shipbuilder and vendors furnish much of what is eventually built into the ship, it is necessary to provide detailed guidance which reflects the Navy experience and needs. As a result, the Gen Specs (and the more complex ship specifications) contain some 2,500 referenced documents. It is these documents, especially the military and federal specifications and standards, that are the focal point for this discussion of standards and where the increased use of commercial specifications becomes an issue.

Assessment

The purpose of standards and standardization is to increase productivity by manufacturing, operating, and maintaining products based on the concept of a uniform specification, design, and production process.

Standards development, whether in the context of technical society activities, or the update of military standards, is a task of significant magnitude and long duration.

Standards development requires the commitment of technical talent on the part of standards users, including the military, shipbuilders, logisticians, vendors, and others. Without the commitment of effort in the form of technical talent and financial support, standards will lag the technology--this, in fact, is what is occurring. The lack of standards, or the application of inadequate standards, complicates procurement, increases engineering requirements, and leads to delays.

Increased development and use of standards represents a very significant opportunity for producibility improvement and cost reduction in shipbuilding. With increased government and industry support, especially in the form of committed technical talent, the benefits of standardization can be realized.

Increased Navy use of voluntary industrial standards could lead to required quality at lower cost, and more timely job completion. Therefore, the Navy should cooperate with designers, shipbuilders, suppliers, and owners in efforts to produce standards common to the U.S. maritime industry. They should make their expertise available and, in some cases, recommend use of U.S. Navy-proven methodology.

Where there are genuine differences (for example, inspection and testing procedures), a Navy exception may need to be written into the standard for those portions requiring a different approach for Navy use.

For example, in voluntary industrial standards, quality assurance and packaging requirements may be missing, or deficient from a Department of Defense (DOD) or Navy viewpoint. This can be remedied by inclusion of such requirements in a DOD or Navy appendix, or by including them as exceptions in the DOD acceptance notice. As a last resort, a military specification can be written around the industry document by citing it in the "requirements" section and adding testing and packaging in their normal sections.

It is in the area of materials applications that industry standards have enjoyed the greatest degree of Navy and DOD acceptance. Navy ship specifications have long referenced ASTM and American Bureau of Shippiing steels, especially for noncombatant ships. In addition, many military specifications now reference ASTM or other society standards for such materials as aluminum alloys, corrosion-resistant steel, ceramics, and plastics.

A considerable number of voluntary industry standards have been prepared and issued for small manufactured products such as pipe and tubing, valves, other pipe fittings, pressure gauges, and similar items. Navy engineers have long been members of technical committees in this sector and have used industry concepts in their military specifications or have initiated action to accept them. A case in point is Military Standard-777, "Schedule of Piping, Valve Fittings, and Associated Piping Components for Naval Surface Ships"; in establishing criteria for the many different shipboard piping systems, industry standards are referenced about as often as military specifications.

In the machinery and equipment area, there is a singular lack of industry standards and thus, not unexpectedly, there are a host of military specifications for engines, pumps, compressors, and similar power plant machinery. However, even here such specifications often reference industry standards for materials and small parts, and the end products are not too dissimilar from their commercial marine counterparts.

The Navy should continue to prepare, use, and update military specifications where mission-related requirements dictate unique characteristics that have no parallel elsewhere in the marine industry. Weaponry, sophisticated electronics systems, unusual temperature/pressure applications, and special electrical requirements may be viewed as areas where military specifications are mandatory to ensure product performance, quality, and maintainability.

In the future, industry standards produced by organizations such as ASTM F-25 will provide the Navy with substantial opportunities to eliminate redundant or out-of-date Mil Specs and to capitalize on the advantages to cost, procurement, and construction times of the use of commercially available equipment and components. Adopting the industry standards may fulfill the Navy's needs, and it may be possible for Navy specifications to maximize the use of industry standards for referenced materials and small parts. The increased utilization of commercially available items would allow the Navy to concentrate its limited manpower and financial resources in areas where they are most needed.

Vendor Certification

The present Navy quality assurance system, that conforms to specification MIL Q 9858A, places the responsibility for quality of the product on the supplier. The Navy qualifies the suppliers' manufacturing system and periodically audits the system and product to assure continued conformance to requirements. MIL Q 9858A is extensive and expensive for the manufacturer to implement and maintain. For certain suppliers and activities, the complementary but simplified system of MIL I 45208 is more suitable.

There may be need for an additional qualification level that would apply to suppliers of standard commercial hardware that do not have military or safety applications. A system of certification of manufacturing facilities through the use of standards could result in large efficiencies over detailed inspection of produced products. Once qualified, the manufacturer's products would be marked as meeting a standard (without detailed inspection of each item produced). The U.S. Coast Guard follows such a system in the certification of lifesaving devices. The Japanese employ it extensively in shipbuilding and elsewhere.

Summary of Advice

Increased development and use of standards represents a very significant opportunity for productivity improvement in naval shipbuilding. Investment in standards development and applications will significantly reduce ship acquisition costs. However, standardization is successful only when the standards are widely used and accepted.

The objectives of the Navy program to update Mil Specs are sound, but the large size of the task and modest scale of the activity portend that military standards will continue to lag technology significantly. Because of the leveraged effect that standards development has on reducing costs, the Navy should support the Mil Specs improvement program with financial support and technical talent sufficient to eliminate the lag between the state of military standards and the state of technology within the projected five-year life of the program.

A significant portion of the SP-6/ASTM industrial standards development activities is directly relevant to Navy construction programs. The need for industry standards in shipbuilding is becoming increasingly apparent and the National Shipbuilding Standards Program is gaining broad support. The Navy will derive substantial paybacks on its investment of financial support and technical participation in these programs.

The Navy should assume a leadership position in these activities, provide the motivational factors necessary to stimulate involvement from remaining segments of the industry, and continue its financial support and technical participation, with the view towards increasing the pace of standards development sufficiently so that the programs satisfy Navy requirements. Technical participation is especially critical since it is by this means that the Navy will be able to make the standards that are developed applicable and useful to the Navy.

Notes

Bennett, John J. 1982. Cost Drivers in Ship Construction. Paper read at the Navy Shipbuilding Technology Conference of the National Research Council, June 28, 1982, at Washington, D.C.

WORKER PARTICIPATION AND ORGANIZATIONAL CHANGE: POTENTIAL CONTRIBUTION TO SHIPBUILDING PRODUCTIVITY IMPROVEMENT

Recent industrial experience has demonstrated the importance of effective use of human resources in attaining productivity. Within organizations, "human resources" constitutes the full range of manpower concerns, including human relations, labor relations, personnel functions and industrial engineering. Basic to the effective use of human resources is the existence of an environment of employment stability and labor/management respect. The contribution of human resources to productivity also is affected greatly by the degree of management commitment to cultivating human resources.

Although it is clear that improvements can be made in a number of traditional human resources concerns in shipbuilding, the most essential challenge in shipbuilding is to improve the physical and organizational conditions of shipbuilding work by altering the relationship between employees and management and the relationship between employees and tasks. The logic for this emphasis is that weaknesses in human resources--for example, manpower shortages--may, in fact, be occasioned by physical and organizational deficiencies, such as failure to provide satisfying and challenging jobs.

Problems and Opportunities

The potential of the U.S. shipbuilding work force has not been sufficiently tapped. A study in 1980 concludes from a comparison of data from a sample of American and foreign yards that labor productivity in U.S. shipbuilding is generally only half that in Scandinavia and Japan (Appledore, 1980). Of this total it attributes 30 to 35 percent of the difference to "...superior organization and systems and a more effective work force in the foreign yards." A 1978 comparison of U.S. shipbuilding technology shows that the greatest shortcoming of the American yards is in the category of "environment and amenities" (Marine Equipment Leasing, Inc., 1979).

While some of the large-scale environmental deficiencies of the U.S. yards may be attributed to their age, another study notes that inferior amenities such as canteens, washrooms, toilets, and lockers could be easily remedied by local management initiative (Lowry, Stevens, and Cragg, 1980). The fact that little concerted effort has been taken is interpreted to reflect management's attitude that the high turnover in U.S. yard workers does not warrant investment in such amenities. The study also notes that the high turnover in the industry is attributed frequently to poor working conditions.

Although U.S. and foreign technology levels are approximately the same overall, a considerable difference between U.S. and overseas practices was found in the area of flexibility in the assignment of work and supervision of the work force (Lowry, Stevens, and Cragg, 1980). Whereas the American yards are characterized as rigidly bound by union rules and trade structures, their foreign counterparts are described as having either high levels of flexibility and interchangeability or maximum flexibility through work station organization.

Greatly affecting American yards are political, social, and environmental factors over which the industry has little control, such as more stringent, and therefore more costly, safety, health, and equal employment regulations and standards, less government assistance, and differences in shipyard work practices, motivation, and ethics (Lowry, Stevens, and Cragg, 1980). The Shipbuilders' Council of America has pointed out, however, that industry has actually done quite well in technology upgrading despite these limiting factors. Of these industry-wide problems, that of shipyard work practices is most suited to unilateral action on the part of shipbuilding companies.

An analysis of disparities in American and overseas human resources practices in shipbuilding must include an examination of worker motivation as well as facilities and engineering. This insight is gained in the findings of a 1976 survey of 1300 shipyard employees in 10 large U.S. yards. Its findings show that shipyard workers believe company management has little appreciation of the individual worker's potential contribution to productivity improvement and specifically has little interest in his or her ideas (Meunch, 1976).

Decentralized Decision Making: Attitude and Aptitude

Worker participation and organizational change innovations may take a number of forms (e.g. physical amenities, quality circles, profit sharing plans, and semi-autonomous work groups). Central to the concept, however, is the notion of decentralized decision making, sometimes referred to as "worker participation" or "participatory management." Participatory management is based upon the premise that workers can often manage themselves better than they can be managed by echelons of managerial specialists. The logic which supports this view has several components.

Primary is the realization that workers closest to the job are in many instances most knowledgeable in terms of the technical and personnel requirements of the tasks. Even if this is not always the case, any innovation or redirection in the manufacturing process is more likely to be adopted successfully if the work force has some say in its design and implementation.

These long-standing arguments, however, do not explain the frequency of participatory management innovations in recent years. The answer lies in a more recent phenomenon - a value change in the work force at large. Contemporary workers tend to be better educated and seek more intrinsic satisfaction from their work than did preceding generations for whom traditional workplace organizations and management styles were designed (Cooper et al., 1979).

It is clear that the changing attitudes and expectations of the work force have prompted managers of overseas shipyards to explore new approaches to the recruitment and retention of shipyard workers and the organization of shipyard work (Broyton et al., 1973). Even in the depressed market of the 1980s, Japanese shipyard management is still faced with the rising expectations of their work force. Japanese managers view the problem of full utilization of skilled workers as critically as they do the problem of obtaining new ship construction orders (Seatrade, 1981). A higher work force educational level is responsible in part for this value shift (Shinto, 1980), and thus is closely linked with the introduction of participatory management programs.

As of 1970, 52 percent of American shipyard workers had completed high school and 6 percent were college graduates (Table 9). This might suggest that the U.S. shipyard employee would be less inclined toward, or capable of, self-management than his overseas counterpart. However, general population surveys of worker dissatisfaction in the U.S. show that 80 percent of American workers today believe that they could improve productivity if management would only listen to their ideas (U.S. House of Representatives, 1981).

Other evidence of American worker interest in, and capability for, self-management is found in the number of quality of work-life programs in U.S. industries (e.g., auto and steel) where work force educational profiles are not unlike that for shipbuilding. Such programs are prospering even in the U.S. construction industry which has the lowest educational profile of the industries appearing in Table 9 (Ross, 1981).

Status of Participatory Management in Shipbuilding

One manifestation of participatory management that has received more U.S. attention than any other is that of quality control circles. Quality control circles have their origin in the Japanese modification and application of Western principles of diffuse management responsibility for quality, statistical techniques, and behavioral science concepts of organizational development. The new twist added by the Japanese was the extension of quality control jurisdiction and responsibility to every individual in an organization through the vehicle of small study groups. This in contrast to the traditional practice of relying upon specialist quality control engineers.

The quality control circle concept was not, therefore, an element of traditional Japanese culture but had very definite beginnings in the early 1960s as Japanese management moved toward adoption of worker participation in decision making and "small-groupism" (shoshudanshugi). Similar workplace experiments in Europe were observed by the Japanese, and by the end of that decade small group participative management practices were widespread throughout Japanese industry. A 1968 survey of 850 manufacturing companies revealed that 73 percent were practicing some form of participatory management through small groups. The shipyards were among the first industries to experiment with the new technique.

TABLE 9 Educational Attainment of Employed Males in Selected Industries, 1970

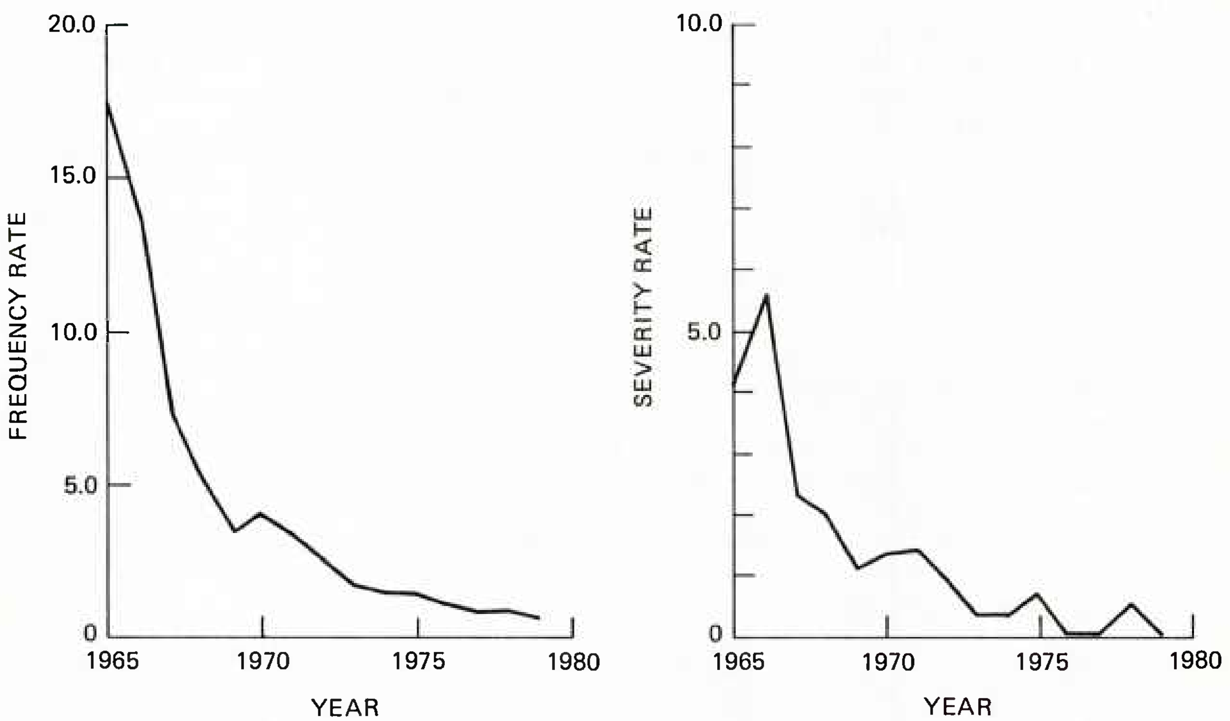
Industry	Percentage of Employed Males[a/] Completing:	
	High School	College
Construction	43.8	3.9
Manufacturing	55.8	9.9
Durable Goods	56.5	9.6
Motor Vehicles	54.1	5.7
Aircraft	73.0	18.5
Shipbuilding and Repairing[b/]	52.3	5.7
Private Wage and Salary Workers	48.6	5.7
Government Workers	60.5	5.9
Railroad Equipment	54.5	5.7

a/Age 16 and over
b/Includes boatbuilding and repairing

SOURCE: Bureau of the Census

The Japanese quality control circles did not address quality issues only. In 1968, the Union of Japanese Scientists and Engineers reported that the existing circles were focusing only half of their attention on narrowly defined quality control. Forty percent of circle activities dealt with productivity and cost reductions, while 10 percent was devoted to safety matters (Cole, 1979).

In Japanese shipbuilding it was "safety" and not "quality" or "productivity" that was the first concern of the newly initiated small group movement. The industry in the mid-1960s was very concerned with the escalating frequency and severity of shipyard accidents. Compulsory enforcement of safety measures provided only temporary improvement, and it was not until the introduction of the small groups, and management's immediate attention to the problems identified by them, that a steady long-term improvement of safety records was realized (Shinto, 1980). The dramatic and continued safety improvement at one Japanese shipyard as the result of quality control circles is depicted in Figure 3. Perhaps an even more dramatic statistic is that there occurred in 1980 fewer lost-time accidents in all the Japanese yards than in one single American yard (Gilbride, 1982). The total tonnage delivered for all American yards that year was only about one-tenth that of Japan (Maritime Administration, 1981), (Naval Sea Systems Command, 1981).



Note: Accident frequency rate: worker injuries per million working hours; accident severity rate: working days lost due to accidents per thousand working hours.

FIGURE 3 Frequency and severity of shipyard accidents at IHI, 1965-1980.

SOURCE: IHI Corporation

Participatory management was introduced into the Swedish Kockums yard in 1970 after a study revealed that the root of the yard's severe personnel problems was a new piecework standards system which was introduced in 1967 with the transition from conventional shipbuilding to the factory-shipyard concept. After organizational changes were made, including those in participatory management, labor turnover rates dropped by one-half and overall productivity was improved by a third (Hill, 1973). In Norway, worker participation (along with improved physical conditions and improved recruitment and retention) has been a central aim of the Norwegian shipbuilding industry (Westhagen and Hotvedt, 1980).

Although the United Kingdom lags Europe in its experience with participatory styles of management, there has been movement in this direction. A number of U.K. ship repair companies now have joint monitoring arrangements, work force involvement as shareholders, or employee profit-sharing schemes.

In U.S. shipbuilding, participatory management has taken the form of several variations on the quality control circle theme. Within the past three years, at least six commercial shipyards have experimented with participatory management programs.* Of five programs still in operation, one reports substantial success (Hayes, 1982), (Hayes and Swanson, 1982), (Smith, 1982), and one is too new to judge. The one cancelled project to date was discontinued by new management upon purchase of the shipyard. Union officials and the previous management were very enthusiastic over the results of the project, which was in the process of expansion at the time of the sale. It is reported that the local union and yard workers are encouraging the new management to reinstitute the program.+

Quantitative accounting of the benefits of several of the U.S. participatory management programs have resulted in very favorable benefit to cost calculations (Tweedale, 1981), (Bradley, 1981), (Harper, 1982).

The Necessity of Organizational Change

Even modest participatory management techniques, such as quality control circles or joint labor-management steering committees, represent organizational change in that they constitute a parallel decision-making structure to the preexisting management framework. However, organizations have frequently gone further in modifying the structure of formal tasks, management systems, and reward systems along the lines of decentralization and flexibility. This trend is especially far advanced in Scandinavia and Japan (Westhagen and Hotvedt, 1980).

*The tally of six is based only upon the personal knowledge of the committee. There may well be other private U.S. shipyards that are quietly experimenting with participatory management styles and new organizations of work.

+Peter Lazes, Cornell University, and James Laird, Sun Ship, Inc., personal communication, June 28-29, 1982.

Participatory management techniques which rely on the formation of small work groups can be viewed as an adaptation to product-oriented work breakdown production processes. The new production system in Japanese yards needed a complementary work force organization, consequently workers were purposefully retrained and reorganized. Team organizations of the workers were suitably altered from functional control to zone control (Shinto, 1980). Rather than moving individually all over a ship, workers under this arrangement remain together as a team working sequentially on similar modules in a particular work station. The predominance of small group organization in Japanese yards is evidenced by a comparatively higher index of supervisors to workers than in the U.S. (Colton and Mikami, 1980).

The concentration of individual worker attention to a specific work station might seem at first glance to run counter to job enlargement practices. In the case of shipbuilding, however, each task may consume a number of hours and gives the worker ample opportunity to exercise skill and discretion (Colton and Mikami, 1980). One U.S. shipyard reports that their experience with the small group/work station innovation (part of a MarAd-sponsored technology transfer program) has been "...exceptionally well received by production personnel" (Colton and Mikami, 1980). This same U.S. shipyard has attempted to stabilize the membership of work station teams by making permanent assignment of individual workers to specific supervisors (Colton and Mikami, 1980).

The principal relationship between participatory management and organizational change is to be found in the ability of organizations that are designed around the principle of participation to respond more easily to change. Structural provisions for participation in decision making provide a degree of organizational flexibility that is absent in companies structured along strict hierarchical and bureacratic lines. Participatory organizations have more ears attuned to signals of the necessity for change and are less susceptible to delays occasioned by the "not invented here" syndrome.

These related concepts of organizational decentralization, de-bureaucratization, and flexibility are quite topical in today's shipbuilding industry. One study makes the claim that:

> "One of the greatest differences in contemporary shipyards is the degree of organization of work and its effect upon the productivity of the man. The high craft skill possessed by some shipyard workers has enabled the adoption in the appropriate companies and countries of a minimum of formal organization. This circumstance is usually accepted by the management in search of a great deal of flexibility" (Appledore, 1980).

Rigidity of organization is not a problem that is peculiar to American shipbuilding but is characteristic of U.S. industrial organizations in general. It has been traced, to a large extent, to the influence of "scientific management" institutionalized in the diiscipline of industrial engineering. Scientific management encouraged the precise and formal description of jobs based upon techniques of task analysis and work measurement. The more circumscribed each job description, and the fewer tasks entailed, the better for purposes of assignment of standard production norms. This one-dimensional, hierarchical, and bureaucratic management approach was complemented and reinforced in the United States by the newly forming unions' interest in unambiguous and discrete job classifications for operating a strict seniority system (Piore, 1974).

It appears that shipbuilding in Japan may be even further advanced in this direction of work-force flexibility than other Japanese industries (Marsh and Mannari, 1976). The majority of the shipyard workers prefer multiskill jobs. The trend towards and preference for flexibility extends to managerial levels as well, especially in middle management ranks. Indicative of the change in emphasis is the elimination of the title "section chief" and substitution of the term "team leader" (Marsh and Mannari, 1976).

The change in work-force organization from functional to zone control necessitates a drastic change in the combination of worker skills needed for particular tasks (Shinto, 1980). Workers need to be retrained so that they can accomplish multiple jobs.

The Scandinavian shipbuilders, experiencing high labor costs, have also developed a highly skilled and high productivity work force operating under the principle of flexibility and interchangeability. Such practice makes most sense in those countries and industries in which a comparatively narrow wage range encompasses the skilled, semiskilled, and unskilled workers (Appledore, 1980).

The British shipyards, who have gauged their performance against the considerably more productive European shipyards, refer enviously to "continental style" working arrangements based on full flexibility, limited only by the competence of individuals to carry out work assignments (Flack and Nichol, 1980).

In the United Kingdom, where craft demarcation lines have been rigidly drawn, a number of shipyards have negotiated with their unions "continental style" work practices. In the United States, a Pennsylvania shipyard has recently announced a labor contract in which the number of labor grades has been reduced from over 400 to approximately 80, with craft departments cut from 65 to 13. It is reported that work rules have been completely eliminated at the shipyard (Journal of Commerce, 1982).

An important aspect of shipbuilding organizational change is the decentralization of professional staff functions (Colton and Mikami, 1980). In at least one Japanese shipyard, production engineering is undertaken by production workshops, each of which has its own production planning and engineering group. This activity includes the analysis and continual improvement of production processes to realize improved productivity. Continual analysis by production engineers working in close contact with production workers serves as the basis for refinement of detailed work drawings, procurement specifications, and materials lists. It promotes collaboration between designers and production engineers and promotes the incorporation of production information into the development of work drawings. It also provides an opportunity for continuous feedback of data to improve the usefulness of design drawings in production (Colton and Mikami, 1980).

One U.S. shipyard reports an independently invented, production workshop structure similar to that which has just been described. However, this shipyard has retained centralized rather than dispersed engineering staff functions (Colton and Mikami, 1980). Another U.S. shipyard has moved in this direction by holding weekly meetings between engineering and production groups for the purpose of reviewing plans (Mongelluzzo, 1981). Although considerable interest has been generated in U.S. shipbuilding circles for design and production integration, concentration has been in the development of an electronic interface (CAD/CAM) rather than on organizational change.

A similar organizational change in Japanese shipbuilding is decentralization of scheduling. Again, the staff engineers that perform this function are found at various levels, yet manage to produce schedules of different degrees of detail that coincide with each other.

One interesting note on the matter of scheduling as it relates to job flexibility comes from a survey of shipyard worker job satisfaction, which revealed that the most common spontaneous production worker complaint related to "working conditions" pertained to poor planning, schedule coordination, and communications; both between crafts and between production workers and staff services. (Meunch, 1976).

As might be expected, the much younger quality of work-life projects in U.S. shipbuilding have not progressed so far as those of the Japanese or Europeans in this matter of organizational change. However, it does seem that the various U.S. programs are following a similar progression from early development of multicraft study groups, to subsequent self-managing action groups of continually associated workers.

Assessment and Summary of Advice

Management commitment, mutual respect of labor and management, and a stable industrial environment are necessary preconditions for improvements in the human resources of shipbuilding. While improvements in the traditional human resources areas of labor relations, personnel functions, and industrial engineering can be made, the most essential human resources challenge in shipbuilding is to improve the physical and organizational conditions of shipbuilding work by altering the relationship between employees and management and the relationship between employees and tasks. This challenge has been addressed by foreign shipbuilders through the application of the social technologies of participatory management and organizational change. Their experiments have focused on productivity, effectiveness, performance, quality, and safety and have resulted in substantial productivity improvements. Three years' experimentation with, and tentative implementation of, similar innovations in American shipyards indicate that they might also work well in this country.

In U.S. shipbuilding, and in other industries, one frequently hears caveats about transferring management styles and organizational forms from overseas, especially in the case of Japan, because of cultural differences. What is often overlooked, however, is that these practices are not part of the traditional heritage of these countries and have been implemented and diffused as a result of purposeful introduction and successful tentative experimentation.

One reason the U.S. shipyards have been behind their overseas competitors in expanding the capabilities of their work force is that it is an expense not easily justified in an environment of high personnel turnover. Such an approach is self-fulfilling in the sense that minimal human resource investment leads to greater voluntary turnover. It is also true, however, that stability of employment is affected by variables less controlled by industry, such as economic climate, government procurement policies, and national industrial policy. Since it is clear that the immediate and mid-term survival of the U.S. shipbuilding industry hinges very largely on Navy construction, the Navy needs to give careful consideration to contracting so that shipyards are able to sustain a stable level of employment. Without a stable workload, it is unlikely that management and the work force will commit themselves to the expense and effort entailed in successful participatory management and organizational development programs.

What is it that the Navy might do to foster worker participation and organizational change to improve shipbuilding productivity? First, it is not appropriate to force programs of this nature upon shipyards and vendors. Experiments with alternative management approaches are entirely within the scope of concern of management and labor. The government has less direct experience and less clear a role than the immediate parties, even though it is very interested in the results of the experiments. Since the Navy is interested in the potential benefits, it should encourage experiments with worker participation and organizational change by sharing the cost of experiments and fostering the transfer of information between companies and unions involved in or considering social technology projects by means of a continuing forum.

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CONCLUSIONS AND RECOMMENDATIONS

Support the National Shipbuilding Research Program

The National Shipbuilding Research Program has resulted in productivity-related research and development in the shipyards and a growing awareness on the part of management of the value of such activities. Benefits result from the process of technical interaction of shipbuilder representatives in the program as much as from the substance of the activities undertaken. The process results in direct benefits in terms of productivity advances to the Navy.

With U.S. Navy shipbuilding currently accounting for the majority of the total ship construction activity in the United States, continued U.S. Navy and Maritime Administration support of the National Shipbuilding Research Program is justified, important, and vital. The support of the program should continue to be shared by those who benefit from it.

> Recommendation: The Navy and the Maritime Administration should continue to participate in and support the National Shipbuilding Research Program.

Analyze and Evaluate the Productivity of the U.S. Shipbuilding Industry in Constructing Naval Vessels

The productivity of the U.S. shipbuilding industry in building commercial vessels has been analyzed and evaluated, and has been established as approximately half that of the leading foreign competitors. In contrast, the productivity of the U.S. shipbuilding industry in building naval vessels has not been well documented; it needs to be analyzed and evaluated so that efforts to improve productivity can be focused on specific problems and opportunities.

> Recommendation: The Navy should conduct studies to analyze and evaluate the productivity of the U.S. shipbuilding industry in building naval vessels and determine the relative productivity of U.S. and foreign naval shipbuilding as an aid in focusing its MT/ST programs on specific problems and opportunities.

Foster Rapid Development and Application of CAD/CAM for Naval Shipbuilding

CAD/CAM technologies offer an opportunity to improve productivity not only by reducing the direct labor contribution to a number of technical tasks, but also by making possible and stimulating the coordination of engineering phases and management functions. Furthermore, shipyards that have applied CAM to their operations have realized reductions in fitting and welding costs.* The Navy, as the major shipbuilding customer in the United States, is in an outstanding position to resolve CAD/CAM legal issues and to cause or foster its rapid application in shipbuilding, in conjunction with the shipbuilding industry.

Recommendation: The Navy should sponsor the development of an integrated product definition data base for establishing its shipbuilding requirements and communicating among the shipbuilding industry. The Navy should encourage its use and the development of complementary, compatible data bases by ship designers, shipbuilders, and vendors.

Recommendation: The Navy should participate in and support the development and application of graphic exchange specifications applicable to shipbuilding. Together with the shipbuilding industry, it should cause a shipbuilding interest group to be established within the IGES program.

Recommendation: The Navy should sponsor a continuing forum in conjunction with the broader CAD/CAM industry to allow shipbuilding and design agent CAD/CAM managers to plan jointly for the Navy development and use of computer technology.

Encourage Development and Use of Standards

Increased development and use of standards represents a significant opportunity for productivity improvement in Navy shipbuilding. With increased support in terms of committed technical talent and also financial resources, the benefits of standardization can be realized.

Recommendation: The Navy should accelerate and increase its support of the Mil Specs improvement program to eliminate the lag between the state of military standards and the state of technology so that standards can be used effectively in the accelerated naval shipbuilding program. This should include minimizing the number of Mil Specs where commercial standards will suffice.

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*W.T. O'Neill, Newport News Shipbuilding and Dry Dock Co., personal communication, December 10, 1982.

Recommendation: The Navy should accelerate and increase its financial support of and technical participation in the industrial standards activities conducted under the auspices of the Society of Naval Architects and Marine Engineers' Ship Production Committee and the American Society for Testing and Materials in order to be as effective as possible in the current accelerated Navy shipbuilding program.

Recommendation: Both the Navy and the ASTM standards program procedures should be reviewed and revised to shorten the period needed to update their standards.

Improve Human Resources

The cultivation of human resources is essential to the productivity of organizations. It begins with management commitment and includes human relations, labor relations, personnel functions (i.e., recruitment, selection, training, and retention), and industrial engineering.

Perhaps the most essential human resources challenge in shipbuilding is to improve the physical and organizational conditions of shipbuilding work by altering the relationship between employees and management and the relationship between employees and tasks. In particular, participatory management and small group/multiskill worker organizational innovations which focus on effectiveness, performance, quality, and safety, have significant potential for improving the productivity of the commercial construction of U.S. Navy ships. An outstanding innovation is the training of workers for multiple skills, and then the organizing of work tasks to take advantage of the flexibility of the multi-skilled worker. The logic for the emphasis on human resources is that weakness in this area--for example, manpower shortages--may, in fact, be occasioned by physical and organizational deficiencies, such as failure to provide satisfying and challenging jobs.

Increased attention to the physical and organizational conditions of shipbuilding work can strengthen an already sound human resources situation, but it cannot substitute or correct for basic deficiencies. Shipbuilding in particular is prey to unstable work load and consequent high personnel turnover as the result of variables outside industrial control, including the economic climate, government procurement policies, and national industrial policy.

Investment in human resources is not easily justified in an environment of high personnel turnover. Yet, such an approach is self-fulfilling in the sense that minimal human resource investment will lead to greater voluntary turnover. Since the immediate and mid-term survival of the U.S. shipbuilding industry hinges very largely on Navy construction, the Navy needs to give careful consideration to contracting so that a number of shipyards are able to sustain stable employment. In any other environment it is unlikely that management and the work force will commit themselves to improving human resources in general and, in particular, to experimenting with participatory management/organizational development programs.

> Recommendation: The Navy should encourage experiments with worker participation and organizational change by considering requests from industry (labor and management) to share in the costs of experimental programs; and, by means of a continuing periodic forum, foster the transfer of information between companies and unions involved in or considering social technology projects. The forum would allow both the Navy and commercial yards to share their growing experience with productivity-related social technologies.

APPENDIX A

INDUSTRIAL ADVISORY COMMITTEE ON NAVY SHIPBUILDING TECHNOLOGY AND MODERNIZATION IMPROVEMENTS

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University of Texas at Dallas
Richardson, Texas

J. T.(Tom) Muller
Leslie Company
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Ellsworth Peterson
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Fontaine Richardson
Consultant
Carlisle, Massachusetts

Wickham Skinner
Harvard Business School
Boston, Massachusetts

Stanley Stiansen
American Bureau of Shipping
New York, New York

APPENDIX B

NAVY SHIPBUILDING TECHNOLOGY CONFERENCE
National Academy of Sciences
Washington, D.C.
June 28-29, 1982

Papers Presented:

"Shipbuilding Technology" - The Honorable George A. Sawyer, Assistant Secretary of the Navy for Shipbuilding and Logistics

"National Productivity - A Perspective" - John T. Dunlop

"The U.S. Shipbuilding Market; The U.S. Shipbuilding Base" - John T. Gilbride

"Navy Shipbuilding Productivity" - Ronald K. Kiss

"Cost Drivers in Ship Construction" - John J. Bennett

Participants:

Stuart Adamson
Shipbuilders Council of America

L. Wayne Arny
U. S. Senate
Committee on Armed Services

James E. Ashton
Special Services

Ronald E. Ault
Metal Trades Council (AFL/CIO)

Joseph P. Banko,
Naval Sea Systems Command

Robert Beeby
Naval Sea Systems Command
Shipbuilding Support Office

John J. Bennett
ANADAC, Inc.

Charles A. Bookman,
Marine Board
National Academy of Sciences

Thomas F. Bridges
John J. McMullen Associates, Inc.

Harvey E. Buffum
Boeing Aerospace Corporation

Howard M. Bunch
University of Michigan

Harold Buoy
Boilermakers International Union

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Louis D. Chirillo
L. D. Chirillo Associates

Thomas Clark
Newport News Shipbuilding and
Drydock Company

Edward Cohen-Rosenthal
ECR Associates

Frank Derwin
Industrial Union of Marine and
Shipbuilding Workers of America

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Gibbs & Cox, Inc.

William Dickinson
Transportation Institutes

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J.J. Henry, Inc.

Edward S. Karlson
Maritime Administration

Art Keegan
Lockheed Shipbuilding

Donald Kerlin
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Frank R. Kesterman
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John F. Kimble
M. W. Kellogg Company

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APPENDIX C

SYMPOSIUM ON COMPUTER-AIDED DESIGN AND MANUFACTURE (CAD/CAM)
Navy Shipbuilding Technology Committee
San Diego, California
September 16, 1982

Papers Presented:

"U.S. Navy Computer Supported Design" - Capt. J.J. Fee

"Productivity Measures in Application of CAD/CAM Systems" - William Beazley

"Sociotechnical Considerations in Computer Application" - Joel Fadem

"IGES: Shipbuilding Software Standards" - Bradford Smith

"Computer Applications in Early Naval Ship Design" - James D. Raber

"Ship Geometric Design and Manufacturing Definition" - George R. Snaith

"Computer Applications in Ship Production" - Lennart M. Thorell

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