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The Productivity Problem in United States Shipbuilding

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16. Abstract

U.S. shipbuilding productivity is significantly less than that of Japan and some European countries. The traditional view has either minimized the importance of the difference in productivity between U.S. and the best foreign shipyards, or focused on the lack of opportunities for U.S. yards to build in long series. As a result of research since 1977 - much of it conducted under the auspices of the Maritime Administration National Shipbuilding Research Program - a new view of the productivity difference has developed. Several studies have established that the productivity difference is very large. A number of studies have related this difference to new methods and systems of shipbuilding developed abroad. Based on a review of the literature, this study describes these methods and systems and examines obstacles to their adoption in the U.S. Implications for public policy are discussed. Some current efforts of U.S. shipbuilders to improve productivity and Maritime Administration and Navy programs of technology promotion are referenced.

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Preface

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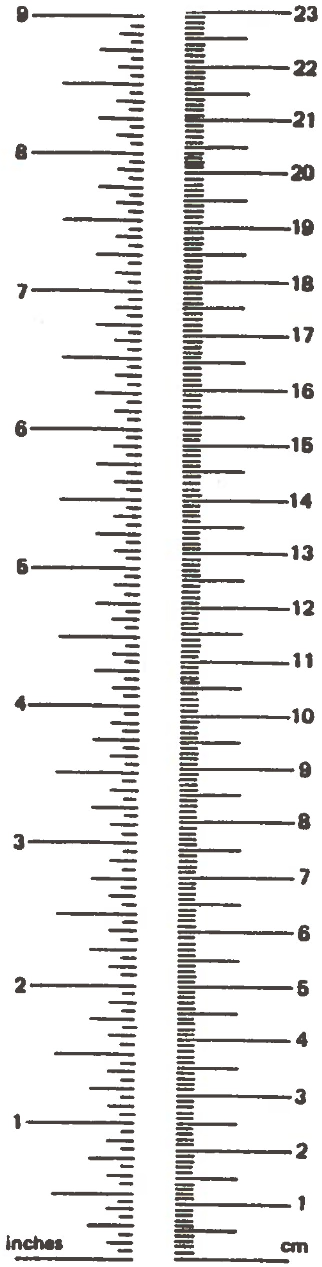
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

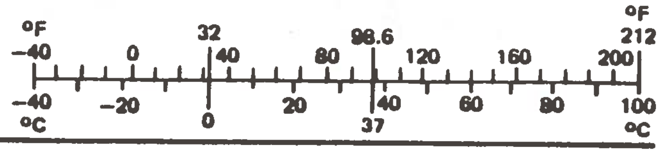
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in. = 2.54 cm (exactly). For other exact conversions and more detail tables see NBS Misc. Publ. 286. Units of Weight and Measures. Price $2.25 SD Catalog No. C13 10 286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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EXECUTIVE SUMMARY

Productivity in United States shipbuilding has been a subject for public debate and a critical issue for U.S. maritime policy for over 15 years. The productivity of U.S. shipbuilders and their potential to improve in comparison to foreign shipbuilders have been key elements in analyses of the U.S. shipbuilding industry's ability to become competitive and to maintain itself as a national resource necessary to the national defense. The traditional view, which was the basis of maritime policy formulated in the early 1970's, tended to minimize the importance of productivity differences between U.S. and the best foreign shipyards. Where differences were acknowledged, they were attributed almost exclusively to market opportunities available to foreign shipyards to build commercial ships in long series, opportunities allegedly not available to U.S. shipyards. Series production, the construction of a series of nearly identical ships was considered the most important factor in productivity.

Over the last five to eight years, a new view concerning productivity has been emerging in research on the subject. The major portion of this research has been done under the aegis of the National Shipbuilding Research Program, a collaborative program of the Maritime Administration (MARAD), involving several leading U.S. shipyards and the Society of Naval Architects and Marine Engineers (SNAME). This research directly contradicts the older, traditional view in two respects. It has established that the productivity difference between U.S. and foreign shipyards is very large and significant, and in analyzing the reasons for this difference, it has focused not on series production, but on some specific methods and systems of work organization and control.

Several studies done in the late 1970s and early 1980s compared U.S. and foreign commercial shipbuilding productivity. A survey done in 1978 compared the levels of technology employed in U.S. shipyards with that employed in leading foreign yards and concluded that U.S. shipyards were far behind in many critical areas relating to productivity. In a subsequent study, Appledore, a British shipbuilding management consultant, made use of the technology survey and some statistical data on shipbuilding labor productivity in ship construction to compare several U.S. shipyards with several foreign yards. Appledore estimated that a U.S. shipyard may require twice as many labor hours to produce a ship as a modern shipyard in Europe or Japan. Exxon, in preparing estimates of tanker building costs around the world, has concluded that, as of 1981, European yards use less than 60 percent and Japanese yards less than half of the labor required to produce a ship in a U.S. yard.

Studies to identify the deficiencies in U.S. shipbuilding which can account for the large differences in productivity have tended to highlight certain modern methods and systems of shipbuilding which have been implemented abroad, but which have not been as rapidly adopted in the U.S. The systems and methods which have proven highly productive abroad are primarily organizational in nature, rather than technological or hardware-oriented. Effective planning and control of the process, not the use of technically complex manufacturing equipment, appears to be the key.

Modern shipbuilders, led in particular by certain Japanese shipyards, have revolutionized shipbuilding by changing the concepts governing how ships are put together and how the tasks of shipbuilding are organized. The traditional organization of shipbuilding, dating from the days of wooden ships, was to construct the ship in place as a unit, working on each functional system of the ship in turn. First, the keel was laid, then the frame erected, and so on. When the hull was nearly complete, outfitting of the ship began. Outfitting was planned and carried out by system, as ventilation, piping, electrical and machinery systems were installed. Even after welded steel construction permitted the construction of the hull in blocks, organization by functional system persisted.

In modern shipyards, shipbuilding is organized by "zone, area and stage," rather than by functional system. The ship is divided into geographic zones and all the planning, engineering, construction, and outfitting is carried out by zone, rather than by functional system. The work is divided into well-defined stages of fabrication and subassembly, with numerous interim products - hull and outfit parts, components, and subassemblies - identified, creating many milestones for managerial control. These interim products are classified and grouped together by the kinds of manufacturing problems which they present, so that their manufacture can be assigned to specialized areas of the shipyard, dedicated to accomplishing certain kinds of manufacturing tasks. Use of a "zone, area, stage" product work breakdown structure enhances the ability of the shipyard to schedule and control work processes, to identify repetitive work which can be assigned to specialized workers and carried out in dedicated workshops, to introduce scientific techniques such as statistical analysis for process control, and to apply computer technology to improve productivity.

A number of impediments to the widespread and rapid adoption of the new methods in the U.S. have been identified. Chief among them appear to be deficiencies in shipyard management and organization. Traditionalist attitudes among managers have slowed implementation of new methods; U.S. shipyards lack sufficient in-house ship design capability, they do little marketing, and their labor-forces are rigidly organized along craft lines and suffer rapid turnover, due in part to management neglect in providing a good working environment and amenities. Implementation of the new shipbuilding technology is primarily a "management problem," not just because the implementation, like any change in work structure, requires management initiative, but because the changes required involve extensive alterations in work organization and management itself. These include changes in how the shipyard does business in every area, from planning and engineering to labor relations. It means adopting entirely new techniques ranging from CAD/CAM to statistical accuracy control, which require new technical skills. More than anything else, the new methods require more effective control and coordination of the whole shipbuilding system. This requirement for greater control and coordination implies a need for more and better management. In contrast, the capital investment requirements of the new methods have generally been described as "moderate."

U.S. shipyards are moving to improve productivity by adopting the new methods and systems. Six U.S. shipyards have contracts with Japanese shipbuilders for aid in adopting the "zone, area, stage" approach. At least one U.S. shipyard has completed and delivered a ship applying this approach from design through construction. The industry, is addressing some of the management/institutional obstacles by developing educational programs, instituting participative management programs, etc.

The view of the shipbuilding productivity problem presented in this report has important implications for the Federal government's policies toward shipbuilding. A traditional policy objective has been to promote series production in the belief that this would induce productivity improvement. The identification of specific systems and methods to improve productivity which appear to function independently of production in long series tends to undercut the importance of series production. In a similar way, the recognition that capital investment to improve productivity is secondary to the adoption of improved management systems and practice tends to lead to the conclusion that policies to encourage capital investment, although useful, might be limited in effect, while programs and policies to promote understanding and adoption of the new shipbuilding methods and systems appear to have the the greatest relevance. The Maritime Administration's National Shipbuilding Research Program has already produced significant results in identifying the importance of the new systems and drawing shipyards into using them. The U.S. Navy's more recently established programs to improve shipbuilding productivity also appear to have significant potential to aid the industry in adopting new methods and systems.

1.0 INTRODUCTION

1.1 BACKGROUND

The United States shipbuilding industry, although by some measures among the largest in the world, supplies only a small fraction of the world's merchant ships each year and is generally considered uncompetitive and inefficient in commercial ship construction. The high cost of merchant ship construction in the U.S. can be attributed to a number of factors, including relatively high wage rates and the absence of direct government subsidies, but the primary factor appears to be the relatively low level of productivity in U.S. shipyards by comparison to Japanese and Western European shipyards.

Productivity in United States shipbuilding has been a subject for public debate and a critical issue for U.S. maritime policy for over 15 years. International comparisons of productivity and the potential of U.S. shipbuilders to improve productivity are key elements in analyses of the U.S. shipbuilding industry's ability to become competitive and to maintain itself as a national resource necessary to the national defense.

Over the last five to ten years, the prevailing view concerning shipbuilding productivity has changed radically. What may be regarded as the traditional view had its most extensive expression in the work of the American Commission on Shipbuilding. In the Merchant Marine Act of 1970, the Congress established a seven-member American Commission on Shipbuilding to review the status of the industry with regard to increasing productivity and reducing production costs. In 1973, the Commission completed its study and concluded that

> Where the (U.S. shipbuilding industry) has the opportunity to build ships in series and has a reasonable stability in its orderbook, it is fully capable of equalling the productive efficiency of any foreign shipbuilding industry for the construction of similar ships.[1]

From its research, the Commission had come to believe, first, that "no substantive data exists to support the thesis that United States shipbuilding is less productive than foreign shipbuilding" and, second, that " . . . construction of large, standard ships in series is apparently the most important factor in productivity . . . "[2]

Although there were some at the time who strongly disagreed, the Commission's was the prevailing view. Moreover, it was a view that confirmed the basic assumptions of public policy toward shipbuilding established in the 1970 Act. There are many associated with the U.S. shipbuilding industry today who still espouse the Commission's conclusions and beliefs but, based on the results of years of sustained study, a different, contrasting consensus has gained strength.

A great deal has been written about productivity in shipbuilding over the last five to seven years. The major portion of work has been done under the aegis of the National Shipbuilding Research Program, a collaborative program of the Maritime Administration (MARAD), involving several leading U.S. shipyards and the Society of Naval Architects and Marine Engineers (SNAME). Beginning in the late 1970s with comparative surveys and investigations of foreign shipbuilding methods, evidence accumulated that substantial differences in productivity existed between U.S. shipyards and leading Japanese and Northern European shipyards. Studies and analysis were initiated to identify what U.S. shipbuilders would have to do to match the achievements of foreign shipbuilders. These studies have emphasized the importance of specific systems and methods of organizing and controlling shipbuilding work in improving productivity, and have tended to give scant attention to series production.

The new view, then, directly contradicts the older one on its two main assertions. The new view is that the productivity of U.S. shipyards does not equal that of the best foreign shipyards and that the system of work organization is the most important factor in productivity. This paper summarizes the new view, based on a thorough review of the published literature.

The recent literature on U.S. shipbuilding productivity covers four main subjects. The various monographs, papers and studies:

1) document the extent of the productivity gap between U.S. and foreign shipbuilders;

2) identify and advocate better systems, methods, and practices for U.S. shipbuilding, based on the foreign experience;

3) identify and analyze conditions in the U.S. which inhibit the rapid adoption of better systems, methods, and practice;

4) recommend policies to industry and government to speed the effective and successful use of better systems, methods, and practice.

These four subjects are reflected in the outline of this paper. Quantitative evidence on the extent of the productivity problem is presented in Section 1.2. There is general agreement in the literature that the better systems, methods, and practice that are responsible for differences in productivity are, in the main, part of a unified set of innovations in the way shipbuilding is organized from design through hull construction to outfitting. These innovations are described in Section 2.0. Section 3.0 is reserved for an identification and discussion of the importance of various factors believed to be inhibiting the adoption of better systems, methods, and technology. Section 4.0 summarizes the paper's main points in terms of their broad implications for public policy. The new view strongly implies that the historical reliance on the concept of series production as a means of productivity improvement is no longer supportable, and that programs to promote the adoption of improved methods and organizational systems are more appropriate.

1.2 THE PRODUCTIVITY GAP

That U.S. shipyards are uncompetitive internationally has been accepted since the late 1950s from the plain evidence of lower ship prices abroad and the absence of foreign orders for ocean-going ships. Assertions that this uncompetitiveness was due, in part, to lower productivity in the U.S. were made as early as the mid-1960s, but expert opinion codified in most of the major studies done at that time, tended to deny these assertions or to explain them away as differences in capital investment or ship design. It was not until the late 1970s that important studies identified and quantified a substantial productivity gap between U.S. and the best foreign shipyards in merchant ship construction, in terms of both the labor and the shipyard capacity required. In 1979, A&P Appledore Limited carried out a comparison of the productivity of a small number of U.S. shipyards building primarily commercial ships with four roughly-comparable foreign yards. Appledore used statistics on ship completions and employment for the period 1976-1979 and applied compensated gross registered tonnage coefficients to adjust for ship complexity, it was further aided by a technology survey of the yards completed in 1978. Appledore concluded that "productivity in the best Japanese and Scandinavian yards is of the order of 100 percent better than in good U.S. 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 on the order of eight ships per year with a labour force the size of the U.S. yard's."[3]

The most detailed published comparison of U.S. and Japanese shipbuilding costs resulted from a comparative study of cost accounting systems conducted by the Levingston Shipbuilding Company under a cost-sharing contract with MARAD. The study examined cost accounting systems in operation in the shipyards of Ishikawajima-Harima Heavy Industries (IHI) of Japan. The impetus for the study was the construction by Levingston of a bulk carrier using a modified IHI design. Comparison of IHI actual labor hours in the construction of the first ship in the series with Levingston's actual labor hours for its first ship in the series revealed that IHI required less than 30 percent of the labor hours required by Levingston. IHI's material costs were also lower, and the difference was also dramatic: 65 percent of Levingston's.[4] Although it might be conceded that Levingston was by no means the best or most productive U.S. shipyard, the difference was astounding and no one could dispute the results on grounds of incomparability.

Other estimates confirm that the Levingston/IHI comparison for a specific ship reflects a general condition. A major U.S.-based tanker owner has presented data used in parametric cost estimation that indicate that the cost of Japanese shipbuilding labor and overhead on a 1981 contract for 1983 vessel delivery would be one-third that for the U.S.; labor and overhead costs for a Western European shipyard were estimated to be half of U.S. costs.[5]

Lower wage rates accounted for only a portion of the difference in costs. Direct labor hours required were estimated to be 46 percent of U.S. requirements in Japan and 57 percent in Europe. Again, material costs were also estimated to be lower in Japan and Europe. The results of the IHI/Levingston comparison and the tanker owner's parametric estimates are presented in Tables 1 and 2, respectively.

TABLE I
RATIO OF IHI-Aioi TO LEVINGSTON LABOR HOURS AND MATERIALS FOR A BULK CARRIER

ITEM	LABOR HOURS	MATERIAL COSTS
Preliminary and Staff Items	.24	.54
Hull Steel Items	.22	.78
Minor Steel Items	.42	.58
Machinery Items	.47	.66
Outfitting Items	.35	.56
TOTAL (ALL)	.27	.65

Source: Levingston Shipbuilding Co. and IHI Maritime Technology, Inc., Cost Accounting Final Report, Maritime Administration, March 1980.

TABLE 2
A TANKER OWNER'S PARAMETRIC ESTIMATES OF RELATIVE COSTS*

	% of U.S.	
	JAPAN	EUROPE
Labor Cost	35	51
Direct Labor Hours	46	57
Wage Rate	74	83
Steel Cost	71	64
Propulsion Machinery and Outfit Material	70	78

*For a ship contracted for in 1981, delivered in 1983.

Source: Jenks, Allen and John E. Larner, Exxon International, "A Tanker Owner's Perception of New Building Costs and Prices in Japanese, North European and United States Shipyards 1971 to 1981," SNAME, October 1, 1983.

Recognition of the poor productivity of U.S. shipbuilders was not confined to researchers doing comparative studies. By the early 1980s, U.S. shipbuilders had earned a reputation for high prices, long construction leadtimes, and unreliability in meeting contract delivery schedules. John Arado, General Manager, Engineering Department, Chevron Shipping Company:

> ...U.S. contracts were without exception late, up to 1½ years late, whereas those in Japan were on schedule and, in some instances, ahead of schedule... In our latest survey of prices around the world, U.S. prices for tankers were 90% higher than in Europe and two to three times higher than in the Far East.
>
> ...the delivery situation in the U.S. seems, if anything, to be worsening. Published data indicated deliveries in the U.S. are continuing to slip. Unfortunately, long and delayed deliveries in U.S. yards appear to be a way of life.[6]

2.0 SOLUTIONS TO THE PRODUCTIVITY PROBLEM

The principal productivity problem in all manufacturing is to organize the work to be done in a way which permits the maximum utilization of the time of the workers and equipment which are available, while minimizing the waste of material. This does not mean that workers should be forced to work at a superhuman pace or that equipment should be run into the ground or that products should be designed to be flimsy. It does mean that, ideally, no worker should have to do an unnecessary task, no equipment should have superfluous capabilities, no material should be thrown away, and, above all else, the flow of work should be continuous so that no time is lost and no worker or piece of equipment is left idle. The organization, layout and scheduling of work, the availability of machine tools and equipment to speed and smooth the progress of work, and the skill and motivation of workers in operating the system are all keys to establishing the control over the production process necessary to solve the productivity problem.

Innovation and automation are two concepts which are often introduced in popular discussion to explain major improvements in industrial productivity. Although innovations can also occur in product design, innovations to improve productivity usually involve reorganizing the production process to facilitate better management control, to permit increased specialization of workers and machines, and to make the flow of work more nearly continuous. The classic example of such a systems innovation is the mass production assembly line. Although systems innovation may involve (or even be triggered by) the introduction of new machinery (such as conveyors in the case of an assembly line), it is fundamentally a matter of introducing new concepts for defining and ordering tasks.

Automation, in its broadest sense, means using machines - especially automatic machines - to do certain tasks in the production process in place of workers. The use of robots to do welding or assembly on production lines may be among the clearest examples. Automation is often viewed in economic terms as simply the substitution of capital for labor, without any changes in the fundamental system. (In actual practice, some changes in procedures, i.e., "systems innovation," are necessary to accommodate even the simplest automation, and extensive automation usually involves extensive innovation.) In this simple economic analysis, automation is seen as a function of the relative cost of labor and capital (i.e., machines). Industries with expensive labor are driven to seek ways of automating; types of machines whose relative cost is falling dramatically, such as robots and computers, become favorite candidates for application in automation schemes.

Current efforts to improve shipbuilding productivity involve both systems innovation and automation. Of the two, systems innovations are apparently much more important in explaining the differences in productivity which exist between U.S. and foreign shipyards. A simplified history of the development of improved shipyard work organization, contrasting more modern and productive methods and concepts with traditional ones, will serve to identify the principal systems innovations. Automation, in the form of numerical control machine tools, computer-aided design and manufacturing (CAD/CAM), and robotics, is also an important topic for those interested in shipbuilding productivity, and will also be discussed.

2.1 METHODS AND PROBLEMS IN TRADITIONAL SHIPBUILDING

The traditional organization of shipbuilding, dating from the days of wooden ships, was to construct the ship in place, working on each functional system of the ship in turn. First, the keel was laid, then the frame erected, and so on. When the hull was nearly complete, outfitting of the ship began. Outfitting was planned and carried out by system, as ventilation, piping, electrical and machinery systems were installed. The traditional organization of work presented several obstacles to high productivity. Managing and controlling the construction of a large ship on which literally hundreds might work was a very difficult task using traditional methods. Except for the launching when the hull was nearly complete, there were few milestones in the process by which progress might be gauged. The failure of one work crew to finish work needed by another would frequently result in overtime for one crew and idleness for another. Poor timing in providing material often slowed progress as well. Worker specialization was difficult because of the sequence of radically different activities; the task of erecting the frame was very different from outfitting. Consequently, workers specialized by skill or craft rather than by task, becoming master welders, pipefitters, etc., instead of master outfitters or master hull builders. Since all the building activity was done at the shipway, use of any but temporary manufacturing equipment was difficult. Outfitting the ship after completion of the hull placed a number of handicaps on efforts to increase productivity. First, and most importantly, the cramped quarters inside a ship severely limited the number of workers who could work in an area at any one time. The size of available openings made moving machinery and equipment inside the ship awkward, and the provision of temporary services such as welding cables, staging, compressed air, etc., could be difficult, costly and even dangerous. Moreover, workers often performed tasks overhead or with compromised access to their work, and frequently worked exposed to the weather.

The evolution of shipbuilding work organization has been the result of many individual innovations. Figure 1 illustrates this evolution by relating some of the most salient of these innovations to four stages in the improvement of shipbuilding methods, tracing in parallel the evolution of both hull construction and outfitting. The first stage - conventional, traditional hull construction and outfitting - is labeled the system stage, because the work organization concept was oriented to the functional systems of the ship. The ship was designed and built one system at a time.

As welding replaced riveting in hull construction before, during and after the Second World War, the whole concept of building a ship began to change. Hull construction became a process of making block-like weldments of hull and decking and assembling these blocks together to erect the hull. Some of the hull-building activity was moved away from the shipways because much of the welding could be done more safely and conveniently on platens adjacent to the shipway or in separate shops. In this approach, the subassembly weldments made in these shops are assembled to form the hull blocks (or modules)* which are erected on the shipway. Block sizes vary from shipyard to shipyard. To facilitate work flow in shops, a typical block might weigh 40 to 50 tons. In shipyards which have large cranes available at the erection site, these smaller blocks

*There is unfortunately no universally agreed-upon terminology for describing shipbuilding processes or interim products. Words like "block", "module" and "unit" are used by different authors to mean different types of ship subassemblies. Every effort has been made to remain consistent in this text and to explain inconsistencies which might be introduced by use of quotations from other sources.

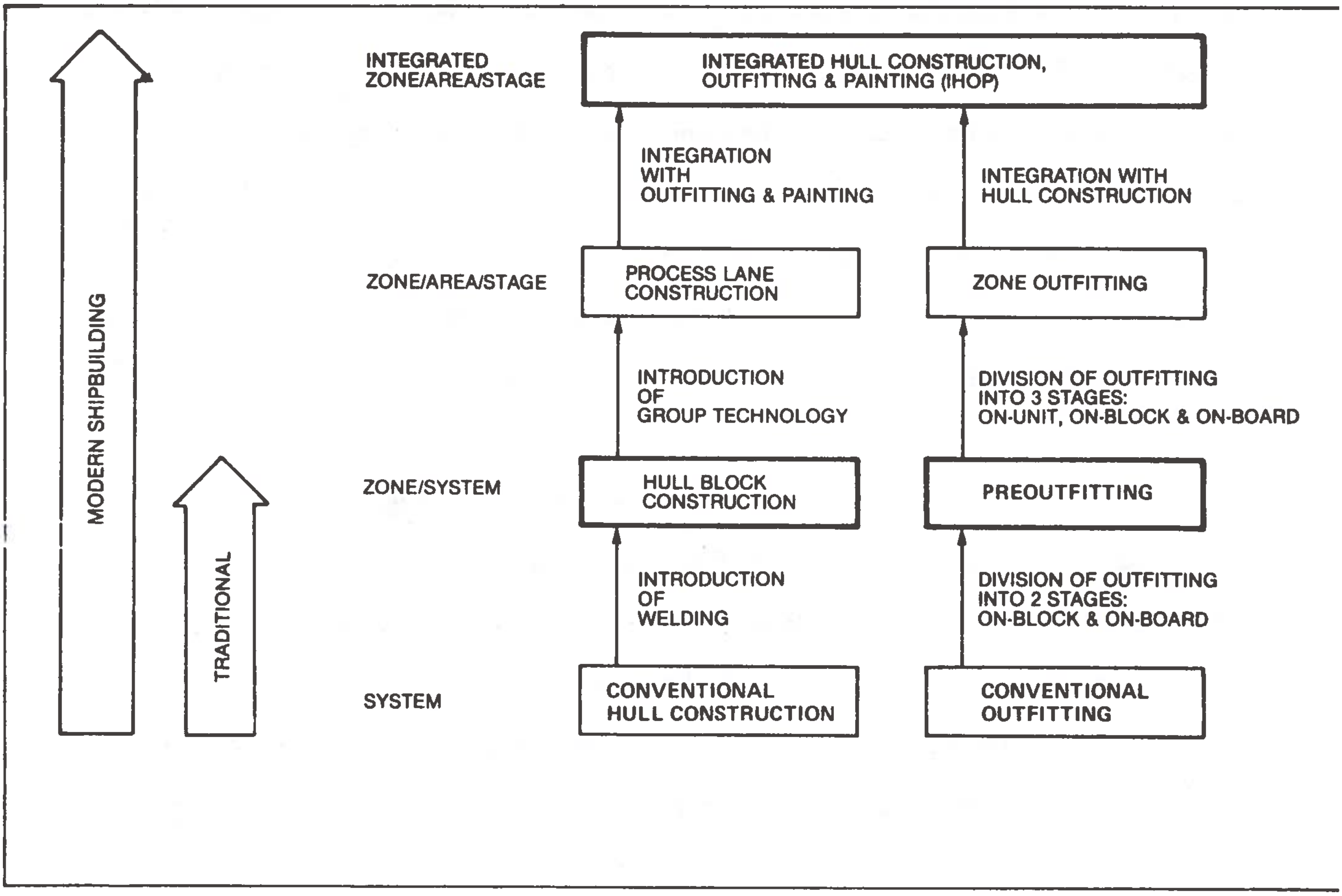


FIGURE 1. HISTORY OF BASIC IMPROVEMENTS IN SHIPBUILDING METHODS

SOURCE: Integrated Hull Construction, Outfitting and Painting, Maritime Administration in cooperation with Todd Pacific Shipyards Corp., May 1983, p. 3.

may be joined together into grand blocks of 200 to 250 tons or more, in order to minimize the time a building berth or shipway has to be occupied for erection. The construction of the ship in blocks permitted a change in outfitting practice. Outfitting could be done either on-board after completion of the hull (the conventional practice) or it could be done on the hull block before its assembly into the hull. On-block outfitting (or "pre-outfitting") was clearly to be preferred for those items which could not be installed later due to component size or compartment access.

Hull block construction and pre-outfitting mark the second stage in the history laid out in Figure 1. This is the stage from which most U.S. shipbuilders are just beginning to emerge, and it must still be considered "traditional" shipbuilding. Design, material definition and material procurement, in particular, are still done by functional system. But, to construct the hull in blocks and pre-outfit those blocks, the work must be organized by zone. Thus, this stage can be labeled "zone/system."

Many opportunities for productivity improvement remain unexploited. On a conceptual level, there is an inherent inefficiency in depending on two conflicting strategies. Construction planning must be done by zone even while such vital aspects of planning as detailed design and material definition are being carried out by system. Perhaps partly because the conceptual conflict hobbles effective planning, traditional shipyards are unaggressive about exploiting opportunities for improving productivity inherent in hull block construction and pre-outfitting. For example, pre-outfitting of the hull blocks in many traditional shipyards may be limited to those items which would be particularly difficult to install aboard ship. Moreover, "even within blocks being outfitted, many of the same problems still occur as in conventional outfitting, with ... temporary services, such as staging, welding cables, compressed air hoses and flexible ventilation ducts. Most overhead fitting work is still performed by workers reaching over their heads."[7]

2.2 SYSTEM INNOVATIONS IN MODERN SHIPBUILDING

The next step in the historical evolution of shipbuilding methods has been labeled "zone/area/stage" in Figure 1. Most modern Japanese and European shipyards are practicing the methods which characterize this step. The evolution of shipbuilding across this demarcation from traditional to modern has been gradual and continuous in terms of the methods employed, but the break has been very sharp and complete in terms of the concepts lying behind the organization of work. Two specific practices distinguish modern yards from more traditional ones: process lanes and zone outfitting. The methods involved may seem very natural developments given the opportunities inherent in hull block construction, but the concepts are widely considered revolutionary.

2.2.1 Process Lanes and Group Technology

First, consider process lanes. A process lane is a series of fixed workstations provided with permanent services (pneumatic, electrical, welding, etc.) and appropriate tooling and jigs to produce a category of products (subassemblies) whose fabrication and assembly involve the application of a given sequence of production processes or which involve a common set of manufacturing problems. The workstations can be efficiently equipped to process these products, and the workers assigned to a process lane quickly become experienced in solving the manufacturing problems associated with the products.

The key concept governing the setting up of process lanes is that of "group technology." (The group technology concept is the basis for much of what has been labeled "flexible manufacturing" in other industries. Thus, process lanes may be considered an example of the introduction of flexible manufacturing in shipbuilding.) Group technology is an analytical method of systematically classifying products into groups or families having design and manufacturing attributes which are sufficiently similar to make batch manufacturing practical. As noted earlier, the introduction of hull block construction in traditional shipyards made it possible to do subassembly fabrication away from the shipyard. Traditional shipyards do define work areas. The opportunity to replace the use of temporary services and staging with permanent services has led many to establish some fixed workstations. A logical material flow among workstations aids production control and is often a feature of good, traditional yards. But traditional yards still employ a job shop philosophy instead of group technology. The perception that the subassemblies which must be produced vary greatly during the course of ship construction and, also, from ship to ship, prevents the traditional shipyard from organizing itself more productively.

Modern shipyards have applied group technology methods to hull construction by establishing specialized process lanes for the fabrication of different kinds of structural subassemblies. Three such lanes may be considered typical for purposes of example: One for the simple flat steel plate subassemblies, one for subassemblies which have some curvature and one for the subassemblies having a complex geometry. These last are usually parts of the stern or bow. By grouping the subassemblies in this way, the shipyard is also grouping together similar manufacturing problems and allowing workers to specialize in solving them. The establishment of process lanes in leading European shipyards is a common development, while this practice is virtually universal among leading Japanese and Korean yards. In the U.S., only one shipyard - Avondale - has established process lanes for hull construction.[8] In a feasibility study done prior to implementing process lanes at Avondale it was estimated that a reduction of 21 percent in hull laborhours was achievable under the process lane concept, a reduction which would save over 100,000 laborhours of effort in a ship construction project then underway.[9]

The approach used in organizing process lanes, that of grouping together the manufacture of different parts which pose similar manufacturing problems, can capture some of the same efficiencies due to specialization of workers and the more intensive use of equipment realized on the mass production assembly line. The group technology approach may be applied to the manufacture of outfitting items, such as pipe, as well. The advantages of extending the group technology approach of process lanes to the manufacture of pipe are numerous.

> Just the engine room of a 22,000 deadweight-ton diesel-propelled ship contains about 3,600 pipe pieces. Many differences among them do not readily disclose commonalities that are useful for planning their manufacture.
>
> The collection of seemingly different pipe pieces into such families, avoids laborious job-shop type planning, scheduling and manufacturing. Instead, different pieces within a family are designated for the same machines and tooling setups which are arranged in a rationalized process lane. The benefits include greater utilization of the same tool setups and simpler material handling requirements between the work stages in each process lane. The manifestly clear stage by stage progression of developing pipe pieces within such work flow lanes greatly enhances production control. Further, the separation by stages permits the switching of work flow from one process lane to another without diminishing control.[10]

2.2.2 Zone Outfitting

Zone outfitting is the second important practice which distinguishes modern shipbuilding from traditional shipbuilding. The term "zone outfitting" refers to the practice of outfitting the ship by region or zone, rather than by functional system.

Modern zone outfitting evolved out of the traditional practice of pre-outfitting hull blocks. As noted earlier, pre-outfitting was initially restricted to the installation of those items which would be particularly difficult to install on-board the completed hull. Relatively advanced traditional shipbuilders found that an advantage could be gained by doing more pre-outfitting. To support a high degree of pre-outfitting, a traditional shipyard sorts outfit material into kits. Kitting improves the provision of material to outfitters, but the small pieces are still installed one at a time, and by functional system. A modern shipyard goes even further: a modern yard attempts to do all its outfitting work before completion of the hull, and excepts only the outfitting work which can only be done practically on board the hull. It supports such extensive outfitting not with kitting, but with the systematic assembly of outfit material into larger units which can be installed whole on the hull blocks. For example, a pump unit might be preassembled with its base, pumps, valves, filters, associated pipework, etc., so that only service connections had to be made when the pump was installed on the hull block. Moreover, a modern yard plans and organizes outfitting by zone. Each block is divided into zones: the top side may be one zone and the bottom, another. Composite drawings showing all the systems in a zone are prepared and an outfitting team is assigned to do all the outfit installation for a zone, regardless of system.

Although zone outfitting may be conceived of as just another logical step in the development of outfitting practice, its impact on the concepts of shipbuilding and its role in creating opportunities for productivity improvement have been revolutionary. Outfitting by zone implies final abandonment of the concept of building up a ship, system by system. Both hull construction and outfitting can be planned and carried out using the same geographical approach. There is a second dimension in the zone outfitting concept, and that is "stage." The practice of assembling outfit material into units prior to installation on the hull block extends outfitting into three stages, which may be conveniently referred to as on-board (meaning on the completed block), on-block (meaning on the hull block) and on-unit (meaning outfit assembly not involving any hull structure). The division into stages creates a number of milestones in the outfitting process which greatly aids management control.

The formal organization of a modern shipyard will reflect this unified conceptual approach. Because design, planning, engineering, work assignment, etc., are all done in terms of regions of the ship and proceed in specified stages, the task of coordinating the organizational functions of a shipbuilding company is greatly simplified. This is illustrated in Figure 2. Figure 2 shows how reponsibility for different areas of the ship is divided up within the design department and outfitting department of a shipyard and how design and outfitting then relate.

The singular difference between archaic pre-outfitting and modern zone outfitting is in the strategy used to prepare drawings, define materials and procure materials. For pre-outfitting, the people responsible for drawings, material definition and procurement work system by system. Afterwards, planners have to obtain bits of information from many system drawings in order to prepare a work package to pre-outfit a block, i.e., to reorganize information by zone. The process is time consuming during a critical period, expensive and error-prone. For zone outfitting, production enginneers give designers a build strategy as contract design starts and continually refine it as design progresses.

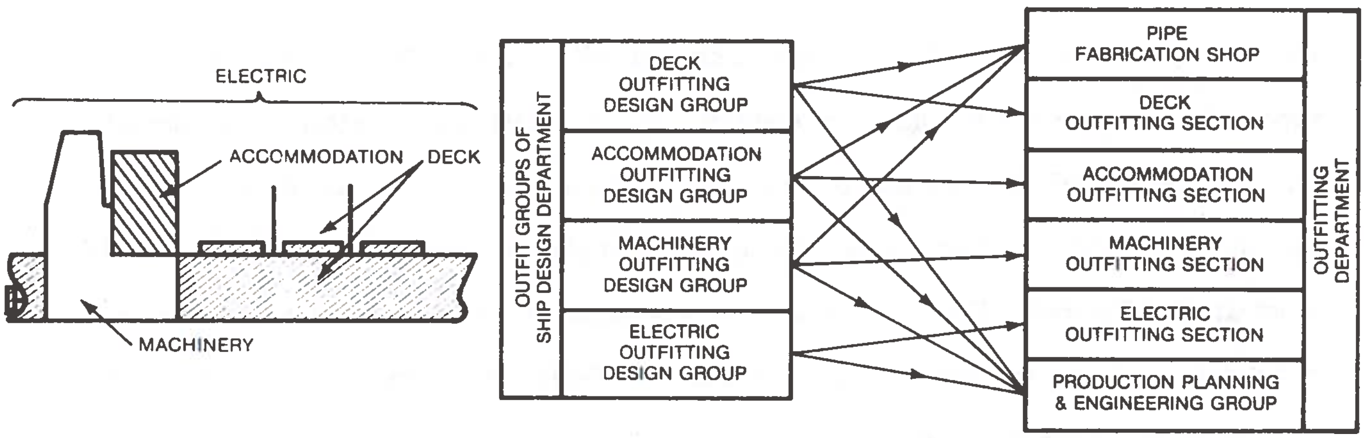


FIGURE 2. DESIGN AND PRODUCTION ORGANIZATION UNDER ZONE OUTFITTING

SOURCE: Okayama, Y. and L.D. Chirillo, Product Work Breakdown Structure, Maritime Administration, in cooperation with Todd Pacific Shipyards Corp., 1983, p. 61.

After systems are defined on diagrammatics, designers reorganize the information so that their outputs are composite drawings which show what is to be assembled in a specific zone during a specific stage, with associated material lists. No extra planning effort is required.

In a traditional shipyard which employs hull block construction and plans its outfitting by systems, a good deal of time may be wasted engineering the details of a system long before those details need to be specified to permit continued construction, while other information is barely generated in time. In a traditional shipyard that makes its outfitting work assignments by functional system, a work crew installing, say, ventilation ducts, may find itself competing for space with another work crew installing pipe on the same hull block, but under zone outfitting, a single work crew has responsibility for all the outfitting in a specific zone. Moreover, with hull blocks being outfitted by zones, the hull block can be turned over when one zone (or side) is complete to permit easier, downhand access to another zone on the same block. In a traditional shipyard, workers must often work overhead or with compromised access.

On-unit outfitting makes possible productivity gains in other areas as well. Just as outfitting on-block is easier than outfitting on-board in most cases, outfitting on-unit is easier than outfitting on-block. The units can be assembled away from the blocks in specialized workshops, and problems of access and reach are minimized.

The labor hour savings from on-unit and on-block outfitting have been estimated by two Japanese shipyards. On-block outfitting was estimated to result in a 30 percent savings compared to on-board outfitting; on-unit was estimated to save 70 percent compared to on-board outfitting.[11]

The specification of an outfitting stage which does not involve any hull structure (on-unit) means that outfitting can begin in earnest simultaneously with the fabrication of hull subassemblies, and does not have to wait for completion of hull blocks. Outfitting no longer needs to be considered a successor function, and shipbuilding no longer needs to be a series of strictly sequential activities. Some workers can specialize in outfitting and be working at the same time other workers are building the structural subassemblies. Moreover, the whole shipbuilding timetable can be speeded up, since outfitting work does not have to wait.

In a strictly traditional yard, outfitting will begin only after hull block assembly and hull block erection is well underway. Even in a relatively advanced traditional yard, which may be employing kitting, etc., outfitting cannot begin before hull block assembly. The proportion of outfit work complete at the time the hull is launched may be only 30 to 40 percent in a strictly traditional yard; for a more advanced, traditional shipyard the proportion may range upward from 50 percent. In a modern shipyard, on-unit outfitting - the subassembly of outfit material - can begin well before hull block assembly. With this "headstart," outfitting may be as much as 90 percent complete at the time of launch.

In fact, modern zone outfitting as applied in Japan may have made it meaningless to speak of percent of outfitting complete at launching. Outfit complete at launch in excess of 90 percent has reportedly been routine at Japanese shipyards for many years. Outfitting complete at keel laying (the beginning of hull erection, a point which was past before outfit work had even begun in traditional yards!) is more commonly used as a gauge of progress. This figure may vary between 40 and 60 percent, depending on ship type.

The time to complete a ship is potentially crucial to cost, both because of the opportunity cost of facilities such as shipways which are occupied during construction and because of the carrying cost of materials and work-in-progress. The time to complete a ship in a modern yard from start of fabrication to delivery might be on the order of eight to twelve months; time to complete in the U.S. ranges up to two years.

The 1978 Technology Survey of Major U.S. Shipyards identified on-unit outfitting (which it called "module building") as one of 16 "critical" areas for labor productivity in which U.S. shipyards on average showed significant deficiencies. Of the 16, on-unit outfitting ("module building") showed the greatest degree of deficiency. Over half of the U.S. yards surveyed did none at all.[13]

2.2.3 Statistical Process Control and Advanced Shipbuilding

The fourth step in the evolution of shipbuilding depicted in Figure 1 is one in which hull construction, outfitting and painting are integrated. This is meant to illustrate the most advanced state of modern shipbuilding, in which the concepts of modern shipbuilding are further elaborated. In the most advanced, modern shipyards, hull construction and outfitting tend to be no longer treated as separate activities. They are integrated. The hull is not so much built up out of hull blocks as the ship is built up out of modules, modules which are as very nearly completely outfitted with the ship's systems as they are complete interms of steel structure. An additional feature of this integration is that painting is integral part of building the ship and occurs at every stage, rather than being carried out at or near completion of the ship.

As important as the zone/area/stage concept is in distinguishing modern from traditional shipbuilding, it is not the further elaboration of this concept in an integrated form which is the most important feature of advanced shipbuilding organization. The key feature from the standpoint of productivity is the application of analytical management techniques, particularly statistical analysis, for the control of the manufacturing process.

In a traditional yard that has not applied the principles of group technology to establish a work breakdown structure to identify common and repetitive elements in shipbuilding or to identify a clear and logical sequence of processes and subassemblies, the application of statistical analysis would be largely impractical and of limited usefulness. Repetition is a prerequisite for statistical analysis; statistical analysis of a process is only valid if it is possible to observe the process repeated many times under substantially like conditions. Similarly, to use statistical theory in analyzing the results of a sequence of processes requires that a clear sequence can be identified, and statistical analysis applied to each stage.

> The effectiveness of an accuracy control program is directly dependent upon the application of Group Technology to ship production, i.e. the use of a Product-oriented Work Breakdown Structure (PWBS). The underlying assumption in the collection and analysis of A/C data is that production processes are (at least initially) in a state of statistical control. This in turn requires well-defined work processes, procedures and coding so that observed variations can be validly interpreted using statistical theory. A Group Technology approach to shipbuilding implies a clear definition of the various work processes employed at a given yard, and these definitions become the basis of standardization. It is standardization and the repeatability of processes that comes with it, which makes application of accuracy control techniques possible and the resulting process useful. In the absence of Group Technology/PWBS, such effort is useless.[14]

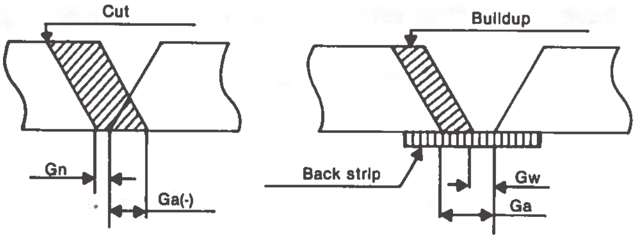
If the zone/area/stage concept makes statistical analysis possible, it also almost seems to require it by making the need for process control so much more apparent. The whole concept of building a ship in modules that must be connected together to form the whole imposes a requirement for much tighter control of the production process. Such a system will not work to improve productivity if errors in module construction result in significant misalignments requiring correction through rework. Zone outfitting simply increases the need for control. The greater the proportion of outfitting that is done on-unit and on-block, the more points there are to measure and control, and the more possibilities there are for misaligning pipes, ducts, decks, and so on. Production in process lanes also imposes a requirement for tighter control of the production process. The process lane depends upon the concept of standardizing "families" of parts and products that may differ widely in their physical dimensions but that resemble each other in terms of the processes involved in their manufacture and in their work content.

Some part of the work of building up assemblies in a process lane will inevitably be rework to correct misalignments, etc. between subassemblies. When the nature and quantity of this rework can not be predicted and controlled, the necessary resemblance among products in terms of processes and work content is lost.

Variation in the results of processes cannot be eliminated; variation can only be measured (by statistical methods) and controlled (by altering the process). The common difficulties encountered in fairing the joints of hull blocks during hull erection may be taken as a simple illustrative example. The fit between hull blocks as they are joined together is never perfect: there is always either a gap or overlap at the joint. Some variation may be tolerable, but that which is not requires rework: either cutting off the excess material or building up one edge and applying a backstrip to close the gap. The traditional "solution" to this problem is to provide a margin to minimize the amount of expensive backstrip welding. The amount of margin provided is a seat of the pants judgement reached without much analysis and, unfortunately, it has the effect of maximizing cutting, which is also rework and costs something even if it is cheaper than the other form of rework. In an advanced shipyard where statistical data and analysis are available for application to this problem, two approaches to solving this problem are available. One is to analyze the sequence of processes feeding the variation in joint fitting to identify processes which might be altered to reduce the variation so that a higher proportion of erection joint gaps would be within tolerable limits. A second approach would be to accept the normal variation in gap size, but make specific allowances for excess so that more of the rework required was cutting and less was backstrip welding. This second approach would differ from the traditional provision of a margin in that, with quantitative measurements available, a precise tradeoff could be made between the increase in cutting and the decrease in backstrip welding achieved by a specific allowance.[15] This example is illustrated in Figure 3.

The example given above illustrates how the use of statistical analysis improves the ability of shipbuilding management to solve problems by controlling the process, instead of relying on non-analytical experience and judgment which leaves the manufacturing process unexamined. As statistical information becomes available on a sequence of production activities, many seemingly minor problems and irregularities will be uncovered and corrected. It is not uncommon when statistical analysis is first applied to discover that workers have no fixed way of performing a given operation simply because no one has ever tried to systematically determine the best way of doing it. Others may be poorly trained and perform certain operations in a way which naturally produces poor results. The development of written procedures is often an important part of applying statistical analysis to process control. Even for operations performed in a regular and prescribed manner, statistical measurement may reveal that the variation in results is so great that tolerance limits are exceeded much more frequently than anyone had previously realized, highlighting the need to adopt more effective procedures and methods in that operation. The result is a general "tightening up" of the production process.

> By including . . . written requirements in work instructions and by systematically monitoring, ,statistical accuracy control. "tightens up" all activities along a production line, e.g., template production, marking, cutting, bending, fitting, welding, and line heating so that the tolerance requirements for each are compatible with the others'. No longer are crucial judgements about accuracy left to opinions and guesses.
>
> A specific example of "tightening up" for a particular work process was further development of line heating to more accurately form curved hull-parts as a means of minimizing erection work. Man-hours required for bending were reduced to almost one third those needed for conventional rolling or pressing, fewer clips, dogs, wedges, etc. were required by assembly workers, and rework for adjusting joint-gaps during hull erection was greatly reduced.[16]

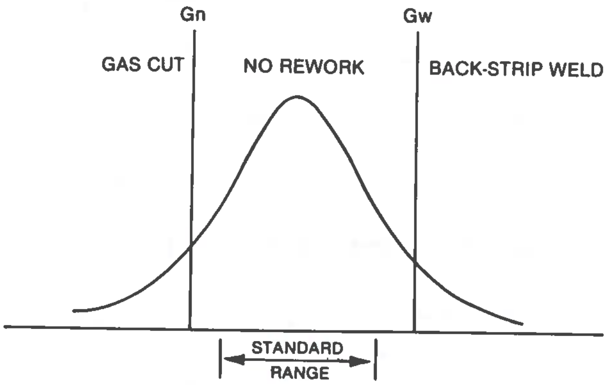


Ga - initial gap

Gn - gap after rework by gas cutting

Gw - gap after rework by back-strip welding

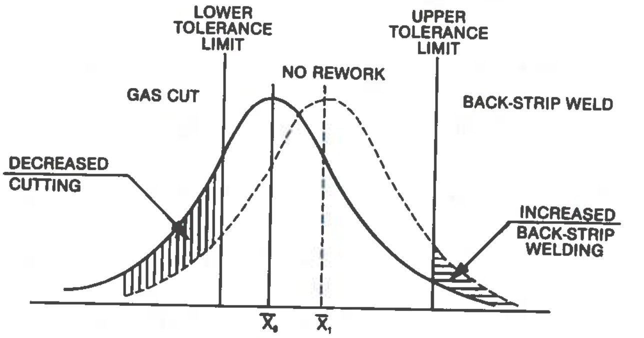
A/C is most effective when it focuses on minimizing the two kinds of rework commonly encountered when joining hull blocks, i.e., gas cutting and back-strip welding.



Gn - lower tolerance limit

Gw - upper tolerance limit

The lower tolerance limit stems from having to create an erection-joint gap or make it wider. The upper tolerance limit arises from having to make a gap narrower.



$\bar{X}_0$ is the mean of an original distribution.
$\bar{X}_1$ is the mean of a proposed distribution
Obtaining a different balance of cutting vs. back-strip welding requires reduction in the specified amount of excess by the same amount as for the shift in mean value.

A/C engineers study all aspects of a distribution before proposing a change. In order to shift the mean value, a change in what's varying is required. In order to change the standard distribution, changing the work process is required.

FIGURE 3. APPLICATION OF STATISTICAL CONTROL TECHNIQUES

SOURCE: Process Analysis Via Accuracy Control Maritime Administration in cooperation with Todd Pacific Shipyards, February 1982, pp. 6, 25-27.

Once firmly in place, the continuous, systematic use of statistical data to analyze and control the production process leads to continual improvements. "Incessant analyses of accuracy measurements and other relevant variables are means used by the most competitive shipbuilders to constantly perfect organization of work."[17] The control of the production process made possible by the combination of the principles of group technology and statistical analysis techniques is also the necessary prerequisite to the development of significant flexible automation and robotics applications.

2.3 AUTOMATION AND TECHNOLOGY

In the introduction to Section 2.0, systems innovations were contrasted with automation as means of achieving productivity increases. In shipbuilding, it is clearly systems innovations that are most important in explaining the differences in productivity between U.S. and foreign shipbuilders. Nevertheless, there are some automation technologies being applied in shipbuilding which are worthy of note. Computer-aided design and computer-aided manufacturing (CAD/CAM) technologies, including numerical control machine tools and robotics, are widely believed to be the most significant. Highly-advanced technology is also finding applications in measuring for accuracy control and in some steel cutting and fabrication operations.

For the most part, in terms of enhancing productivity, these technologies are most effective when they complement or enhance the adoption of modern shipbuilding methods and work breakdown structure. Applied independently, technologies such as numerical control can be technically impressive while producing only limited results. An automated piece of equipment may yield a prodigious output in a short time, but unless the whole shipbuilding system is geared to consume that output at the same pace, the equipment will simply earn itself long periods of idleness or the shipyard will accumulate costly inventories of work-in-progress material.

The term CAD/CAM is commonly used in its broadest sense to refer to the use of computers in applications ranging from design to production and including production management information processing. CAD/CAM technology has the potential for significantly reducing the cost and difficulty of planning, controlling and coordinating a modern shipbuilding operation. 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. Application of this computer technology in the absence of a modern, zone-oriented shipbuilding system, however, can only result in more accurately and rapidly planning, controlling and coordinating in an unproductive manner. Bound by an obsolete building strategy, computers can offer only limited results. CAD data can also be used to produce the instructions for numerical control machine tools used to bend pipe, cut sheet metal, and so on. Numerical control machining is most suited to applications in fabrication operations, such as plate and pipe shops, which resemble manufacturing more than construction. The use of numerical control machine tools in these areas greatly improves accuracy, reducing material waste and problems of fitting and welding associated with a poor matching up of parts. The increased accuracy of numerical control machine tools and the use of sophisticated measuring equipment in accuracy control can facilitate the task of matching and mating modules in modern shipbuilding.

Numerical control machinery, however, is generally thought to be less significant than the application of computers in managing the overall shipbuilding process.

> Although (numerical control) operations favorably impact module assembly and outfitting through improved accuracy most of the savings realized are not in high cost areas.... 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 process-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.[18]

CAD/CAM has the potential to create integrated information systems that encompass product definition data, engineering computer control, manufacturing engineering, production planning, materials requirements planning, purchasing, manufacturing and quality assurance. However, the use of integrated CAD/CAM, robotics, etc. have not been fully implemented anywhere in the world. A 1982 National Research Council study estimated that only one to five percent of shipbuilder design and drafting tasks are conducted with CAD assistance.[19]

Looking toward the future, there is also an increasing interest in robotics. The use of robots in U.S. yards is still largely experimental, and even abroad it remains very limited. Consequently, robots are not considered a factor in the current productivity gap. The difficulty in applying robots in shipbuilding is that there is little repetition from day to day, and current robotics technology is most easily adapted to situations involving endless repetition. In most shipbuilding applications, a robot has to be "retrained" too frequently to be very efficient. Nevertheless, the Japanese are putting great emphasis on robotics in their shipbuilding research. There is potential as shipbuilders gain better control of the process and can identify or introduce repetition on the one hand, and robotics technology evolves toward greater intelligence and tolerance of variation, on the other, for increasing application of robotic technology in shipbuilding. The immediate potential for robots in shipbuilding to have a large effect on productivity does not appear great, however.

In summary, computer and computer-related technologies have potential for improving shipbuilding productivity. Where CAD/CAM and other sophisticated technology is being applied, it has the greatest impact on productivity where it enhances modern shipbuilding systems and methods.

3.0 OBSTACLES TO PRODUCTIVE SHIPBUILDING

In a market economy and a competitive industry, it may appear remarkable in itself that a gap in productivity as large as the one described here could develop. "How could a modern, technologically advanced nation fall so far behind other industrial countries in a major industry?" "What could hold it back from closing such a gap?" These are reasonable questions. The mere existence of knowledge that could reduce production costs by over half would appear to present an irresistable opportunity and overwhelming incentive in a competitive economy. From such a viewpoint, the situation of the U.S. shipbuilding industry seems almost inexplicable.

Developing an understanding of what may be inhibiting the U.S. shipbuilding industry from meeting world standards of productivity must begin with the recognition that the productivity gap is acting as an important incentive driving shipbuilders to improve. U.S. shipbuilders are adopting the new technology; the market system is working. The problem is not that they are failing absolutely to improve, but that they started late and may be moving slowly. In examining this situation for causes, it is worthwhile to remember that the search is for inhibiting factors and not necessarily for absolute obstacles.

It is also worthwhile to note that the implementation of process lanes and zone outfitting is not a simple, effortless matter of changing from one way of ordering tasks to another. The way people, information and work are organized must change, making obsolete a whole way of doing business. Although an abstract discussion, as in the previous chapter, may highlight many problems which will be solved by adoption of the new methods, managers and workers actually implementing changes are confronted with the exchange of familiar problems for unfamiliar ones and the displacement of previously highly valued skills or experience by demands for new training, approaches and procedures. Because the changes required are pervasive, every input to the production process is affected, and deficiencies in any one of them could become an obstacle to rapid implementation of more productive systems and technology. Indeed, factors associated with all the inputs -- management, labor, capital, materials and even what might called "strategic opportunity" -- have been cited in the literature as inhibiting productivity improvement in U.S. shipbuilding. This chapter discusses some of these factors, beginning with those associated with management of the shipbuilding process.

3.1 SHIPYARD MANAGEMENT AND TECHNICAL CHANGE

Implementation of the new shipbuilding technology described in Section 2.0 is primarily a "management problem," not just because the implementation, like any change in work structure, requires management initiative, but because the changes required involve extensive alterations in work organization and management itself. These include changes in how the shipyard does business in every area, from planning and engineering to labor relations. It means adopting entirely new techniques ranging from CAD/CAM to statistical process control, which require new technical skills. More than anything else, the new methods require more effective control and coordination of the whole shipbuilding system. This requirement for greater control and coordination implies a need for more and better management. Indeed, it has been observed that highly productive foreign shipyards employ proportionally more supervisors and more college-trained managers. Participatory management schemes, such as the quality circle concept, are also common features of highly productive shipyards and are being actively promoted in the U.S. as a mechanism for improving productivity.

Several obstacles to improving U.S. shipbuilding productivity identified in the literature are management-related. Education in the new methods and in analytical management techniques are, of course, widely recognized requirements, but more intangible factors are also cited, as well as a variety of organizational needs. Traditional attitudes and cultural differences are among the more intangible factors cited as obstacles to transferring the systems innovations and technology of Japanese and Northern European shipbuilding to the United States. Cultural differences are among the objections raised to the introduction of participatory management. The reorganization of the shipyard to include participatory management is just one aspect of extending management control over the whole shipbuilding process. Another aspect of that process -- the design of the ship, its subsystems and components -- also needs to be extensively controlled for productivity to improve. In this respect, U.S. shipyard management is believed to be deficient for institutional reasons, including the U.S. practice of relying on outside design agents and the lack of either individual shipyard or national design standards. Education, attitudes and culture, participatory management, design organization and standards are each discussed in turn below.

3.1.1 Attitudes and Education

Because management initiative and change are so important, a host of intangible factors - beliefs, experience, habits, attitude - are, in themselves, important obstacles to improving U.S. shipbuilding productivity. Although difficult to measure and quantify, the attitude factor may be crucial. In the foreword to an important publication on new ship construction methods, the author pointedly states that his "publication should be particularly useful to . . . senior managers who have decided to revolutionize their shipbuilding methods and who have sufficient authority to counter traditionalists, . . ." (emphasis added).[20] The problem of countering traditionalists can lead to a kind of schizophrenia, in which the shipyard pulls forward while still clinging to the past, resulting in unproductive half-measures. This difficulty is clearly reflected in the following quotation from the advertising brochure of a major Gulf Coast shipbuilder (circa 1981):

> Probably the most respected position in most shipyards for hundreds of years has been that of loftsman. This is the highly skilled craftsman who physically draws out the plans of a ship to full scale on the floor of a huge loft and then proceeds to construct templates and pattern guides which are used to manufacture the various sections of a ship under construction....

> In the early 1970s, the company studied the various computer systems on the market and chose (a system) . . . to computerize this basic and time-consuming operation in the production of ships. . . .
>
> Modern technology has moved aside the traditional loftsman, but his skill and expertise are not yet a forgotten art at (the shipyard). Indeed, (the shipyard) still employs highly qualified loftsmen and maintains a full scale physical loft facility. Craftsmanship and pride in the skilled trade are what have long set (the shipyard) apart.

Behind these traditionalist attitudes, of course, lie some more fundamental problems, of which education is paramount. It is not simply pride in craft that makes it difficult to introduce new methods, but a basic unfamiliarity with principles and concepts of manufacturing. Abstract ideas are being offered to people who learned to build ships through experience, and not through formal education. The National Research Council's Committee on Navy Shipbuilding Technology identified this as an important issue in their study.

> 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 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.[21]

Even among those entering the shipbuilding industry with formal training in college, there is considerable evidence of significant deficiencies in their familiarity with manufacturing in general and shipbuilding in particular. One study found that "approximately 80 percent of the entry-level technologists most likely have not been exposed to the shipbuilding industry (and its products, processes, terminology, etc.) prior to graduation." The study also found that " . . . entry level engineers are inadequately prepared to work effectively in a shipyard because they lack the ability to write and speak effectively; do not have an adequate knowledge of manufacturing and its impact on design, materials, and production efficiency; and are unable to adequately manage or supervise work - of their own or others."[22]

The issue of formal education is particularly important, because the U.S. shipbuilding industry is attempting to adopt concepts and techniques developed elsewhere over a long period of time. While a Japanese shipbuilder can offer his employees what is perhaps the best training in these methods - eight to ten years experience in all aspects of shipbuilding applying group technology principles, statistical analysis, etc. - it will be some time before U.S. shipbuilders have the same option. In the meantime, formal training in the abstract principles is essential.

3.1.2 Culture and Participatory Management

A major premise of this report in analyzing and discussing productivity has been that the techniques and approaches developed abroad to improve shipbuilding productivity could be applied in the United States. This premise has been disputed by some on the grounds that the methods are incompatible with American culture. The argument made is that these techniques and approaches have been successfully applied

> in other major shipbuilding countries such as Japan and Korea, where shipbuilding management is based on organizational, decision-making, and operating structures and procedures founded on quite different cultural backgrounds, human relations, and traditions than those found in the United States. While some of the techniques and approaches found successful in those countries may be transferable, it must be recognized that the environment in the United States cannot be changed in the short run. This makes successful application of some of these methods difficult.[23]

This argument is a difficult one to confront because it seems to excuse poor management practice as due to some broad, largely undefined influence -- "culture" --beyond anyone's ken or control. It depends, in part, on exploiting the American tendency to view Oriental cultures as alien. Sweden, Denmark and West Germany are seldom mentioned in connection with the cultural argument, although their shipbuilding labor productivity is almost as high as Japan's and better than either the United States or Korea.

The cultural argument can be used to obscure the important differences in the real factors which have direct, operational connections to differences in productivity. While acknowledging that differences in attitude, education and other qualities between U.S. shipbuilding management and foreign management may represent real obstacles to improving U.S. shipbuilding productivity, experts writing on the subject of the new shipbuilding systems and methods have generally rejected the cultural argument as dubious and vague. They tend to rebut the cultural argument by reasserting that foreign shipbuilders have succeeded by means of acquired skills and deliberate problem-solving.

> One often hears the claim, that there is a certain 'something' about the Japanese culture that produces better managers and ideal workers. This is, however, erroneous. The true reason is twofold:
>
> - In general, Japanese shipbuilders, including ship managers and their deputies, have more education and more experience in analytical manufacturing methods than do Americans.
>
> - The Japanese have over the years developed a superior scientific shipbuilding system, and methods to constantly improve the system.[24]

Cultural attitudes, e.g., individualism, have been cited as possible obstacles to the implementation of group-oriented participatory management schemes, such as quality circle programs. This is a particularly important aspect of the cultural argument because participatory management is evidently a vital element in implementing modern shipbuilding methods, and of all the elements it is the one which most directly involves workplace culture. Participatory management schemes involve organizing workers into small teams or groups that engage in a degree of self-management and problem-solving. Combined with the implementation of the analytical techniques of statistical process control, they are a method for extending and refining control of the production process. Some writers, however, have associated them with the group orientation said to be characteristic of Japanese culture, rather than with the necessities of an approach to manufacturing. Experts on the subject of participatory management in shipbuilding have tended to assert in rebuttal to the cultural argument that participatory management is more a practical solution than a cultural phenomenon.

> 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.[25]

Indeed, quality circles, small group organization and participatory management can be seen as direct outgrowths of the implementation of particular techniques, such as statistical quality control, and the major system innovations discussed earlier.

> 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. 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.[26]

A number of U.S. companies, including shipbuilders, have established quality circle programs in recent years, and many have reported great success, although in some cases it appears that participatory management programs have not always emphasized the use of analytic problem-solving techniques in the ways which many experts assert is necessary for controlling the production process and achieving continuing increases in productivity.

3.1.3 Design Organization

Common U.S. practice has included the use by shipyards of outside design agents. In the 1978 technology survey of U.S. shipyards previously cited, poor ratings were given U.S. shipyards' design, drafting, production engineering and lofting technology relative to foreign shipyards. The explanation offered:

> "In ship design the difference (between U.S. and foreign yards) is largely explained by the fact that some U.S. yards use outside naval architects and consultants rather than having in-house facilities as found in all the foreign yards surveyed. This does not necessarily impair the efficiency of the design function, although this may be one of the reasons why the design for production and production engineering ratings in the U.S. yards were lower than their foreign counterparts."[27]

Others, too, have noted the difference between U.S. and foreign practice and have deplored the inhibiting effect on the adoption of efficient production technology. "... until recently few ships designed for construction in U.S. yards were configured for efficient, large-scale pre-outfitting or system outfitting...Most foreign yards build mainly from their own designs, which obviously permits consideration of the most efficient fabrication, assembly and outfitting approach in the design of the ships."[28]

Critics emphasize that design, building strategy and production planning are inextricably linked.

> Just give us the plans and material on time and we can build ships as productively as anyone.' So say traditional production bosses. Nothing could be further from the truth because a critical element is missing. Managers of the most productive shipyards have succeeded in getting their production people highly involved in design matters, starting with development of contract plans. Thus, each of their design efforts begins and continues in the context of a premeditated building strategy. Design is truly an aspect of planning.[29]

It should be emphasized here that what is at issue is not who does the contract design. The issue is the shipyard's need to control the design in order to ensure conformity with the yard's build strategy. Whether the contract design is prepared by an in-house design group or an independent naval architecture firm, the shipyard must have a building strategy that begins with and includes design, and it must be prepared to communicate this strategy in negotiations with the ship owner over contract design.

3.1.4 Standards

Bringing the design function into the shipyard may be one step toward increasing control over the shipbuilding process and making it more production-oriented. Another is the establishment of shipbuilding industrial standards. The shipbuilding industry is burdened with thousands of standards imposed by several organizations, so it may seem confusing to write about still more standards. The Navy imposes standards mostly to ensure combat-worthiness; the American Bureau of Shipping imposes standards for classification to guarantee insurance value; the Coast Guard has standards to maintain safety and environmental protection. However, shipbuilders need common standards to permit implementation of more productive manufacturing systems. None of the major innovations discussed -- process lanes, full zone outfitting, CAD/CAM -- can cope efficiently with eccentric designs and layouts.

For example, one major U.S. shipbuilder has installed a CAD/CAM system to do the lofting and cutting of steel for ventilation duct work. In order to program the system, the shipbuilder had to define a universe of possible duct work shapes. If an inventive naval architect specifies an unanticipated shape, the system is rendered useless. Standards are needed to inform the naval architect about what shapes are producible, thus increasing the coordination of design and production; a narrowing of the number of possibilities would further simplify the process.

The Japanese have established national standards for many of the components and parts supplied to the shipbuilding industry. The Japanese have over 500 national shipbuilding standards compared to 23 currently published for the U.S. Standards include everything from valves and fittings to large diesel engines. The use of these standards greatly simplifies material procurement as well as the shipbuilding process.

In addition to national standards, individual shipyards have established proprietary standards of their own which may be useful in design, planning and procurement. For example, standards for the functional layout of various parts of a ship are useful in facilitating zone outfitting. By codifying the design and production experience from earlier ships, subsequent design and planning are simplified. A standard outfit package might be developed for the basic lube oil system, for example, so that two or three different sizes of pumps could be fitted with only minor modifications to the layout. As the system is required on different ships, only minor modifications are required to arrive at a systems design and outfit plan using specific pumps.[30]

The most effective Japanese shipbuilders employ files of vendor-catalog items which they have pre-approved and elect to call their "standards". For example, for each pump requirement in a standard machinery arrangement for a particular main engine model, each of two or three vendors' pumps are listed in a shipyard's file of standards. Although physically different, the pumps have the same functional capabilities. By special agreements with vendors, all vendor-furnished information is maintained up to date. In effect, vendors compete twice. First to gain position in the shipyard's file of standards, and secondly, to obtain a specific order.[31]

Particularly in a market for ships dominated by orders for a wide variety of different ship designs in small quantities including single orders, timely arrival of vendor-furnished information to permit design progress is often more important than timely arrival of the machinery item. Shipbuilders who maintain files of vendor-catalog items declared as standards, do not burden themselves during design, when schedule adherence is extremely critical, with preparation of performance specifications and with conducting reviews of vendor proposals. Nor do they burden vendors, during an equally critical time, with requests for proposals that contain many non-technical terms and conditions. Such matters are resolved beforehand.

3.2 LABOR

As in any manufacturing undertaking, the skills and motivation of the workforce are critical to productivity. The systems innovations described place some special requirements on the workforce. Participatory management, described earlier, subsumes some of these. The change to zone construction entails some of the others.

The skills of American labor are almost certainly not part of the productivity problem. "It is noteworthy that the problem of low output of labor from U.S. yards cannot be traced in any way to worker skill. U.S. shipyard workers are as skilled as their Japanese or Korean counterparts."[32]

Two major problems with U.S. shipbuilding labor that are often discussed in the literature as obstacles to improving productivity are the craft organization of U.S. shipyards and the high turnover among U.S. shipyard workers. U.S. shipyards are 90 percent unionized. Avondale Shipyard is the only major non-union shipyard. Characteristically, the unions are craft unions, and multiunion yards are common. The craft orientation of the unions is considered a major problem because it conflicts with the transition from systems-oriented to zone-oriented shipbuilding. Under a systems-oriented shipbuilding scheme, workers can logically be oriented by craft: pipefitters install the pipe, welders build the weldments, etc. Zone construction requires that workers be formed into flexible teams that must perform all different kinds of work. Workers must be trained to do multiple jobs or to have some basic skills, such as tack welding or gas cutting, in addition to their main expertise. The craft form of organization is incompatible with the new system of shipbuilding, and the craft orientation of U.S. shipyard unions is considered prejudicial to its implementation.

> The craft orientation has produced numerous demarcation disputes. More important, it prevents flexible use of labor, complicates planning and scheduling, and discourages career changes ... Craft dominance of the shipyard labor force means that technological change must be negotiated, which is time-consuming and can be extremely difficult.[33]

The inflexibility associated with the craft structure is an area in which United States shipyards are particularly deficient in comparison to foreign shipbuilders. The 1978 Technology Survey of Major U.S. Shipyards highlighted 16 areas important to labor productivity in which U.S. shipyards lagged significantly behind foreign shipyards. Of these 16, organization of work as it pertains to supervising and assigning work to craftsmen ranked second in terms of the degree to which U.S. shipyards were behind foreign yards.[34]

The high turnover rate among U.S. shipyard workers has long been a concern to the industry and the government. A high turnover rate erodes the training, experience and commitment of workers which is needed for productivity. Shipbuilding methods that depend upon learning among workers would be less effective in a yard with a high turnover.

Although some in the industry have associated high turnover with the fluctuations in demand and market uncertainty that are said to characterize the industry, others direct attention to poor working conditions and a lack of amenities in U.S. shipyards. The 1978 Technology Survey found that U.S. shipyards were far behind their foreign counterparts in terms of working environment and amentities. Old buildings and uncovered workplaces that left workers exposed to the weather were found to be a common condition in U.S. yards. Differences were also found in the quality of food services, washrooms, etc., between U.S. and foreign yards. The authors concluded: "the importance of environment and amentities should be reviewed for their impact on productivity. It is possible that traditional U.S. practices in this area are not economical in the long run, particularly when employee turnover and training costs are considered."[35]

The relationship between shipyard worker dissatisfaction and poor management practice was highlighted in a 1976 survey of 1300 workers in ten large U.S. shipyards.

> ...the greatest complaint of production workers about working conditions involves inadequate scheduling, planning coordination, and communications among crafts, shifts, and working groups in the shipyard. The second greatest source of complaints involved inadequate machines, equipment, and materials. Unsatisfactory aspects of the physical working environment proved the next major source of worker irritation. Work safety was the physical factor most often mentioned.[36]

3.3 CAPITAL INVESTMENT

Of all the changes required at individual U.S. yards to implement modern shipbuilding technology, investment in new facilities is definitely of secondary importance. The shift to hull block construction and pre-outfitting - which most U.S. shipyards have accomplished, at least in part - required investment in huge cranes and workshops with heavy-lift capabilities to move the blocks around. The use of process lanes and the extension of pre-outfitting to zone outfitting will require investments to change work layouts and material handling. However, there is no special, particularly expensive piece of equipment, such as a crane, which can be identified as necessary. In general, the capital investments necessary to bring U.S. shipbuilding productivity to world standards have been characterized by writers on the subject as "moderate."

Louis D. Chirillo, who assists the Los Angeles Division of Todd Pacific Shipyards Corporation in management of part of the NSRP and is a principle in several studies of Japanese shipbuilding methods, has written "there is no reason why U.S. shipyards cannot become nearly or fully as productive as those in Japan. To do so, the U.S. does not need to leapfrog ahead of Japan in 'high technology,' because the focus of these advances is not primarily on facilities. America's shipyards have already made substantial capital investments in technologically advanced production equipment, enough so that, in my opinion, there is not a single U.S. shipyard that is inhibited by its facilities. Instead, greater gains can currently be achieved by fully exploiting the advanced managerial techniques already available."[37]

The previously cited 1978 technology survey found that of 16 critical areas, improvement in nine of the areas was judged not to require more than "minor capital investment." Five areas, it was judged, would require "modest capital investment" in order to improve the technology. Only two critical elements were judged to require major investments.[38] The two elements requiring major capital investment were ones relating to the need for heavy lifting capability to facilitate hull block construction. (As has been noted, U.S. shipyards have adopted hull block construction in recent years; numerous investments in cranes, etc., have been made since 1978. Future requirements are, therefore, likely to be more modest today than in 1978.)

3.3.1 Shipyard Age

It has been suggested that present U.S. shipyards are seriously handicapped by their age and the accretions of the past. One recent report notes that all but one major shipyard in the U.S. exceed 65 years of age and that more than a third are over 100 years of age, and concludes that, "A modified 65-year-old yard can never achieve the efficiency of a modern yard configured and designed to build modern ships using modern shipbuilding techniques."[39] Although there may be some truth in the notion that a "greenfield" site offers some advantages in freedom of layout, it is easily exaggerated, and deserves to be addressed here because of the implicit challenge to the assertion that only moderate capital investment is needed.

In 1979, a U.S. team of six individuals with broad shipbuilding experience visited six Japanese shipyards to identify low investment, high return Japanese shipbuilding technology as part of the National Shipbuilding Research Program. Six shipyards belonging to three different companies were visited. With one exception, all were old yards that had been modernized. Moreover, the visiting Americans noted that in the previous year (1978) the Japanese government requested that all shipbuilders reduce their facilities by 35 percent as a consequence of the world oversupply of tankers, that two of the companies visited had chosen to close new, modern yards in preference to the older ones visited, and all the companies had reduced employment at some of their new, large yards.

Officials of Exxon's Tanker Department have made comparative estimates of productivity and production cost among Japanese shipyards. Although acknowledging that the third generation Japanese shipyards have the highest productivity levels, they estimate that, because of the high equipment overhead costs in these highly automated yards, the maximum variation in total construction cost among the three generations* of Japanese shipyards is on the order of 12 percent.[40]

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*First generation Japanese yards are, for the most part, pre-World War II shipyards which have been modernized. Second generation yards, built in the late 1960s and 1970s were designed for series production of tankers and bulk carriers. Third generation Japanese shipyards have been built with heavy reliance on automation; they are equipped with numerical control cutting facilities, automated panel lines, numerical control pipe fabrication, etc.

3.3.2 Capital Formation

It has been suggested that the U.S. shipbuilding industry has a capital formation problem. The assertion that the industry is inadequately profitable due to a fluctuating and uncertain market has been made repeatedly over many years. The National Research Council (NRC), having taken note of the capital formation controversy in its report, Productivity Improvements in U.S. Naval Shipbuilding, is nearing completion of a second Navy-sponsored study that includes a discussion of the capital formation issue. Pending publication of the NRC study, the results of an earlier study and a few observations may serve to demonstrate that whether or not the shipbuilding industry has a problem with profitability is not clear. A 1978 study completed for the Office of Naval Research on the profitability of the industry from 1947 to 1976 found that overall the industry's profits were "less than satisfactory." It also found that while some companies in the industry were consistently profitable, others almost as consistently sustained losses. The study concluded, "Our analysis would tend to support the conclusion that a firm's profitability is more a function of the quality of management than it is of the general economic environment in which the industry operated."[41]

A review of the financial results of those shipbuilding companies which publish publicly available annual reports reveals no consistent pattern for the industry as a whole. In 1982, General Dynamics, with yards in Groton, Conn. and Quincy, Mass., was the only major shipbuilder to report a loss on shipbuilding operations. At the other extreme, Litton (Ingalls in Pascagoula, Miss.) reported a return of 50 percent on assets for shipbuilding operations. Tenneco (Newport News) reported a 25 percent return. Todd

(San Francisco, Los Angeles, Seattle, Galveston) reported a 17 percent return on assets. Ogden (Avondale in New Orleans) reported on a 4 percent return on assets. Other shipbuilding companies covered the same broad range.

3.4 SUPPLIER BASE

Approximately half the cost of a commercial ship is for purchased materials and components. The availability, cost and quality of marine material and components has great potential for affecting the productivity and competitiveness of U.S. shipbuilders. Standards for shipbuilding material and components are needed to facilitate zone outfitting, but have been lacking in the U.S., as was noted in Section 3.1. The cost of some U.S. materials, notably steel plate, is high relative to the cost abroad. Finally, in some important areas, most notably in the development of diesel propulsion machinery, the U.S. has lagged significantly behind Japan and Europe.

The development of shipbuilding standards is a matter requiring the initiative of the shipbuilding industry as well as government cooperation (especially that of the Navy, the industry's biggest customer). The problems represented by the high cost of steel plate and the limited availability of modern diesel engines involve several factors including the volume of commercial ship construction in the U.S., "Buy America" restrictions on the use of foreign materials and components, and the general inefficiency of certain industries such as steel.

U.S.-built vessels have been subject to various "Buy America" requirements. Foreign materials and components have been prohibited, subject to waiver in some cases, for ships built with construction differential subsidies or with government-guaranteed (Title XI) financing. More limited "Buy America" requirements have applied to vessels for the Jones Act fleet.[42] (The Coast Guard has recently eased these requirements.) These restrictions may be important factors in limiting U.S. shipbuilder's ability to obtain the lowest prices and best technology for marine material and components.

The small volume of commercial shipbuilding work handicaps the shipbuilding industry in seeking suppliers of components and materials. The disadvantage relative to the ability of Japanese shipbuilders to obtain economical supplies is significant. A few points of comparison will serve to illustrate the magnitude of the problem. Historically, the number of new orders for merchant ships over 2000 gross tons coming to U.S. shipyards annually has ranged from single digits to the low forties; in 1982, only three commercial orders were received (totaling 12,200 gross tons). The Japanese shipbuilding industry usually receives orders for several hundred ships a year; in the April 1982-March 1983 period, new orders totaled 267 vessels over 2500 gross tons (4.4 million gross tons). The Japanese steel industry in 1982 produced 7,860,000 tons of steel plate, over 30 percent of which went to shipbuilding. The U.S. steel industry shipped 4,146,000 tons of steel plate, 7 percent of which went to shipbuilding. The Japanese steel industry produced over eight times as much steel plate for shipbuilding as the U.S. steel industry. In these circumstances, the Japanese steel industry can be more responsive to the needs of shipbuilders than can the U.S. steel industry, and this greater responsiveness is reflected in such practices as doing more fabrication work.

More important than mere responsiveness, however, is that foreign-made steel plate is often significantly cheaper than U.S.-made steel plate. The cost shown previously in Table 2 reflected estimates of steel plate prices that were less than three-quarters of the price in the United States. The differences in prices reflect the greater efficiency of foreign steel production as well as, in the case of some European countries, government subsidy.

For different reasons, the U.S. shipbuilding industry is not supported by a strong supplier base for propulsion machinery either. Most new commercial ocean-going ships are diesel-powered, but the U.S. has lagged in adopting this technology. While several Japanese and European shipbuilders are active builders of low-speed and medium-speed marine propulsion diesel engines, no U.S. shipbuilder builds engines. Only two U.S. companies - neither a shipbuilder - actively market medium-speed marine propulsion engines. A recent venture to establish a producer of low-speed diesels ended after the delivery of three engines. The design and manufacture of marine propulsion diesels is a global industry involving complex licensing arrangements and the export of parts. "Buy America" restrictions are believed to have played a role in limiting U.S. participation in diesel sales and production.

3.5 STRATEGIC ISSUES

Whatever the ease or difficulty of innovating in the shipyard, the owner of the shipyard must consider whether the decision to innovate is a good business policy, considering all the costs, benefits and risks to his firm. It is possible that the decision to innovate would benefit the firm, but still not be the best possible strategy. It is possible that innovation would lower his production costs, but not by enough to ensure sufficient future sales because of a declining or uncompetitive market, or because competitors, too, had lowered their costs. It is possible that the firm's internal situation, due to thin management, poor shipyard location, a militant union or some other factor, makes attempts to innovate prone to failure. These are strategic issues. This section will briefly review the shipbuilding industry's competitive situation and market prospects, with comments on the potential role of productivity improvement.

There are today in the United States fewer than 25 shipyards capable of large ship construction, and only about 13 seriously seeking large ship construction as a mainstay of their business. Of these 13, 12 are capable of, and interested in, merchant ship construction; 7 are capable of building naval combatants as well; 5 can build only merchantmen or naval auxiliaries.

The U.S. shipbuilding and ship repair market is dominated by the U.S. Navy. Over half of the industry's revenues in 1982 were from Navy procurements. Naval shipbuilding is highly concentrated. Three-quarters of planned FY83 ship construction Navy funds were allocated to the four largest U.S. shipyards.[43] Of these four, one has a monopoly in building strategic nuclear submarines, and another, a monopoly in building aircraft carriers.

Commercial shipbuilding is presently in decline. Traditionally, the major sources of private merchant shipbuilding orders have been for ships intended for operation in the domestic intercoastal, non-contiguous or coastwise trades (i.e., the so-called Jones Act fleet, where foreign-built ships are prohibited under the sabotage laws), and for ships purchased by U.S.-flag foreign trade operators with construction differential subsidies (CDS). CDS, intended to enable U.S. flag operators to buy U.S.-built ships for the foreign trade by paying the difference between the cost of U.S. construction and foreign construction, has been eliminated from the Federal budget since 1982. In recent years, CDS construction accounted for about one-quarter to one-third of the number of commercial ships built.*

A major part of current commercial shipbuilding activity in U.S. yards has been generated by the Military Sealift Command (MSC). The MSC has signed a number of long-term charter agreements with private operators, causing those operators to build or convert vessels to fulfill those charters.

During the late 1970s, oil rig construction became a major business for U.S. shipbuilders, especially those located along the Gulf of Mexico where there is much offshore oil production. When oil rig construction peaked in mid-1981, over one-third of the commercial construction backlog of the industry could be accounted for by oil rigs. Oil rig construction has since declined to near zero as a surplus of idle rigs has developed worldwide and offshore exploration has been curtailed.

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*During the period 1971-1980, CDS construction accounted for an average 12.5 percent of direct labor employed in the Active Shipbuilding Base (shipyards capable of and interested in building large ships, as defined by the Maritime Administration). Private construction (non-CDS) accounted for 16.8 percent; Navy construction accounted for 51.9 percent; the remainder can be attributed largely to repair and non-ship work. Figures for January of each year supplied by the Maritime Administration, Office of Maritime Labor and Training.

Major U.S. shipbuilders face two critical, strategic questions:

1. Given the dominance of the Navy in the U.S. market, what are the most effective ways to obtain Navy business?
2. Given the decline of regular, commercial shipbuilding opportunities and government subsidies, what are the most effective ways to generate new commercial business?

How the potential of new, more productive shipbuilding systems and methods relates to these questions defines the strategic issues surrounding the new methods. In relation to the Navy, the question is whether the new methods and techniques would be effective in obtaining or retaining Navy business. Observations both positive and negative can be made in answer to this question.

Building Naval vessels differs from commercial construction in several respects. Naval vessels are designed and built to withstand high-impact shock. Extensive documentation of material procurement and work accomplished is required to ensure that the Navy's standards are met. Naval combatants, in particular, are very "dense" ships, having crew accommodations and weapon systems packed into them instead of the empty space of cargo holds. This density implies a much higher proportion of outfitting work. Despite these differences between commercial and naval construction, there appears to be no practical obstacle to the application of the advanced shipbuilding concepts developed abroad for building commercial ships to the construction of Naval vessels, even combatants. Indeed, the new methods may be particularly effective in providing the effective control required by the Navy and in coping with dense fittings.

Only a fraction of the cost of a warship will be attributable to building the ship itself. Ray Ramsay of the Naval Sea Systems Command presents an illustrative calculation for a generic destroyer in which the cost of the "platform" (the ship itself) is only 22.7 percent of the total cost of the ship. Weapons systems and various programmatic costs and allowances make up the rest. Of the shipyard construction cost for the platform, only one-third represents manufacturing cost; material costs are over half, with program management, engineering and other functions accounting for the remainder. In these circumstances, a shipyard which had achieved a 50 percent reduction in manufacturing costs through productivity improvements could offer only a 17 percent reduction in platform cost, and that reduction would represent less than a 4 percent reduction in program costs to the Navy!.[44]

The full cooperation of the Navy would be necessary to implement the new systems and methods. Design and planning are keys to the new systems, and the Navy is very actively involved in designing and planning the construction of their ships. The incentives within Navy contracts, as well as the method for determining original award, ought to be sensitive to rewarding productivity improvement. There is considerable evidence that the Navy is increasingly interested in improving shipbuilding productivity. The Navy has altered some contract procedures with the intent of rewarding good performance and reportedly has gotten results.[45] The Navy has initiated a major shipbuilding technology program to promote modernization in Naval ship production.[46]

In the case of commercial shipbuilding, there is no question of whether the new systems and methods are applicable or acceptable for building new ocean-going ships. The question is whether building new ships is a good bet for a U.S. yard.

The Maritime Administration has estimated that new merchant ship construction for the Jones Act fleet over the next five years will total 22 vessels, yielding an average of three to five orders per year. The number of Naval auxiliaries and Military Sealift Command ships to be built has not been estimated, but might reasonably be supposed to be on the order of five to ten per year. At best, an expectation for orders for 15 merchant vessels (including naval support ships) per year can be expected to flow to U.S. shipyards. This would be roughly comparable with historic experience.

A moderate-size shipyard building ships using integrated hull, outfitting and painting work organization and employing a good level of other technology, employing 3000 to 5000 workers, could produce at least 6 to 8 ships a year, in addition to doing a fair volume of ship repair. The inescapable conclusion is that, in the absence of successful market expansion or other measures to increase demand for U.S.-built ships, to increase productivity in U.S. shipbuilding would imply concentrating merchant shipbuilding in as few as two shipyards.

Mixed commercial and naval combatant shipbuilding might extend the number of shipbuilders competing for commercial orders, but not by more than one or two. Several of the dozen shipyards now seeking commercial orders would have to abandon their ambitions for new construction of commercial vessels. Any U.S. shipyard setting out to make the necessary effort and investment to revolutionize its shipbuilding will be gambling that it can achieve the gains much more rapidly than its rivals and will be able, subsequently, to use these gains to virtually exclude all but one or two or - at the outside - three competitors from the commercial shipbuilding market and also from the market for non-combatant Naval ships, or to develop new markets simultaneously.

One alternative for a U.S. yard would be ship repair. Ship repair accounts for about 30 percent of all private U.S. shipbuilding and repair industry revenue and is the principal activity of most U.S. shipyards. Although demonstrating very little growth, ship repair has been a fairly steady business for U.S. yards over the long-term. The revolutionary concepts introduced in organizing shipbuilding have little direct application in the simplest kinds of ship repair (which are often little more than maintence and cleaning activities), but they are potentially very important in organizing ship overhauls and damage repair. For example, replacement of the propulsion plant (a not uncommon activity, as ship owners seek more fuel-efficiency) could be done in a way which held the ship in drydock for only a fraction of the time required by traditional methods, since the whole propulsion plant could be pre-assembled for installation. Moreover, many of the associated improvements in management practice and production equipment would greatly enhance a ship repair yard's competitiveness. For example, industrial standards could reduce costs and speed repairs. Use of computers for flow management, inventory control, and maintenance can vastly improve efficiency. Numerical control machine tools can improve the quality of and reduce the time needed for metal cutting and fabrication. Labor-management changes such as the introduction of participatory management and improved working conditions can improve productivity and reduce costs. Commercial ship repair yards generally do little marketing; they have little advanced equipment, many have problems with dissatisfied work forces. Although the situation is less dramatic, and much less studied, it appears possible that in time ship repair will feel intense pressure to modernize.

U.S. yards might be more competitive producing more technologically complex ships or non-traditional products. Historically, U.S. yards had some success with LNG ships and oil rigs. There are many who believe that the best hope of U.S. shipyards seeking new business internationally would be in marketing a new, technically advanced product. Various advanced ship designs have been offered as solutions by naval architects. Non-traditional products intended to repeat the success of oil rigs have also been proposed. One of the most promising of the proposed non-traditional products is the floating industrial process plant. Over 40 such plants that have been built or designed were described in a 1981 Maritime Administration report. The total market worldwide in the 1985-1990 timeframe was estimated at over 1500 units, at a cost per plant ranging from 10 to 200 million dollars.[47] The potential cost advantage of foreign shipbuilders was considered a major competitive factor.[48] The concepts and systems of modern shipbuilding could well be applied in the U.S. to negate that factor.

The passivity of U.S. shipyards in the area of marketing may be a significant obstacle to the development of a larger market, however. In regard to the possibility of marketing advanced ships, it has been observed that while leading Japanese shipbuilders have fairly complete hydrodynamic testing facilities, engage in considerable propulsion research, conduct market studies, and develop new vessel designs, U.S. shipbuilders have few research facilities and there is little evidence of innovative design efforts.[49]

This passivity extends as well to the development of non-traditional markets. In relation to floating industrial plants, it has been observed that U.S. yards are far behind their foreign competitors in marketing floating plants.

> During the course of this study it became apparent that U.S. shipyards are doing little to develop their participation in the markets described in this report. Foreign shipyards, not only the Japanese but also the principal European yards,

> are flooding the international marketplace with plans, brochures, films and sales presentations extolling the virtues of floating industrial plants. Clearly, these shipyards, and their related industrial parents or sister companies, have not only identified the market, but are convinced that the market is viable, sustainable, and growing. It is obvious that considerable sums of money have been devoted to the development of conceptual plans, detailed specifications and drawings, elaborate brochures and films. On the other hand, U.S. shipyards appear to be waiting for orders to appear by some magical process.[50]

The reasons for this passivity can only be speculated upon. There are many who believe that it is related to a tendency in the U.S. shipbuilding industry to turn to the government for a solution in the form of a subsidized market.

4.0 POLICY IMPLICATIONS

This paper has attempted to summarize the consensus view that has emerged from numerous studies over the last five to seven years on shipbuilding productivity and related problems. The conclusions of the American Commission on Shipbuilding, arrived at slightly more than a decade ago, were referenced in the introduction to indicate the extent to which the prevailing view concerning shipbuilding productivity has changed since the last major review of shipbuilding policy in the early 1970s. Informed opinion about what the productivity problem is and what is needed to address it is very different today, regardless of what assumptions are made concerning policy objectives or means.

In the foregoing sections, the sources of productivity in modern shipbuilding have been discussed. It has been emphasized that the systems innovations associated with modern shipbuilding are organizational in nature. They are <u>not</u> the consequence of automation or technologically sophisticated equipment. The vision of an advanced, modern shipyard that emerges from the various studies of highly productive methods and practices is one which is distinguished more by its use of organizational methods that enhance its capability to control the shipbuilding process than by its capital equipment. Accordingly, deficiencies in management quality, and management and labor organization rank high among the obstacles to adoption of the new methods.

This paper has not been concerned primarily with policy. The recommendation of specific policies would require analysis of their likely results, resource requirements, etc., and is beyond the paper's scope. Nevertheless, what has been said in this paper about shipbuilding productivity has definite implications for policy and these will be outlined here. The discussion here simply puts the findings regarding productivity into context. An important part of this context is the direction which the shipbuilding industry has assumed in recent years as a new understanding of the potential for shipbuilding productivity was being developed and applied in the United States.

4.1 FUTURE DIRECTION OF U.S. SHIPBUILDING

There is no doubt that the United States shipbuilding industry is moving forward toward adopting more productive methods and techniques. If the 1978 Technology Survey cited so often in this report was repeated today, very substantial progress would be reported at a number of yards. If the detailed comparison of productivity done at Levingston in 1980 could be repeated today at a leading U.S. yard, it would still show a substantial difference in productivity in favor of the Japanese, but the difference would undoubtedly be much smaller. This kind of quantitative data is, unfortunately, not available to measure the progress of American shipbuilding, but there are many other indications of an improving situation.

Six U.S. yards - Avondale, Bath, Lockheed, NASSCO, Tampa, Todd-Los Angeles - are currently employing Japanese consultants in an effort to implement the new methods. Avondale, considered by many to be the leader in applying the new methods, may well have been the first U.S. shipyard to complete a merchant ship to a contract design which incorporated a modern build strategy when it delivered the Exxon Charleston in October 1983. In August 1984, Exxon entered into a similar arrangement with NASSCO, with the award of a contract for two large tankers. Avondale implemented the process lane concept for hull construction for the Exxon project. Other shipyards are preparing to also establish process lanes. All major yards make at least some use of zone outfitting, and several are beginning to apply statistical analysis techniques. The record of U.S. shipyards in meeting production schedules and making deliveries on time has improved tremendously in the last five years for both commercial and naval shipbuilding. Significant programs for college-level training in ship production methods have been instituted at the University of Michigan and the University of Washington. Although the eventual achievement of productivity levels comparable to those demonstrated by the most modern shipbuilders internationally is very far from assured, there is clearly momentum in the industry toward significant improvement.

Recently, as part of a workshop on the application of social technologies in U.S. shipbuilding, a panel of experts speculated on what a modern U.S. commercial shipyard of the 1990s would look like. In many ways, their collective view confirms the one presented in this paper.

> For the most part, our shipyard of the future profile highlights changes of a social/organizational rather than technical nature. And that's not because this is a human resource conference, it's because we don't see any major hardware technological innovations in this time-frame. To an outside observer, the shipyards of the 1990's will look very much like the yards of today. They will not be the shipbuilding equivalents of the factory of the future....
>
> We predict that most changes will center around the adoption of the zone-by-stage construction method, a variation of the concept of group technology....
>
> One exception to our prediction of few hardware technology changes is that...we predict that computers (especially microcomputers) will play a very important role in management information systems. They will be widespread throughout the yard and will be used not only by full-time managers, but also by first-line supervisors and even by skilled tradesmen.
>
> We also see a shortage of skilled workers in the 1990s... Therefore there will be a renewed emphasis on training...complemented by efforts to attract and retain qualified employees...shipbuilders will be making extensive efforts to improve the working environment within the yard.[51]

The panel also predicted "that more design work will be done at the yard rather than at external design agencies," that design "will be facilitated by the use of computers," and that "an integration of the now distinct functions of the design and production departments" would occur.[52]

4.2 POLICY AND PRODUCTIVITY

National policy toward shipbuilding, as part of the government's overall maritime policy, has long been motivated by a concern for national security, as well as the concerns for advantage in international trade, competition, employment and economic well-being that are a part of most government policies toward industry. Shipbuilding is a necessary support to the nation's sea power, and, it is argued, a shipbuilding industry of a certain minimum size and capability is needed in the event of war or national emergency for the conversion, repair and construction of vessels used by the Navy and merchant marine. The experience of both World Wars, when enormous resouces had to be mobilized to build ships to sustain commerce as well as military efforts, is often cited in explaining the role of shipbuilding in national security.

One consequence of the preoccupation with national security is that national policy toward shipbuilding tends to be focused on providing a sufficient market to sustain a substantial shipbuilding industry. A combination of means have been used. Procurement of U.S. Naval ships is now done almost exclusively from private, U.S. shipyards and, as a matter of policy, a certain portion of naval overhaul and repair work is allocated to private U.S. shipyards (with the remainder handled by Naval shipyards). Ship operators carrying cargo in the domestic trades (between points within the U.S.) are required to use only ships built in the United States. A high tariff is imposed on non-emergency repairs performed on U.S.-flag ships abroad.

Until very recently, subsidized U.S.-flag operators in the foreign trades were required to obtain their ships in the U.S. and a subsidy (construction differential subsidy) up to 50 percent of the cost of the ship was paid to cover the difference between the U.S.

cost and the foreign cost of construction. A number of schemes have been put into place, as well, to aid in financing new ship construction in the United States.

The role of productivity in national shipbuilding policy can be viewed in two, complementary ways within the context of meeting the national security, economic and other overall objectives that that policy may have. First, and rather obviously, improving productivity may be a goal of policy because it is viewed as a means of making achievement of larger objectives affordable. Sustaining a relatively inefficient and unproductive industry is an expensive and wasteful proposition.

Second, improving productivity may be viewed as a means of making the industry more commercially competitive as part of a strategy for achieving larger objectives. If the industry were more nearly competitive internationally, it would be more capable of obtaining on its own merits some portion of the commercial business required to sustain its economic well-being and to achieve national security objectives. In addition, government policies to support the industry's market through incentives to ship operators and other indirect means will be more effective if those incentives, etc., do not have to overcome a discouragingly high cost of construction.

The feasibility of significantly enhancing the competitiveness of U.S. shipbuilders through productivity improvement is frequently called into question. Factors affecting competitiveness other than productivity, such as foreign government subsidies and other policies restricting international competition, and high wages in the U.S. compared to Korea, China and other emerging shipbuilding nations, are often cited by pessimists to justify the view that productivity improvement has very limited potential to significantly alter the prospects of the industry.

An optimist might reply by observing that the world's most successful shipbuilders - the Japanese - have captured over half the world market for merchant ships in large part by being the most productive shipbuilders in the world, and despite what ever obstacles other nation's governments might have tried to erect to international competition. An optimist might also attempt to minimize the concern about wages by pointing out that high U.S. wages are the result of high productivity in most U.S. industry and that many other industries have learned to cope with foreign competition which depends on low wage labor. Countries like China, the optimist might argue, are unlikely to become highly productive in shipbuilding simply because they lack the educated people necessary to effectively organize and control the shipbuilding process in the manner described in this report, even though extremely low wages will undoubtedly make them an important competitor in the world market. Higher productivity would also enhance a shipyard's competitiveness vis-a-vis domestic (U.S.) firms for non-shipwork, where high wages are much less of a factor.

Probably neither optimist nor pessimist is fairly evaluating the potential of productivity for improving the prospects of the shipbuilding industry. A more balanced view would acknowledge that while becoming dominant in commercial shipbuilding worldwide for all types of ships is unrealistic, it may not be necessary for the achievement of national policy objectives. A highly productive U.S. shipbuilding industry would be cheaper to support by whatever means in pursuit of any national objective, and might be quite competitive in certain segments of the world market for which it could develop special advantages of expertise, technology or geography.

Policies which aim, in whole or part, to improve U.S. shipbuilding productivity may be classified into four general categories. Only the general categories can be commented on here; detailed policy analysis is beyond the scope of this paper. These categories are: 1) measures to increase demand for ships, 2) measures to reduce the effective cost of investment in shipyard facilities, 3) direct and detailed programs which exhort or subsidize shipyards to introduce new technology, and 4) regulatory relief.

4.2.1 Stimulating Demand and Series Production

Stimulating shipbuilding improvements through increased demand is undoubtedly the preferred option of the shipbuilding industry, which frequently and repeatedly over the years has touted its value in achieving various national objectives. The notion that a Federal program to increase ship purchases could have a direct effect in terms of improving productivity rests on the concept of series production. Series production, i.e., the production of a series of nearly identical ships, was formerly thought to be the principal, perhaps even the only means of improving shipbuilding productivity. One of the most important implications for policy of the new view concerning shipbuilding productivity is that series production is not a necessary or perhaps even viable strategy for improving productivity.

While the identification of specific systems and methods of shipbuilding that apparently can improve productivity without regard to building in long series has tended to reduce the emphasis placed on series production, recommendations to employ series production to improve productivity are still commonly made. For example, E.G. Frankel, Inc., in a report to the Office of Technology Assessment, suggested a list of actions to stimulate productivity improvement, led by a recommendation to "impose serial construction of ships in sets of not less than 12, all built in one yard."[53]

The alleged connection between productivity and series construction is also used to make excuses for low U.S. productivity, excuses which imply that productivity would improve if only U.S. shipyards were given sufficient work, and, moreover, should not be expected to improve in any other circumstance than vigorous market demand for series-constructed ships. A recent Congressional Budget Office report, for example, states,

> The lower productivity of U.S. shipyards, as indicated by man hours per ship, results from generally older facilities and the lack of series production opportunities. In shipbuilding, success tends to breed more success - that is, sufficient orders for ships of a given type can lead to series production which leads to lower costs which leads to still more orders. A shipyard with few orders, on the other hand, cannot realize the benefits of multiple-unit production, which results in higher costs and continued slack demand. The U.S. shipbuilding industry is now stuck in this adverse cycle, resulting in uncompetitive prices for U.S.-built ships.[54]

Given the persistent claims made for series construction and the emphasis placed on it by so many, it is not enough simply to reject it as a fallacy or exaggeration. It may be worthwhile to review briefly how series construction apparently came to be connected with productivity.

The effectiveness of series production in improving productivity has been recognized at least since World War II, when the U.S. shipbuilding industry turned out a prodigious volume of ships and, in the process, accomplished what even today appear to be phenomenal feats of shipbuilding. The days from keel laying to launch and the number of labor hours required declined dramatically as successive ships were built. The most dramatic of these reductions came with the first four or five ships in the series as workers learned their tasks and the engineers worked out details in the design of the ship. Further reductions came as the production process was rationalized.*

Many of the basic concepts for a zone/area/stage product work breakdown structure were developed during the 1950s in Japan and advances in many made aspects of shipbuilding methods were being made in Northern Europe as well. In the 1960s, a boom in the demand for tankers and bulk carriers led many Japanese and European shipyards to exploit the demand for these relatively simple ships to build their businesses. They developed their own designs and invested in huge new shipyards. Able to market essentially similar designs to many different buyers, they built ships in series; some series were very long if all the generations of design are counted together. In these circumstances, it was perhaps natural to associate productivity with series production, no matter what underlying methods might be identified by closer study. It was easy first of all to associate series production with the concept of mass production, even though it might be patently obvious that production of five or ten ships a year could have little resemblance to the assembly of 20,000 automobiles per month (the typical output of an auto assembly plant). It was simply assumed that the productivity improvements being made were inherently linked to volume and a standardized product in the same way that volume and standardization were linked to economies of scale in mass production.

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*For some figures on WW II shipbuilding productivity, see Productivity Improvements in U.S. Naval Shipbuilding, pp. 10-12, which quotes figures from a 1949 report of the U.S. Maritime Commission. The legendary achievements of WW II shipbuilding may have been due more to the heroic efforts of those involved than to either their systems or to series production. Louis Chirillo has made estimates of deadweight tons produced per man-hour to illustrate the trend in productivity in Japan and the U.S. since WW II. It is interesting to note that he estimates that current productivity in the U.S. is about 50 percent higher than it was at the end of World War II, and current Japanese productivity, by his measure, is more than twice the current U.S. level. L.D. Chirillo, p. 24.

What was seldom recognized about series production is its limitations. The immediate gains from series production are short run: they are the result of people learning better how to put together a particular ship according to a particular system. They are economies of learning, not economies of scale or mass production. These gains will be realized without changing the way the ship is put together, without making any of the systems innovations discussed in Section 2.0.

When the series is over, and a new ship design has to be built, the productivity gains from series production are gone; a new ship has to be learned. Long run productivity improvement depends on making significant changes in the way ships are built. To some extent, these long run changes may be aimed at "capturing" some of the learning from series production and institutionalizing it, as in the case of setting up shipbuilding standards which apply from one ship design to another. But, fundamentally, long run productivity improvement depends on initiatives independent of the mere fact of constructing a series of ships.

Some students of the industry have used "series construction" as a kind of rhetorical shorthand condensing their understanding of fundamental problems with a policy recommendation, believing that series construction would embody a solution to those problems. Concerns that U.S. shipyards do not have sufficient control over design to standardize production and that the instability of the market for large ships denies them the strategic opportunity to make investments to improve productivity are often articulated in discussions about the need for series construction. Failing to differentiate between series construction and more fundamental factors in productivity can easily lead to misdirected policymaking, however. For example, the shipyard's taking control of the ship design in preference to custom-building to a buyer's design might be recognized as a fundamental step in improving productivity, and certainly shipyards which undertook series production of their own designs did this. Focusing attention on series production in devising government policy, however, might easily lead to a policy in which the government took control of design, in order to impose series construction. This clearly would not achieve the desired result; shipyards would still not have taken control of design.

Regarding Federal assistance to stabilize the market, the associated policy of subsidy to stimulate demand and promote series production has been discredited in recent years. Subsidy has been blamed for encouraging U.S. shipbuilding industry to be passive concerning the adoption of new methods and technology and the development of new markets. It is apparent that a policy of artificially manipulating the market through subsidy may be responsible for isolating the industry from exposure to the new methods, systems and technology it needs to become more productive. The Congressional Office of Technology Assessment, for example, has noted the claim "that the reason for lack of progress is the tendency of the industry to identify a Government-sponsored 'stable increasing (sic) ship construction program' as the solution to the lack of international competitiveness, rather than to develop a program based on the industry's own resources and planning," and gone on to conclude that "Federal assistance to U.S. shipyards through construction subsidies over the past two decades appears to have discouraged independent attempts to reach and maintain commercial viability."[55]

Extensive documentation and analysis of the fundamental changes in organization and method required for productivity improvement in shipbuilding has made the simplistic notion of series production obsolete. One factor that has made this easier to accept is that, responding to fundamental shifts in the world market for ships such as the collapse of the market for oil tankers, some of the world's most productive shipbuilders are no longer building continuous series. In 1982, for example, I.H.I. of Japan reportedly "delivered 16 ships, no two identical, to 15 owners in 11 countries. The ships featured three different types of main propulsion diesels in various sizes. Simultaneously, the same company was producing a polyethylene plant for installation in South America and complex warships."[56] As shipyards in the U.S. are beginning to make significant gains in productivity by applying the new methods, without series construction opportunities, the central importance assumed for series construction is being dismissed.

The potential difference between the short-term productivity improvements of series production and the long-term improvements possible with the adoption of new methods has recently been highlighted in a U.S. Navy procurement. The procurement was for a landing ship dock (LSD). The Navy had previously contracted with Lockheed Shipbuilding and Construction Co. for three LSD's. The first LSD built by Lockheed had a contract price of approximately $338 million. Enjoying the economies of series production, the second and third LSD's had contract prices of approximately $304 million and $271 million, respectively. The first ship of the new procurement -- which would have been the fourth in the series -- was expected by the Navy to continue the established pattern of cost reduction. The Navy's cost estimates reportedly ranged as low as $225 million, and Lockheed's bid was somewhat higher than this estimate. Avondale Shipyards, widely considered to be the leader among U.S. yards in adopting the zone, area, stage concept, made a bid in which the target price of the first LSD was approximately $167 million, won the procurement. Avondale's lower labor cost, as well as dissimilar delivery schedules, contract terms, and fee requirements were undoubtedly factors in explaining the difference. However, Avondale executives, in response to questioning before the House Merchant Marine Subcommittee, testified that the adoption of modern, highly productive shipbuilding methods was the primary reason they could make the bid which they did and still expect a profit.

It is apparent that series production is no longer a preferred prescription for productivity improvement, given the availability of other, more powerful medicine.

4.2.2 Encouraging Investment

Encouraging companies to invest in facilities and equipment through investment tax credits and related tax incentives is a popular method for aiding industry in the United States and abroad. The impact on shipbuilding productivity of an investment tax credit (for shipbuilders) is likely to be more limited than it might be for some other industries because shipbuilding is labor-intensive, requiring relatively little invested capital per unit of output and because, as described above, the capital investment required to introduce the systems innovations needed to boost productivity is modest. Moreover, many of the required "investments" for organizational change, such as the expense of instituting a statistical control system may not be capitalizable for tax purposes. Whether the industry has a capital formation problem due to inadequate profitability and an uncertain market is a somewhat separable issue. As noted earlier, the evidence on this point is inconclusive, although the problems of low profitability and market uncertainty are frequently cited by the industry.

4.2.3 Encouraging the Adoption of New Technology

Programs to encourage the development and application of new technology are common elements in the Federal government's policies toward many industries. Two such programs are of particular interest in the case of the shipbuilding industry. They are the Maritime Administration's National Shipbuilding Research Program (NSRP) and the Navy's Manufacturing Shipbuilding Technology (MT/ST) program.

The NSRP was initiated in 1971 pursuant to the Merchant Marine Act of 1970. It is a collaborative program financed by both industry and government. Industry involvement in program management and execution is provided by the Ship Production Committee of the Society of Naval Architects and Marine Engineers. The committee is composed of senior technical managers from all the major U.S. shipyards. Under the main committee, there are special panels, each responsible for a specific technical area. There is also a lead shipyard assigned to each area. The lead yard is responsible for the program management and administration of projects undertaken in its area. At the present time, four major yards are acting as lead shipyards in the program. The University of Michigan takes the role of lead yard for the education panel.

Although modestly funded, the NSRP has been instrumental in disseminating knowledge of the new shipbuilding methods and practices developed abroad. Most of the reports referenced in this paper are products of the NSRP. The Maritime Administration, through the NSRP, began calling the attention of the shipbuilding industry to the achievements of Japanese in developing superior shipbuilding organization and methods in the late 1970s when a survey team was sent to Japan to identify specific methods and technology which could be applied in the United States. The Levingston study was sponsored under the auspices of the NSRP. The 1978 Technology Survey and the Appledore comparison, referenced earlier, were also Maritime Administration-sponsored studies.

The NSRP has produced publications describing concepts and implementation of zone/area/stage product work breakdown structure, process lanes, statistical analysis for process control, etc. There is a panel on design-production integration, which is looking at CAD/CAM on a broad basis. The NSRP is also directly addressing many of the recognized obstacles to productivity improvement described in Chapter 3. A panel on shipbuilding standards has produced over one hundred draft national shipbuilding standards and is working for their prompt adoption. A panel on education has sponsored a symposium on "social technologies" including participative management, has developed a college textbook on ship production methods and techniques and is sponsoring the publication of a professional journal, as well as developing and distributing a number of training aids to shipyards across the country. Looking to the future, a panel has been established to look into flexible automation.

The Navy's MT/ST program is part of a larger Department of Defense Manufacturing Technology program implemented through all three services. In October 1981, a reassignment of functions in the Naval Sea Systems Command (NAVSEA) placed the responsibility for the NAVSEA manufacturing technology activity in the Navy's Office of Maritime Affairs and Shipbuilding Technology and marked the beginning of a major shipbuilding technology initiative. With the rationalization that other Defense

Department manufacturing technology program components contribute to production technology improvements in electronics, aircraft and weapons, the Navy has chosen to concentrate on advancing shipbuilding technology.

Recognizing the importance of the problems being addressed by the NSRP, the Navy has chosen to provide significant funding for that program and is encouraging participation in the Ship Production Committee oversight panels. The Navy also sponsors projects of its own at various shipyards doing Navy work, although many of these are focused on the introduction of advanced technology and related facilities, rather than the introduction of modern systems and methods or broad organizational change. Nevertheless, the Navy has a variety of program frameworks available to encourage the adoption of new systems and technology. In this regard, the Defense Department's Industrial Modernization Incentives Program (IMIP) is of particular interest, because it provides a mechanism under which the Navy can make a formal agreement with a contractor to make phased improvements in the whole manufacturing system. Under IMIP, the government and the contractor make an agreement based on a structured analysis of the total manufacturing system concerning improvement projects, levels of contractor and government investment, contractor investment protection and shared savings arrangements. The Navy has a variety of options for providing incentives, and if necessary, direct funding for reaching contractual objectives in modernizing the manufacturing system.[57]

Because the Federal government is effectively the shipbuilding industry's largest customer, directly and indirectly, it may be worthwhile to consider whether it has available any special leverage to promote the use of new methods and technology, through the Navy or the Maritime Administration. Certainly, coercive policies are not likely to be effective in encouraging complicated organizational change. If it were simply a matter of buying a certain machine or hiring a quality control inspector, such an approach might be effective, but given the need for subtle and complex changes in whole systems, this does not seem to be a viable approach. Nevertheless, because the changes are so pervasive and reach back into vessel design, it may be helpful if the industry's best customer is a sympathetic and understanding one. The supportive cooperation of Exxon appears to have played an important part in enabling Avondale to undertake implementing a build strategy incorporating many modern methods from contract design forward in the construction of the Exxon Charleston and its sister ships, and Exxon may play a similar role at NASSCO. There is a growing body of sympathetic and knowledgeable people in the Navy promoting adoption of zone/area/stage product work breakdown structure and statistical norms in ship construction and major ship overhaul. More aggressive and extensive programs of education in these matters in the Navy may be helpful.

Whether the Maritime Administration could effectively take an active role in pressing adoption of the methods through its influence on commercial buyers of ships may be a policy question, especially if some form of directed subsidy is again adopted to aid the industry. Academic supporters of the series production argument in the past were inclined to bemoan the tendency of the Maritime Administration (and the Navy) to encourage "spreading the work around," because they supposed that opportunities to improve productivity were being lost. Certainly, to the extent that "spreading the work around" is a policy enforced without regard to competitiveness, shipyards may see less incentive to innovate and invest in productivity improvement. Whether some sort of supplemental information to competitive bidding is desirable to highlight a shipyard's productiveness is, perhaps, a separate, but related question. Developing data on labor productivity is fraught with difficulty, and it is hard to see how such information would be of any more interest than price, which, presumably, reflects the shipbuilder's costs and efficiency already. A more promising possibility might be to develop statistical norms reflecting the accuracies actually achieved by some subset of builders in the U.S. industry. As U.S. shipbuilders progress in applying statistical analysis, these norms will tend to reflect the industry's capability for controlling production processes, and thus, the industry's productivity. They would form a yardstick by which individual shipbuilders could monitor their own progress, and the government could monitor the progress of the industry. The Japanese Society of Naval Architects has reportedly published such norms for a number of years.[58]

4.2.4 Regulatory Relief

A common complaint of U.S. industry is that it is burdened by government regulation more stringent than that in effect abroad. The U.S. shipbuilding industry is affected by a variety of government regulations and restrictions. These may conveniently be considered in three categories: 1) technical requirements for certain ship features; 2) "Buy America" restrictions on procuring foreign material and components; 3) ordinary industrial regulation affecting employee benefits, occupational safety, environmental protection, reporting of information, etc. The first two categories are exclusive to shipbuilding; the third category of regulations is largely shared with all American manufacturing and construction.

In 1978, the Shipbuilders Council of America prepared an estimate of the cost of U.S. laws and regulations based on a survey of member shipyards. Using a hypothetical product carrier of 56,000 deadweight tons, costing $45 million, as a basis, and considering only the regulations directly affecting the shipbuilder (and excluding those affecting only suppliers), they estimated that the impact of government regulation on the total cost of the ship was between 7 and 11 percent.

Over half of the cost increase due to regulation was attributed to the technical requirements of the U.S. Coast Guard, the American Bureau of Shipping and the U.S. Public Health Service. The remainder was attributed to various regulatory requirements in the category of ordinary industrial regulation, with the largest portion due to employee "fringe benefits" required under the Longshoremen's and Harbor Workers' Compensation Act, the Employee Retirement Income Security Act, Federal Unemployment Insurance, and so on. Requirements of the Occupational Safety and Health Administration were also a large category, accounting for between 10 and 15 percent of the cost increase.[59]

"Buy America" regulations were not considered by the Shipbuilders Council. Nor was any attempt made to compare the cost of U.S. regulation to the cost of regulation in place abroad. It can be observed that other nations have technical requirements corresponding to those in effect in the U.S., although there is a general impression that some U.S. requirements are more stringent. Where the technical requirements apply to the ship specifically - as most Coast Guard and American Bureau of Shipping requirements do - foreign shipbuilders building ships for U.S. operators bear much the same burden that would fall on a U.S. shipbuilder. Other nations also have extensive requirements regarding employee welfare. Those in effect in some Northern European countries have long been believed to exceed those in the U.S. for general industry.

Whether government regulations inhibit the adoption of more productive technology methods or systems has not occasioned much comment or research. "Buy America" restrictions are often said to have had a role in the American failure to adopt modern diesel propulsion systems sooner, as was noted.

4.2.5 Summary of Policy Implications

Of the four generalized policy approaches reviewed above, the most directly relevant to improving shipbuilding productivity seem to be programs to promote and facilitate adoption of the specific methods and systems recognized to be responsible for superior foreign shipbuilding productivity. These programs appear especially relevant for two reasons. First, improving shipbuilding productivity in the U.S. at the present time appears to be mostly a matter of disseminating knowledge about how better to organize and control the shipbuilding process, knowledge that has been developed and demonstrated abroad. Second, because the government, through the Navy and more indirectly, through the Maritime Administration, is the industry's major customer, it seems clear first that the adoption of better methods and systems will require the active cooperation and support of the government and that the government has considerable responsibility to promote the adoption of more productive methods and systems. The Maritime Administration's National Shipbuilding Research Program, co-funded by the Navy, has proven to be especially effective.

Policies aimed at increasing demand appear to be less clearly and directly relevant to the goal of improving shipbuilding productivity (although they may, of course, be necessary to achieve other policy objectives). While policies of ensuring increased demand for U.S. ships have been advocated in the past based on an assumed connection between series production and productivity, the most recent studies of shipbuilding productivity emphasize methods and systems that do not require production in long series to be effective. It is no longer the accepted wisdom that large shipbuilding orders of a dozen or more ships of a kind are necessary to improve productivity. Indeed, some now argue that the Federal government's past role in promoting ship demand through subsidy may have stifled the industry's own efforts to innovate.

Policies to promote capital investment appear to be not as important to shipbuilding in improving productivity as they may be to some other industries for two reasons. First, shipbuilding is not very capital intensive and, second, the identified means available to improve productivity are mostly systems and methods rather than capital equipment. Although some have asserted that the industry has a capital formation problem, the readily available evidence does not strongly support them.

Finally, regarding the relevance of regulatory relief to improving productivity, no direct connection can be highlighted, although "Buy America" restrictions have been identified as associated with slowing the adoption of modern propulsion systems and with the high cost of U.S. materials, particularly steel plate.

It should be noted in closing that productivity is not the only objective of public policy toward shipbuilding. National security objectives, for example, may be better furthered by different approaches. The purpose of this brief review has not been to recommend any policy toward the shipbuilding industry. It has been to sketch the connection between shipbuilding policy and what has been discovered and documented about U.S. shipbuilding productivity in the last five to seven years: that the large difference between U.S. shipbuilding productivity and the productivity of some foreign shipbuilding industries is due in large part to better foreign methods and systems of shipbuilding.

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