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MODULAR SHIPBUILDING AND ITS RELEVANCE TO CONSTRUCTION  
OF NUCLEAR POWER PLANTS

by

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OF NUCLEAR POWER PLANTS

by

Thomas W. Seubert

Submitted to the Department of Nuclear Engineering  
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ABSTRACT

→ The modern techniques of modular shipbuilding based on the Product Work Breakdown Structure as developed at the Ishikawajima-Harima Heavy Industries Co., Ltd. of Japan are examined and compared to conventional shipbuilding methods. The application of the Product Work Breakdown Structure in the building of the U.S. Navy's DDG-51 class ship at Bath Iron Works is described and compared to Japanese shipbuilding practices. Implementation of the Product Work Breakdown Structure at Avondale Shipyards, Incorporated is discussed and compared to Bath Iron Works shipbuilding practices.

A proposed generic implementation of the Product Work Breakdown Structure to the modular construction of nuclear power plants is described. Specific conclusions for the application of Product Work Breakdown Structure to the construction of a light water reactor nuclear power plant are discussed.

Thesis Supervisor: Dr. Michael Golay

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## CHAPTER 1

### INTRODUCTION

#### 1.1 Preface

Construction costs of the next generation of nuclear power plants will be strongly influenced by the utilities' desire to have a plant with low capital costs and increased availability along with a reduction in the cost of life extension and eventual decommissioning. Modularization of the various components and systems of the nuclear power plant can help to attain these goals.

The Technology Transfer Modularization Task Team, under the auspices of the Department of Energy, published an assessment in June 1985 of modularization in nuclear and non-nuclear industries. The key conclusion of the task team was that there was a need for further study to establish guidelines for future development of light water, high temperature gas and liquid metal reactor plants. These guidelines should identify how modularization can improve construction, maintenance, life extension and decommissioning.(1)

This thesis examines the modularization techniques of Product Work Breakdown Structure (PWBS) as utilized in the shipbuilding industry, then focusing on its potential applications to the construction of nuclear power plants. The remainder of this chapter is devoted to a brief overview of the evolution of modularization in shipbuilding in the United States from pre-World War II to present day and the relevance of modularization to the U.S. nuclear industry. Chapter 2 details the methods of Product Work Breakdown Structure at the Ishikawajima-Harima Heavy Industries Co., Ltd. (IHI) of Japan. Chapter 3 focuses on the application of PWBS in the building of the U.S. Navy's DDG-51 class ship at Bath Iron Works, Bath, Maine. Chapter 4 outlines the implementation of PWBS at Avondale Shipyards, Incorporated of New Orleans, Louisiana. Chapter 5 describes a proposed implementation of PWBS to the modular construction of nuclear power plants. Specific conclusions for the application of PWBS to the construction of a light water reactor nuclear power plant are discussed in Chapter 6. Finally, a summary and conclusion is given in Chapter 7.

## 1.2 Evolution of Modularization in U.S. Shipbuilding

Prior to the start of World War II, the U.S. shipbuilding industry, subsidized by the U.S. Maritime Commission (established by the Merchant Marine Act of 1936), was recovering from a deep post World War I recession.(2)

The Maritime Commission had enacted a "long range plan" for construction of ships based on a design known as "standard types". This design distinguished them from emergency, military and minor-types of ships. The standard dry cargo carrier, designated C-types, were the first to evolve and incorporated the important feature of standardization of design. While designing the C-types, the Maritime Commission developed three designs of flexible end use that allowed minor modifications by a shipbuilder after construction was completed. At the same time the Commission shift from single to multi-ship contracting facilitated the implementation of mass production techniques in shipbuilding.

The start of World War II in 1939 and its growth in 1940 produced an industrial revolution in the shipbuilding business that led to one of the most amazing shipbuilding expansions in U.S. history. Henry Kaiser's introduction of Group Technology contributed directly to the revolution.(3) However, design simplification, standardization, quantity production, technological innovation and a sense of national urgency also contributed. Suffice it to say that during the period 1939 to 1945 the deadweight tonnage of ships produced in the Maritime Commission program exceeded 50 million tons.(4)

Introducing Group Technology achieved the benefits normally associated with production lines even while

producing many different subassemblies in varying quantities. These subassemblies, or modules, were prefabricated away from the shipbuilding ways because of their limited number available for production. Modules were then assembled and launched. Each shipyard was free to define the module boundaries in a way best suited to that yard's crane and storage area capacity. While structural prefabrication dominated, it is unclear how much equipment/system outfitting prefabrication was completed prior to assembly on the building ways. Outfitting, however, was probably not a critical issue on these "Liberty" ships since cargo and tanker ships tended to be almost all structure.(5) Some World War II shipyards did use progressive outfitting. Progressive outfitting involved different piers of specialization where one trade, such as electrical, would complete all outfitting. All ships would then move simultaneously to the next specialization pier, for example piping, and so on, until completed.(6)

As stated previously, Henry Kaiser's introduction of Group Technology to the shipbuilding business during World War II caused an industrial revolution within that industry. Following World War II, Elmer Hann, a former Kaiser employee, took Kaiser's methods to Japan where he taught the Japanese how to organize shipyard work in accordance with the basic principles of Group Technology.(7) Utilizing these methods the Japanese were producing 40 percent of the

world's total new ship tonnage by 1964. Ishikawajima-Harima Heavy Industries Co., Ltd. (IHI), under the leadership of one of Elmer Hann's pupils, Dr. Hisashi Shinto, developed and refined Product Work Breakdown Structure (PWBS) from the logic of Group Technology.(8) During the decades of 1960 and 1970, IHI built over 2,000 ships utilizing PWBS. Thus, PWBS is not just based on theory.

While PWBS was being developed and refined by IHI, U.S. shipbuilders for the most part returned to the conventional methods of building ships after World War II. The conventional method involved laying the keel, erecting the frames and just prior to the completion of the hull, outfitting of the ship by system as ventilation, piping, electrical and machinery systems were installed.(9) This resulted from a systems approach for ship design. The U.S. Navy's Ship Work Breakdown Structure (SWBS), not to be confused with Product Work Breakdown Structure, is an example of the systems approach. SWBS passes on to the shipbuilders the systems approach via the issue of plans by system. Thus, each system has its own drawings with outfit drawings generally not being issued until hull construction is well underway.(10) This has proven to be a very inefficient way to build ships.

The Merchant Marine Act of 1970 established the National Shipbuilding Research Program (NSRP).(11) This Act provided the stimulus for transfer of the Japanese



technology to the United States. Under NSRP sponsorship, shipbuilders, program managers and academicians toured shipyards in Europe and Japan looking for ways to improve productivity. In 1976 the significance of the IHI system for shipbuilding was realized. A research contract between IHI and NSRP resulted in the 1979 publication of the book, "Outfit Planning", (12) which showed that Japanese success was based on managerial methods to allow workers to work more efficiently. This was followed closely by the publication of the book "Product Work Breakdown Structure (PWBS)" in 1980. (13) This book details the Japanese logic and principles applied to the organization of work at IHI. It is based on the Kaiser/Shinto methods of Group Technology. In 1983 the NSRP published "Integrated Hull Construction, Outfitting and Painting" (14) and "Design for Zone Outfitting" (15) to show that designers and purchasing agents must become zone oriented.

These NSRP initiatives have caused an irreversible shift in U.S. shipbuilding methods. Avondale Shipyard's delivery in October 1983 of the complex product carrier "Exxon Charleston" saw the first ship built in North America from contract to delivery in accordance with these highly refined Group Technology methods developed in Japan. Several other U.S. shipbuilding firms have contracted IHI as consultants in the introduction of Group Technology methods. (16)

### 1.3 Modularization and the U.S. Nuclear Industry

Various methods of modularization have been pursued by the U.S. nuclear industry over the years to reduce construction costs. Modularization in light water reactor plants has been studied resulting in modularizing subsystems, e.g., combining pumps, pipes, valves and instruments on skids which are pre-tested prior to installation in the plant. Other examples of modularization in light water reactor plants include prefabrication of pipes and pipeways, rebar subassemblies, turbine generator pedestal legs, pool liner subassemblies, steel containment rings and condenser units. Even reactor vessels have been constructed offsite. Yet, the scale of modularization to date has been modest.(17) An important aspect of the modularization is the transport capabilities afforded for the modules. Improvements in rail and barge transportation along with large-size, heavy-lift cranes has provided the capability to lift and accurately position heavy loads in the 900 to 1,000 ton range at the construction site.(18) Thus, modules must be sized according to the mode of transportation and lift capability at the job site.

The incentives for modularization are apparent based on the 1981 study by the Atomic Industrial Forum.(19) This study showed that the construction phase of a nuclear power plant accounted for more than 50 percent of the total

capital costs of the project. These costs are directly attributable to poor labor effectiveness at the job site because of congestion, complexity and degree of required modifications. The report specifically states, "Compared to fossil plants, craft manhours per cubic yard of concrete are 2 to 3 times greater for nuclear plants, craft manhours per cubic foot of pipe installed are 3 to 4 times greater, craft manhours per foot of installed conduit, cable tray and cable are 1.5 to 2 times greater and craft manhours for support of pipe and electrical raceway hangers are about 5 times greater." (20) Modularization would relieve the congestion problems and reduce construction costs and improve quality considerably. Further, modularization would allow improvement of maintenance and repair, facilitate life extension and reduce decommissioning costs. (21) A keypoint of the Technology Transfer Modularization Task Team report is that "If nuclear power is to compete for new electrical generation, ways must be found to reduce the uncertainties and financial risks associated with capital intensive and long lead construction." (22)

This thesis discusses Product Work Breakdown Structure principles applied to the construction of commercial and naval ships. The scales of complexity of nuclear power plant construction and shipbuilding are similar. Products within each industry have similar cost and quality requirements. Thus, the current advanced

construction techniques in the shipbuilding industry utilizing PWBS should be directly applicable to reducing the costs and improving the quality in the construction of nuclear power plants.

## CHAPTER 2

### PRODUCT WORK BREAKDOWN STRUCTURE IN SHIPBUILDING

#### 2.1 Introduction

Dr. Hisashi Shinto's development and refinement of the Product Work Breakdown Structure (PWBS) in shipbuilding at the Ishikawajima-Harima Heavy Industries Co., Ltd. (IHI) of Japan is based on the logic of Group Technology (GT). Group Technology is the method for applying mass production techniques to a variety of products in widely varying quantities.(23) GT is also defined as the logical arrangement and sequences of all facets of company operations in order to bring the benefits of mass production to high variety, mixed quantity production.(24) In shipbuilding the GT logic in PWBS classifies parts to be fabricated, components to be purchased and planned subassemblies. This creates uniform and coordinated work flows. IHI shipyards have utilized PWBS in the construction of over 2,000 ships, thus PWBS is not just based on theory.(25) PWBS' main features include integration of hull

construction, outfitting and painting (IHOP), and cost centers that match a zone-oriented organization.(26)

This chapter describes the basics of the Product Work Breakdown Structure and integrated hull construction, outfitting and painting as used at the Ishikawajima-Harima Heavy Industries Co., Ltd. of Japan. The primary references are the National Shipbuilding and Research Program (NSRP) publications "Product Work Breakdown Structure"(27) and "Integrated Hull Construction, Outfitting and Painting".(28)

## 2.2 The Basics of Product Work Breakdown Structure (PWBS)

As discussed in Chapter 1, traditional shipbuilding results from a systems approach for ship design. The subdivision by ship's functional systems is good for early design and estimating but very inefficient for planning, scheduling and the execution of construction. This leads to poor coordination of work and the lack of control of material, manhours and schedules.(29)

This section defines interim products and their relationship to the Product Work Breakdown Structure (PWBS) in shipbuilding. Group Technology (GT), as applied to the machined parts industry, is briefly described to establish the importance of classification of parts by design and manufacturing attributes. This is followed by the PWBS'

three classifications of a work package. Next is a discussion of productivity values in the reiterative process for analyzing interim product work package development. The three dimensional nature of PWBS is then illustrated followed by comments on the versatility and benefits of PWBS.

Large construction projects, such as shipbuilding, require subdivision of the work in order to analyze and manage the project. Parts are procured and fabricated and joined to create subassemblies. Subassemblies are combined to form larger subassemblies and so on until the ship is built. The parts and subassemblies are the interim products, and the method of subdivision of work on interim products is a product-oriented work breakdown structure.(30)

Machined parts industries utilize Group Technology as a means for improving productivity. Parts are grouped by their common characteristics. The basis for such groups is that there are common processes for the manufacture of all parts within a particular group. Parts are classified by design and manufacturing attributes which are reflected in coding schemes. Codes identify form, dimensions, tolerances, material and types/complexity of machining operations.(31)

Interim products in shipbuilding utilize similar classification schemes to identify problems in their

manufacture. These classification techniques more uniformly distribute work between contract award and delivery for each ship. Further, there is better coordination of the outputs of the various work process lanes for a simultaneous mix of ship types and sizes.(32)

PWBS classifies a work package three ways.(33) First, PWBS divides the shipbuilding process into three basic types of work - hull construction, outfitting and painting. Each of these basic types of work have their own inherent work problems different from the other. Each division is subdivided into fabrication and assembly work. These subdivisions form the zone-oriented production techniques utilized by managers and are titled Hull Block Construction Method (HBCM), Zone Outfitting Method (ZOFM) and Zone Painting Method (ZPTM).

The second classification of PWBS is based on the interim product and its needs for product resources. These product resources include material, manpower, facilities and expenses and are classified and allocated based on common parameters for a particular interim product regardless of its intended location within the ship. Definitions of the product resources are:(34)

- Material, to be used for production, either direct or indirect, e.g., steel plate, machinery, cable, oil.
- Manpower, to be charged for production, either direct or indirect, e.g., welder, fitter, rigger, material



arranger, transporter.

- Facilities, to be applied for production, either direct or indirect, e.g., buildings, docks, machinery, equipments, tools.

- Expenses, to be charged for production, either direct or indirect, e.g., designing, transportation, sea trials, ceremonies.

The third classification is by four product aspects - system, zone, area and stage. This classification by product aspects optimizes productivity in the construction of a ship by providing controls for the production processes. These production processes include manufacturing parts and subassemblies, i.e., interim products, leading to outfit units and structural blocks within time frames that can be coordinated, and the simultaneous use of each production process for the requirements of different systems, even in different ships. System and zone product aspects divide the ship design into planned manageable parcels while area and stage product aspects divide the work process from material procurement to completion of ship construction. The specific definitions of each product aspect are:(35)

- System - A structural/operational function of a product, e.g., longitudinal/transverse bulkhead, fuel oil service system, lighting system.

- Zone - An objective of production which is any

geographical division of a product, e.g., cargo hold, superstructure, engine room and their subdivisions or combinations.

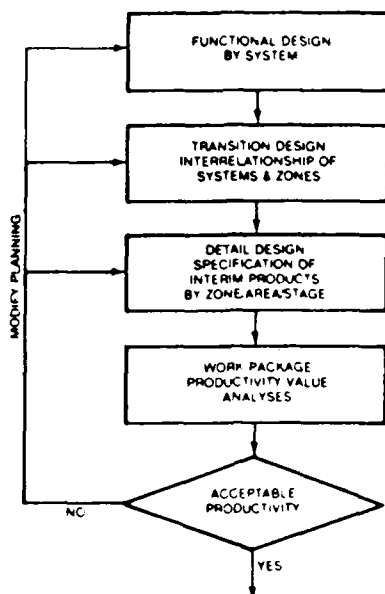


Figure 2-1. Reiterative development of work packages.(36)

- Area - A division of the production process into similar types of work problems by feature (e.g., curved vs. flat blocks, small diameter vs. large diameter pipe, pipe material), quantity (e.g., job-by-job vs. flow lane, volume of on-block outfitting for machinery spaces vs. volume of on-block outfitting for other than machinery spaces), quality (e.g., grade of workers required, grade of facilities required), kind of work (e.g., marking, cutting, bending, welding), and by anything else that creates different work problems.

- Stage - A division of the production process by

sequences, e.g., substeps of fabrication, subassembly, assembly, erection.

Figure 2-1 illustrates the reiterative process of analyzing work package development of an interim product through several planning levels based on the four product aspects to determine productivity value.

The key step in the reiterative process, productivity value analysis, can be expressed by the empirical formula:(37)

$$PV=f(T,N,Q)$$

where:

PV = productivity value, i.e., the productive efficiency of a work package,

T = time allowed for its accomplishment, i.e., working time,

N = number of units of resources, particularly components in the material list and manhours allocated, and

Q = quality of work circumstance, e.g., downhand vs. overhead, high vs. low, etc., and also quality specified for the interim product.

T, N, and Q are interdependent and affect PV differently.

PV is optimized when the influences of T, N, and Q are balanced.(38) As stated, the function  $f(T,N,Q)$  is empirical and must be determined for each classification of the production process by problem area by each individual shipyard. It must consider prior and follow-on work stages.

For example, Q includes consideration of the quality specified for an interim product. If its contribution to PV is not enough, the quality of the interim product is not good enough for a larger assembly. Since productivity values are empirical in nature, they cannot be precisely determined. However, productivity value determination is the key step of the judgmental process for evaluating the work package. Further experience with the work package via the reiterative process shown in Figure 2-1 eliminates the initial trial and error of this empirical process.

Figure 2-2 illustrates the three dimensional nature of the PWBS.

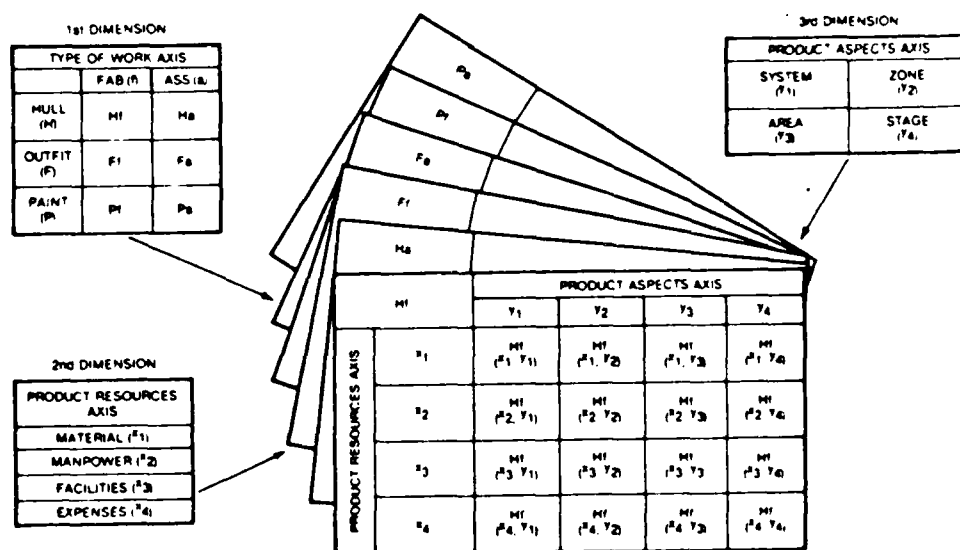


Figure 2-2. The three dimensional PWBS. (39)

In Figure 2-2 the three classifications of a work package are

each subdivided into fabrication and assembly classifications normally associated with hull construction and outfitting only. Fabrication and assembly in painting relate to its manufacture/preparation and application, respectively.

The versatility and benefits of PWBS have become clear during the past three decades. By adapting the logic of Group Technology, as utilized in the machined parts industry, to shipbuilding via interim products and a three-dimensional work package classification scheme, Ishikawajima-Harima Heavy Industries Co., Ltd., and other shipbuilders worldwide have increased productivity. The zone-oriented processes, Hull Block Construction Method (HBCM), Zone Outfitting Method (ZOFM), and Zone Painting Method (ZPTM), alone and in combination have contributed to increased productivity. The adoption of the area-oriented Pipe Piece Family Manufacturing Method (PPFM) in addition to the aforementioned zone-oriented processes has also contributed to increased productivity. The results are simpler assembly methods, the rationalization and automation of facilities and more uniform and simultaneous workloads for fabrication shops and assembly teams. Further, these results have contributed to improved safety and work environments along with better quality and higher productivity.

### 2.3 Application of Product Work Breakdown Structure

This section will deal with the application of the Product Work Breakdown Structure in shipbuilding. First, the transformation of a ship from a total system/basic design to a zone-oriented design is discussed and illustrated. Next, work process lanes are described and illustrated to show their relationship to the integrated hull construction, outfitting and painting of a ship. Finally, there is a discussion of zone-oriented scheduling, progress reporting and cost collection.

A naval or commercial ship as a total system/basic design is the starting point for the application of PWBS. The ship as a total system is then broken down into individual systems/functional design by their functional drawings and associated material lists.

The next and key step is the transformation from a system to a zone-oriented design. Zone-oriented design starts with a block plan for hull construction and composite drawings for outfitting that incorporates all systems and shows zone boundaries. Area/stage breakdowns follow with assembly, subassembly, and cutting plans for hull construction; and work instruction drawings with material lists for outfitting.

Subdivision continues by zone/area/stage with preparation of detailed design drawings reflecting pipe pieces and other components along with associated material

lists. The subdivision is completed when the zone is broken down to the minimum level. The minimum level is comprised of components to be purchased and material requirements for the fabrication of parts.

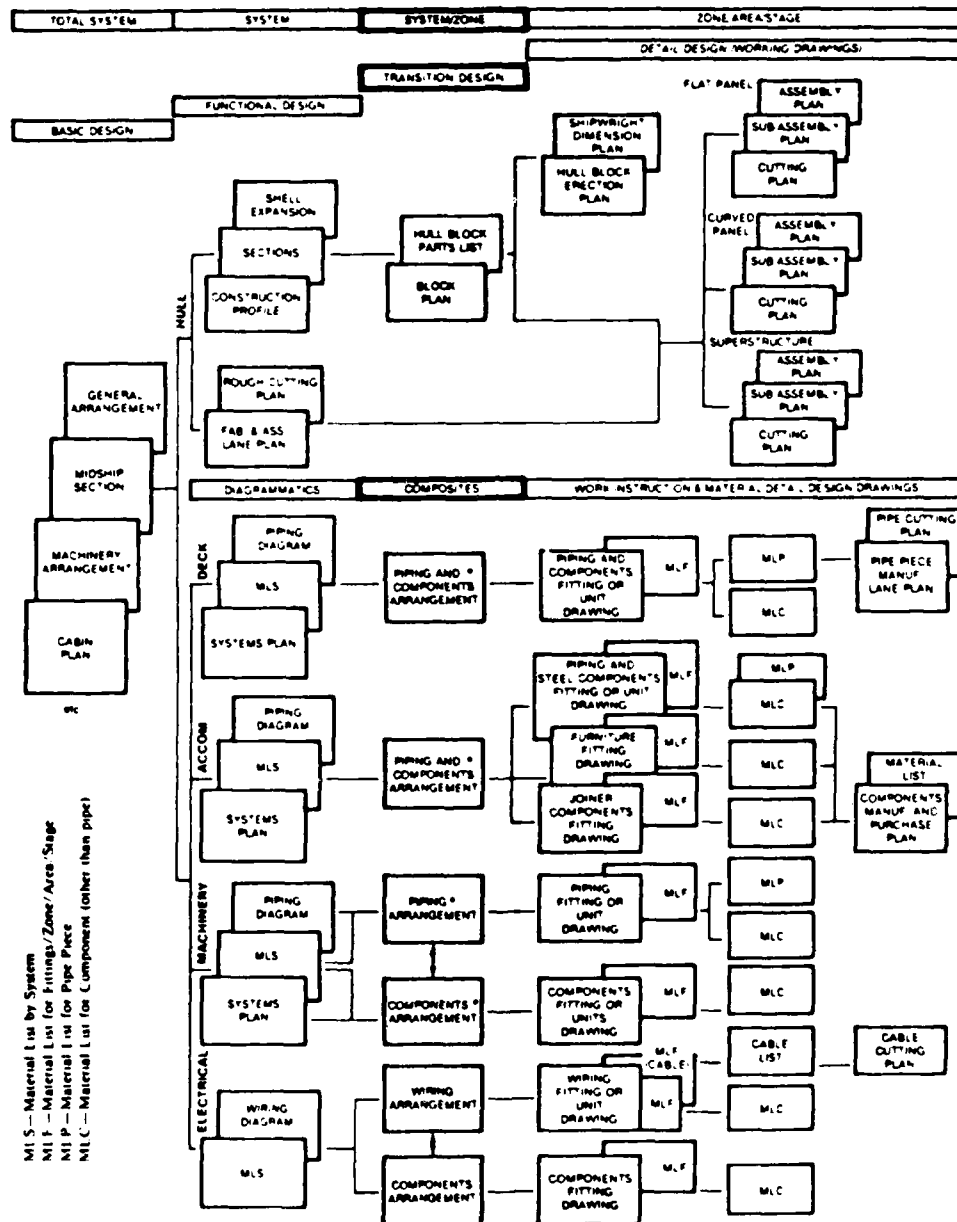


Figure 2-3. Product-oriented Design Process.(40)

Figure 2-3 is a detailed block diagram representing the product-oriented design process as described in the previous paragraphs. The transition design incorporates the transformation from systems to zone-oriented design. Items marked with an "\*" in Figure 2-3 are sometimes sketched freehand for piping and component arrangement transition design for deck, accommodation, machinery and electrical systems. The freehand sketches are sufficient for quickly establishing arrangements and system/zone relationships to detail designers. Detail designers then refine the arrangements and designate stages during the preparation of work instruction and material detail design drawings. The right hand side of the figure reflects the minimum level of the subdivision by zone/area/stage, i.e., components that are to be purchased and the material requirements for such parts that are to be fabricated.

Construction can begin with the completion of detailed design. Work process lanes where interim products, i.e., parts and subassemblies, will be produced are established and organized by classes of production problems based on the product aspects of area and stage. These work process lanes are in turn integrated for zone-oriented production based on the end product, in this case a ship. Within the various work process lanes are the fabrication shops and assembly sections.

Figure 2-4 is a simplified block diagram of the



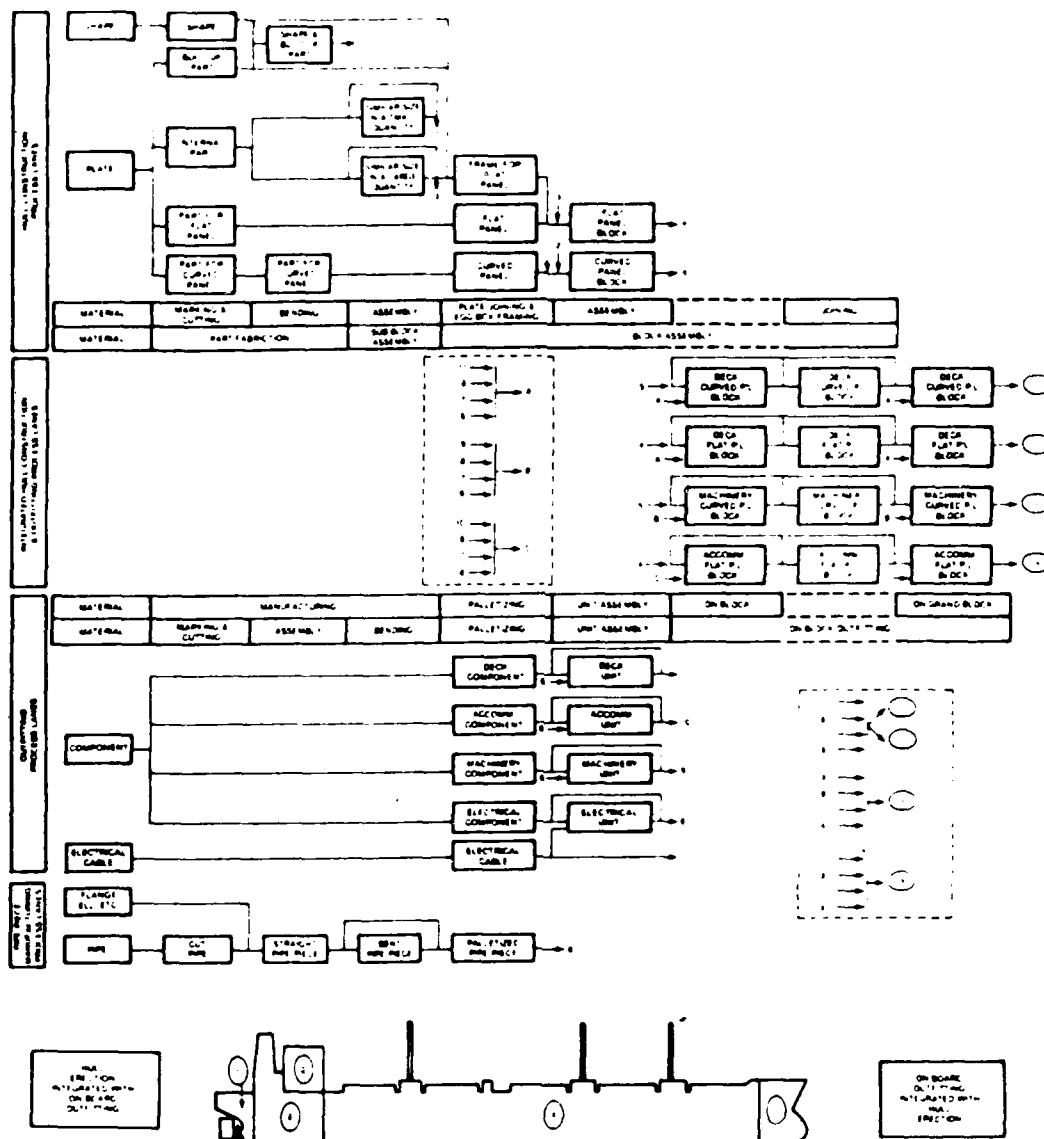


Figure 2-4. Integrated Work Process Lanes. (41)

work process lanes for integrated hull construction and outfitting. Zone painting would be represented as additional processes in additional sub-stages in the various flow lanes. The figure includes hull construction, integrated hull construction and outfitting, outfitting, and pipe piece manufacturing work process lanes. Its detail will be

described in Section 2.4.

Zone-oriented scheduling is an important and necessary part of the PWBS. Zone-oriented scheduling controls flow of work on the various process lanes in order to complete interim products as they are needed. This scheduling coordinates the hull construction, outfitting and painting allowing for the collection and distribution of interim products to follow-on work stations. Figure 2-5 is a block diagram of the organization of an integrated hull construction, outfitting and painting schedule.

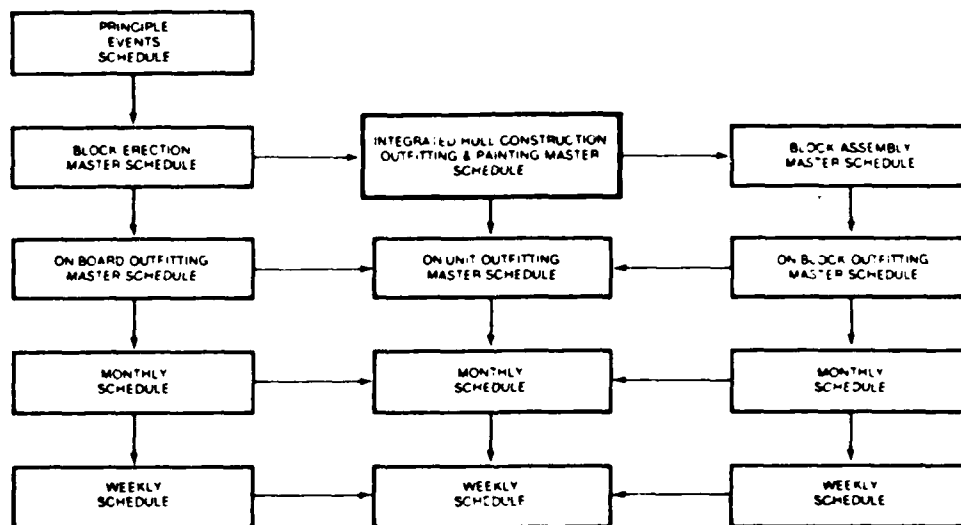


Figure 2-5. Integrated hull construction, outfitting and painting schedule.(42)

The weekly schedule is based on a work package that is ideally sized for completion by two workers in one week. Work packages of this size allow control of work flows and accurate progress reporting of material and manhour costs by

zone/area/stage. The importance of small work packages cannot be understated. Small work packages along with the structural material lists provide control because "progress determinations are based upon only tangible aspects, i.e., material is either assembled or unassembled and the greater number of work activities enhance flexibility".(43)

Flexibility is important and necessary for successful use of PWBS. The ability to identify required production adjustments to counter potential delays and early completions based upon feedback about work progress and material procurement allow transfer of workers between work process lanes, use of overtime and short term schedule changes. Thus, the objectives of uniform work flow within each work process lane and coordinated outputs from all work process lanes is maintained.

Finally, in the application of PWBS, zone orientation provides progress reporting and cost collection which can be directly related to work completed. Thus, managers can forecast work remaining and resources required. However, shipyard cost estimators, by tradition, remain systems-oriented throughout construction with respect to manpower costing. Zone-oriented manpower costs are rationalized to a systems orientation using cost indices to distribute spent manhours to systems. Thus, these "indirect collection" costs appear to be less precise and a degradation of feedback to cost estimators. But, it

produces more accurate data due to the inherently better control that zone orientation provides because of the control linked to many relatively small amounts of material grouped by zone/area/stage. When comparing this to shipyards that use conventional methods of shipbuilding based on large and sometimes open-ended systems-oriented work packages that are commonly abused by front-line managers, i.e., foreman and general foreman, to absorb other work or idleness caused by insufficient work, the advantages of zone-oriented manpower costing are justified. PWBS allows easy corroboration of material requirements between zone and system. Functional systems designers typically use this flexibility to ensure that errors in material estimates are identified before procurement begins. Functional systems designers can also corroborate estimated manpower requirements based on the material lists for zones by utilizing system/zone transformation indices based upon material, e.g., manhours per foot of electric cable, manhours per hundredweight of fittings, etc.

All material requirements are listed by system for purchasing and subsequently on structured material lists for issue purposes. Therefore, the interrelationships maintained by designers permit material progressing by zone to be accurately converted to material progressing by system if a customer so desires. Similarly, the system/zone transformation indices can serve a customer's requirement to

check the progress of manpower cost by system.

In this section the application of PWBS was described and illustrated. The application of PWBS begins with the transformation of a ship as a total system/basic design to a zone-oriented design. This is followed by establishment and integration of work process lanes for zone-oriented production of interim products that ultimately lead to a completed ship. Lastly, the importance of zone scheduling, progress reporting and cost collection were discussed.

#### 2.4 Integrated Hull Construction, Outfitting and Painting (IHOP)

This section of the chapter deals with integrated hull construction, outfitting and painting (IHOP). The manufacturing levels and product aspects of the zone-oriented processes - Hull Block Construction Method (HBCM), Zone Outfitting Method (ZOFM), Zone Painting Method (ZPTM) and the area-oriented process - Pipe Piece Family Manufacturing (PPFM) are described and illustrated. The section concludes with a discussion of the integration of these zone/area-oriented processes in the construction of a ship and the management organization to support IHOP.

The zone-oriented processes - Hull Block Construction Method, Zone Outfitting Method and Zone Painting Method and the area-oriented process - Pipe Piece

Family Manufacturing can be applied to shipbuilding alone or in combination. HBCM is the method for manufacturing hull parts, sub-blocks, and blocks in organized work process lanes. ZOFG provides precise zone-by-stage control of outfitting in three basic stages - on-unit, on-block, and on-board. ZPTM ensures that the painting work process is coordinated with HBCM and ZOFG. PPFM is the production line method for the manufacture of many different pipe pieces in varying quantities. PWBS facilitates the integration of these processes by emphasizing expertise in contriving and classifying ideal interim products, i.e., parts and subassemblies, which permit coordinated work flows. Shipbuilders who have mastered such integration routinely achieve over 90 percent completion of outfitting at time of launching because of the coordinated work flows of interim products.(44)

#### 2.4.1 Hull Block Construction Method (HBCM)

Figure 2-6 is a block diagram of the seven typical manufacturing levels for HBCM. A block is defined as an interim product and one zone. Starting with the block assembly level, work is divided and subdivided down through the sub-block/semi-block and part assembly level to the lowest level of subdivision - part fabrication. In Figure 2-6 the grand block level serves to minimize the duration required for erection in a building dock by assembling and

joining several blocks together outside the dock into grand blocks. Grand block joining results in better scheduling and use of a shipyard's normally limited dock space and availability. An ideal block, i.e., zone, is the basis for production control in the HBCM, but care must be taken in defining the block because of the resulting impact on integration with zone outfitting and painting.

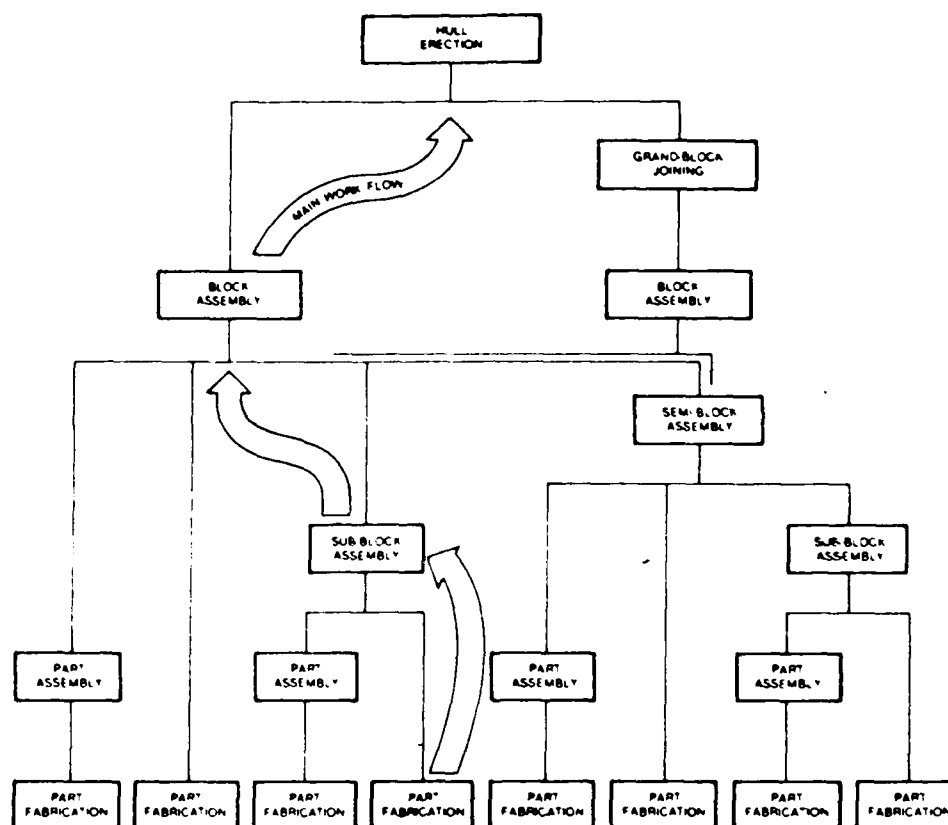


Figure 2-6. Manufacturing Levels for HBCM.(45)

The definition of the block has the greatest influence on shipbuilding productivity. Therefore, blocks should be designed so that:(46)

- for block assembly purposes, the blocks are

assignable to one of a minimum number of work package groups which considers similarities in problem area and the need to minimize variations in working times,

- for block erection purposes, blocks will be stable configurations requiring no temporary support or reinforcement and otherwise shaped to achieve minimum working times, and

- for on-block outfitting and painting, blocks are sized for maximum space (area and/or volume).

Blocks should be designed with similar volume, weight and shape characteristics in order to distribute work evenly during fabrication and assembly levels which precede block assembly. Planners break down the work leading to block assembly to ensure that welding is shifted from difficult to down-hand, i.e., welding in the downward position taking full advantage of gravity, in order to reduce working times needed and to distribute work performed during block assembly among the parts fabrication and assembly levels to equalize their working times. Block design should also be of the largest size permitted by the industrial facilities' capabilities, e.g., crane capacity, dock space/availability, buildings, etc.

Excluding the grand block and hull erection levels as depicted in Figure 2-6, interim products are analyzed for similarities in their product aspects and grouped by these similarities in order to further modularize the production



process, justify expensive but highly efficient facilities to enhance the production process and achieve manpower savings.

Figure 2-7 shows the typical groupings by product aspects for HBCM.

PLANT LEVEL	MFG LEVEL	PRODUCT ASPECTS										CODES		
		ZONE	AREA					STAGE			ZONE	AREA	STAGE	
1	7	SHIP	FORE HULL	CARGO HOLD	ENGINE ROOM	AFT HULL	SUPERSTRUCTURE	TEST		ERECTION	SHIP NO	BLOCK CODE	STAGE CODE	
2	6	BLOCK	FLAT PANEL	CURVED PANEL	SUPERSTRUCTURE	BACK PRE-ERECTION		NIL		GRAND-BLOCK CODE	GRAND-BLOCK CODE	STAGE CODE		
						PRE-ERECTION		NIL						
						JOINING		NIL						
3	5	BLOCK	FLAT	SPECIAL FLAT	CURVED	SPECIAL CURVED	SUPERSTRUCTURE	BACK ASSEMBLY		NIL		BLOCK CODE	BLOCK CODE	STAGE CODE
								ASSEMBLY						
								FRAMING		NIL				
								PLATE JOINING		NIL				
4	4	BLOCK	SIMILAR SIZE IN A LARGE QUANTITY	SIMILAR SIZE IN A SMALL QUANTITY	BACK ASSEMBLY		NIL		GRAND-BLOCK CODE	GRAND-BLOCK CODE	STAGE CODE			
					ASSEMBLY									
					PLATE JOINING		NIL							
					BACK ASSEMBLY		NIL							
5	3	BLOCK	SUB-BLOCK PART	BUILT-UP PART	BENDING		NIL		SUB-BLOCK CODE	SUB-BLOCK CODE	STAGE CODE			
					ASSEMBLY									
					BENDING		NIL							
7	1	PART	PARALLEL PART FROM PLATE	NON PARALLEL PART FROM PLATE	INTERNAL PART FROM PLATE	PART FROM ROLLED SHAPE	OTHER	BENDING		NIL		PART CODE	PART CODE	STAGE CODE
								MARKING & CUTTING						
								PLATE JOINING		NIL				

Figure 2-7. Product Aspects for HBCM.(47)

The horizontal and vertical combinations in Figure 2-7 characterize various types of work packages for the seven manufacturing levels of Figure 2-6 and the work process

lanes for hull construction, respectively. Note that codes for interim product identification and work process lane flow control are established by zone, area and stage for each level. "NIL" means no product aspect exists and is skipped in a process lane. With allocation of product resources a productivity value (PV) is determined to ensure that each work package is sized correctly. Reiterative analysis of the work package, as depicted in Figure 2-1, is normal because grouping by problem area at each manufacturing level is dependent upon productivity values that are achievable. Productivity is maximized when work is evenly allocated to work packages grouped by their product aspects, and there are quick responses to potential work imbalance such as shifting workers between manufacturing levels and/or flow lanes, authorizing overtime or even astute short-term schedule changes.(48)

See Appendix A-1 for an additional detailed description of each of the seven manufacturing levels of HBCM.

#### 2.4.2 Zone Outfitting Method (ZOFM)

The Zone Outfitting Method (ZOFM) employs similar manufacturing level and product aspect classifications as the Hull Block Construction Method (HBCM). As discussed previously, the HBCM established interim products starting with the hull as a zone and then subdividing zones to the

minimum or lowest level, i.e., part fabrication. Each zone in HBCM is associated with a specific manufacturing level. This regimentation is well suited for hull construction. However, it is not natural for outfitting.

The three types of outfit zones are:(49)

- On-unit, refers to a zone which defines an arrangement of fittings to be assembled in-house independent of hull structure. Assembly of such fittings is called outfitting on-unit. Doing this enhances safety and reduces both required manhours and durations which would otherwise be allocated to outfitting on-block and on-board.

- On-block, for outfitting purposes refers to a rather flexible relationship between block and zone. The assembly of fittings on any structural subassembly (e.g., semi-blocks, blocks and grand blocks) is referred to as outfitting on-block. The zone applies to that region being outfitted. The fitting arrangement on the ceiling or overhead of a block set upside down is a zone, while the fitting arrangement on the deck or floor following block turnover is considered another zone.

- On-board, for outfitting purposes refers to a division or zone for packaging work for the assembly of fittings during hull erection and subsequent launching. An ideal zone for outfitting on-board avoids the need to disperse and/or continuously relocate resources, particularly workers. In general, compartments defined by

shell, bulkhead, deck or other partitions are suitable for establishing an ideal zone for outfitting on-board. Even entire cargo holds, tanks, engine rooms, superstructure decks or weather decks can be useful zones for final outfitting of on-board stages.

Planners break down outfit work into packages by considering outfit components for all systems in on-board zones and trying to maximize the number of components fitted into on-block zones. On-block zones are then assessed to maximize the number of components that can be fitted into on-unit zones. The ultimate objective is to minimize outfit work during and after hull erection and to achieve maximum productivity.

Figure 2-8 is a block diagram of the six typical manufacturing levels for the ZOFG. The left-hand side of Figure 2-8 represents on-unit outfitting independent of hull structural zones that will eventually be incorporated into the on-board outfitting manufacturing level. The right-hand side represents the on-unit, on-block and on-board outfitting that is entirely dependent on hull structural zones. Main work flow is from component procurement to on-unit assembly/outfitting to on-block outfitting. However, emphasis is placed on the on-unit outfitting independent of hull structural zones because on-unit outfitting is the primary means for shortening the durations required for on-block and on-board outfitting.

Excluding the grand-unit level as depicted on Figure 2-8, interim products are analyzed for similarities in their product aspects and are grouped by these similarities in order to further modularize the production process, justify expensive but highly efficient facilities to enhance the production process and achieve manpower savings.

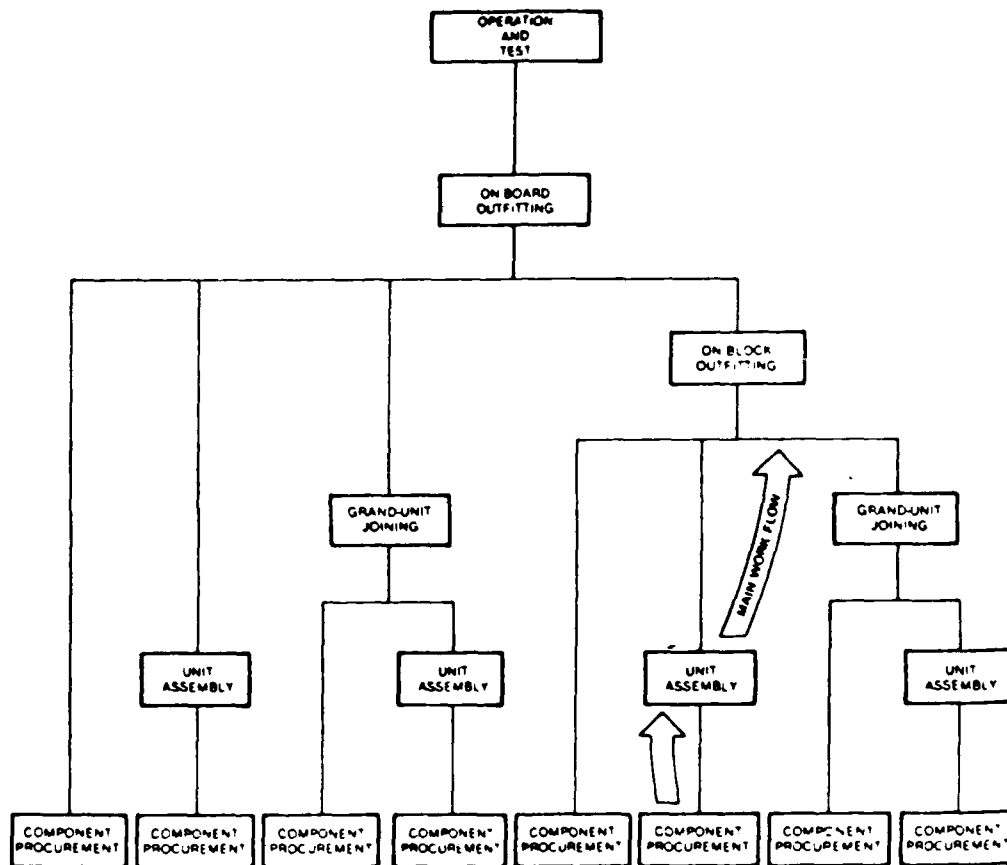


Figure 2-8. Manufacturing Levels for ZOFG.(50)

Figure 2-9 shows the typical groupings, by product aspects, for ZOFG. The horizontal and vertical combinations of Figure 2-9 characterize various types of work packages for the six manufacturing levels of Figure 2-8 and the work process lanes for outfitting work, respectively.

PLANNING LEVEL	MFG LEVEL	PRODUCT ASPECTS										CODES		
		ZONE	AREA				STAGE			ZONE	AREA	STAGE		
1	6	SHIP	DECK	ACCOMMODATION	MACHINERY	ELECTRICAL	OPERATION AND TEST			SHIP NO	SHIP NO	OPERATION CODE		
2	5	ON BOARD DIVISION	NIL	SPECIALTY/SIMILAR WORK IN SMALL VOLUME	SPECIALTY/SIMILAR WORK IN LARGE VOLUME	SPECIALTY/SIMILAR WORK BY HIGH SKILL	WELDING	NIL	ON CLOSED SPACE FITTING	OUTFITTING SIGN/ ON BOARD DIVISION CODE	BLOCK CODE	MULL ERECTION STAGE CODE		
3	4	BLOCK	NIL	SPECIALTY COMPONENTS IN A LARGE QUANTITY	SPECIALTY COMPONENTS IN A SMALL QUANTITY		WELDING	NIL	ON FLOOR FITTING	OUTFITTING SIGN/ BLOCK CODE	WORK TYPE CODE	BLOCK ASSEMBLY SIGN/ FIN		
4	3	UNIT	NIL	LARGE SIZE UNIT	NIL		WELDING	NIL	JOINING	UNIT ASSEMBLY SIGN/BLOCK OR ON BOARD DIVISION OR MACHINERY UNIT CODE	BLOCK OR ON BOARD DIVISION OR MACHINERY UNIT CODE	GRAND UNIT SIGN		
5	2				SMALL SIZE UNIT		WELDING	NIL	ASSEMBLY	BLOCK OR ON BOARD DIVISION OR MACHINERY UNIT CODE	UNIT SIGN			
6	1	COMPONENT	IN HOUSE MANUFACTURING	OUTSIDE MANUFACTURING	PURCHASING		PALLETIZING			COMPONENT CODE/ PALLET CODE	NO SIGN			
							MANUFACTURING	NIL	DESIGN AND MATERIAL PREPARATION	COMPONENT PRECISEMENT SIGN				
								NIL						

Figure 2-9. Product Aspects for ZOFM.(51)

Note that codes for interim product identification and work process lane flow control are established by zone, area, and stage for each level. "NIL" means no product aspect exists and is skipped in a process lane. "Specialty" designates deck, accommodation, machinery or electrical.

Balanced planning and scheduling and cooperation between hull construction, outfitting and painting planners

is necessary and essential as the ZOFM progresses.

See Appendix A-2 for an additional detailed description of each of the six manufacturing levels of ZOFM.

#### 2.4.3 Zone Painting Method (ZPTM)

Figure 2-10 is a block diagram of the four typical manufacturing levels for the Zone Painting Method (ZPTM).

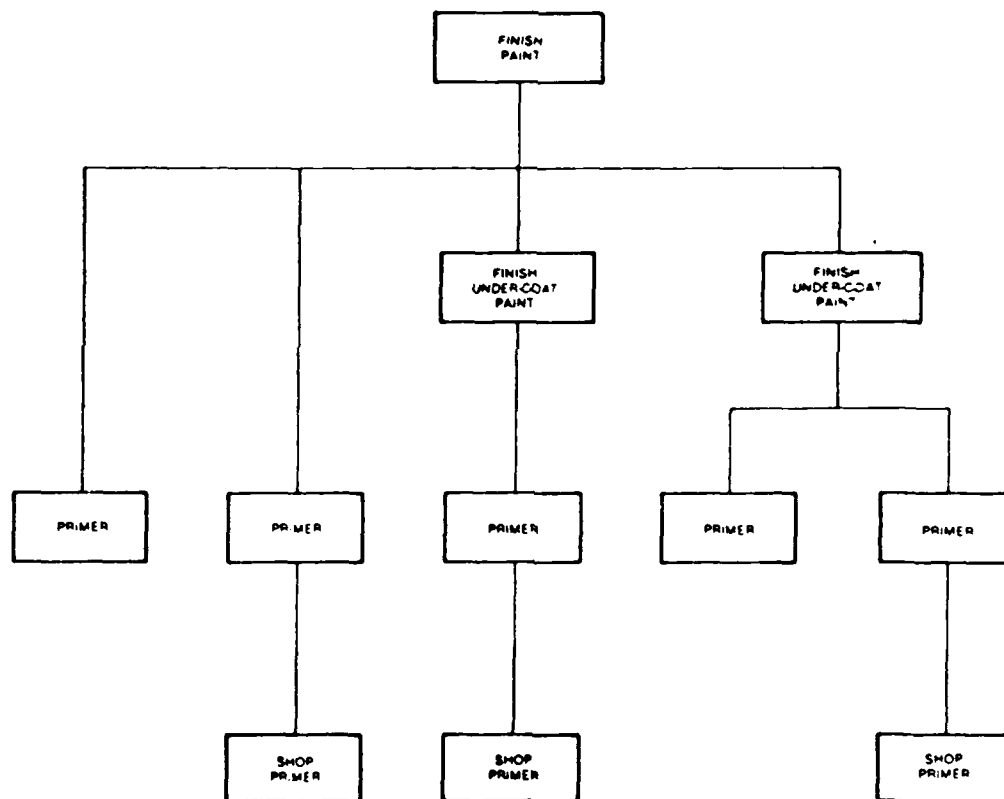


Figure 2-10. Manufacturing Levels for ZPTM.(52)

ZPTM employs manufacturing levels and product aspect classifications similar to those of HBCM and ZOFM. The traditional method of painting a ship is in a building dock

or outfit pier. ZPTM shifts the painting procedure to the appropriate manufacturing levels through integration of the painting procedure with those of the hull construction and outfitting processes. Constraints for successful application of paint are:(53)

- the painting interval between one coat and a next coat must be shorter than the allowable exposure period for the former,

- each hull block should be virtually finished in order to minimize surface preparation and painting rework caused by further cutting, fitting and welding, and

- the shop primers applied to plates and shapes should not impede efficient cutting and welding.

The final constraint requires that hull construction, outfitting and painting planners work together to shorten the durations between each successive manufacturing level shown in Figure 2-10.

The majority of painting should be completed prior to on-board painting. This is accomplished by planning paint related work among the manufacturing levels with the following objectives:(54)

- to shift the attitudes of the work from overhead to downhand or, at least, to a vertical orientation, from high to low elevations, and from confined to readily accessible places,

- to facilitate the use of temperature and humidity



controlled buildings, especially for sophisticated coatings,

- to provide safer environments without use of extraordinary devices that would encumber workers,
- to prevent rust formation and the requirement to perform associated rework,

PLANT LEVEL		MFG LEVEL		PRODUCT ASPECTS												CODES			
				ZONE		AREA		STAGE						ZONE	AREA	STAGE			
1	4	2	3	3	2	4	1	UNIT TO BE FITTED AT ON BOARD OUTFITTING	COMPONENT FITTED ON BLOCK AT ON BLOCK OUTFITTING	PAINTING ON BOARD DIVISION	PAINT MATERIAL NUMBER OF COATS TYPE OF ZONE PAINT SCAFFOLD REQUIRED OR NOT	PAINT MATERIAL NUMBER OF COATS TYPE OF ZONE PAINT SCAFFOLD REQUIRED OR NOT	PAINT MATERIAL NUMBER OF COATS TYPE OF ZONE	PAINTING		NIL	FINISH PAINT SIGN ZONE CODE	PAINT CODE NUMBER OF COATS	
														TOUCH UP					
														CLEANING					
														SURFACE PREPARATION					
2	3	3	2	3	2	4	1	UNIT TO BE FITTED AT ON BOARD OUTFITTING	COMPONENT FITTED ON BLOCK AT ON BLOCK OUTFITTING	PAINTING ON BOARD DIVISION	PAINT MATERIAL NUMBER OF COATS TYPE OF ZONE PAINT SCAFFOLD REQUIRED OR NOT	PAINT MATERIAL NUMBER OF COATS TYPE OF ZONE PAINT SCAFFOLD REQUIRED OR NOT	PAINT MATERIAL NUMBER OF COATS TYPE OF ZONE	PAINTING AFTER OVERTURNING		NIL	FINISH UNDER COAT PAINT SIGN ZONE CODE	PAINT CODE NUMBER OF COATS	
														TOUCH UP AFTER OVERTURNING		NIL			
														CLEANING AFTER OVERTURNING		NIL			
														SURFACE PREPARATION AFTER OVERTURNING		NIL			
3	2	3	2	3	2	4	1	UNIT TO BE FITTED AT ON BOARD OUTFITTING	COMPONENT FITTED ON BLOCK AT ON BLOCK OUTFITTING	PAINTING ON BOARD DIVISION	PAINT MATERIAL NUMBER OF COATS TYPE OF ZONE PAINT SCAFFOLD REQUIRED OR NOT	PAINT MATERIAL NUMBER OF COATS TYPE OF ZONE PAINT SCAFFOLD REQUIRED OR NOT	PAINT MATERIAL NUMBER OF COATS TYPE OF ZONE	PAINTING			PRIMER SIGN ZONE CODE	PAINT CODE NUMBER OF COATS	
														TOUCH UP					
														CLEANING					
														SURFACE PREPARATION					
4	1	3	2	3	2	4	1	UNIT TO BE FITTED AT ON BOARD OUTFITTING	COMPONENT FITTED ON BLOCK AT ON BLOCK OUTFITTING	PAINTING ON BOARD DIVISION	PAINT MATERIAL NUMBER OF COATS TYPE OF ZONE PAINT SCAFFOLD REQUIRED OR NOT	PAINT MATERIAL NUMBER OF COATS TYPE OF ZONE PAINT SCAFFOLD REQUIRED OR NOT	PAINT MATERIAL NUMBER OF COATS TYPE OF ZONE	PAINTING AFTER OVERTURNING		NIL	SHOP PRIMER SIGN ZONE CODE	MATERIAL CODE	
														CLEANING AFTER OVERTURNING		NIL			
														SURFACE PREPARATION AFTER OVERTURNING		NIL			
														PAINTING					
		CLEANING					SURFACE PREPARATION												

Figure 2-11. Product Aspects for ZPTM.(55)

- to minimize use of scaffolds needed only for

surface preparation and painting, and

- to levelize the work schedule throughout the entire shipbuilding process in order to avoid performance of large work volumes in the final stages of construction that could jeopardize achievement of scheduled delivery.

Figure 2-11 shows the typical grouping of paint related work packages by their product aspects. The horizontal and vertical combinations characterize the various types of work packages for the four manufacturing levels of ZPTM in Figure 2-10 and the work process lanes for painting work flow, respectively. "NIL" means no product aspect exists and is skipped in a process lane.

The need for balanced planning and scheduling and cooperation between construction, outfitting and painting planners is essential to ensure a successful ZPTM.

See Appendix A-3 for an additional detailed description of each of the four manufacturing levels of ZPTM.

#### 2.4.4 Pipe Piece Family Manufacturing (PPFM)

Pipe Piece Family Manufacturing (PPFM) uses the logic of Group Technology to systematically classify pipe pieces into families that have design and manufacturing attributes which are sufficiently similar to make batch manufacturing possible. Different pipe pieces within a family are designated for the same machines and tooling

setups in order to efficiently organize work process lanes. The greater utilization of the same tool setups and simpler material handling requirements between work stages in each work process lane along with the clear stage-by-stage progression of developing pipe pieces provides an opportunity for excellent production control. Further, the separation by stages permits the switching of work flow from one work process lane to another without diminishing production control.

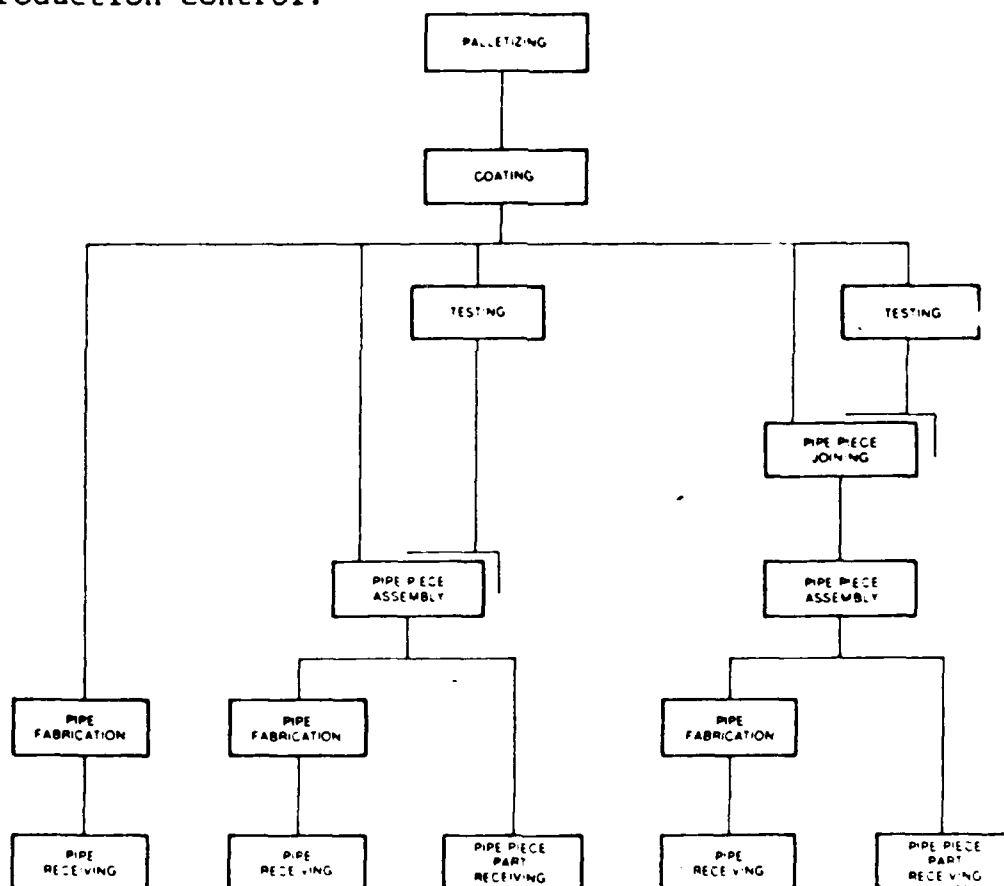


Figure 2-12. Manufacturing Levels of PPFM. (56)

PPFM is problem area-oriented as compared to the zone orientation of HBCM, ZOFM, and ZPTM. PPFM is problem

LEVEL	MFG LEVEL	PRODUCT ASPECTS						CODES			
		ZONE		AREA		STAGE		ZONE	AREA	STAGE	
1	7	PALLET		DECK INCLUDING ELECTRICAL	ACCOMMODATION INCLUDING ELECTRICAL	MACHINERY INCLUDING ELECTRICAL	PALLETIZING		PALLET CODE	SHIP NO	SHIP NO
2	6	PIPE PIECE	NIL	COATING PROCESS		COATING		NIL	PIPE PIECE NO	COATING CODE	COATING CODE
3	5					TEST PROCESS		TESTING			
4	4			PIPE MATERIAL X-RAY OR NIL BORES STRAIGHT OR BENT LENGTH				FINISHING			
5	3					PIPE MATERIAL X-RAY OR NIL MAIN OR BRANCH BORES STRAIGHT OR BENT LENGTH		WELDING			
6	2			PIPE MATERIAL PIPE MAIN OR BRANCH BORE				JOINING			
7	1					PIPE PIECE PART		MARKING & CUTTING			
		PIPE MATERIAL PIPE MAIN OR BRANCH BORE		MARKING & CUTTING							
				PIPE MATERIAL PIPE MAIN OR BRANCH BORE		MARKING & CUTTING					
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				PIPE MATERIAL PIPE MAIN OR BRANCH BORE		MARKING & CUTTING					
		PIPE MATERIAL PIPE MAIN OR BRANCH BORE				MARKING & CUTTING					
				PIPE MATERIAL PIPE MAIN OR BRANCH BORE		MARKING & CUTTING					
		PIPE MATERIAL PIPE									

cut pipe, flanges and/or elbows, sleeves, tees, etc. Even electrical conduit pieces can be regarded as pipe pieces.

PPFM is a fabrication process as compared to the assembly processes of HBCM, ZOFM and ZPTM. It consists of seven typical manufacturing levels as depicted in the block diagram of Figure 2-12.

Product aspects of PPFM are shown in Figure 2-13. Grouping of pipe pieces by problem area takes into account similarities in material specified (e.g., steel, copper, polyvinylchloride, etc.), bore size, shape, length and other factors. The horizontal and vertical combinations of Figure 2-13 characterize the various types of work for the seven manufacturing levels and work package types by work process lane, respectively. "NIL" means no product aspect exists and is skipped in a process lane. Figure 2-14 reflects the typical area subdivisions for pipe fabrication, pipe piece assembly and pipe piece joining manufacturing levels. Blank spaces in Figure 2-14 indicate that no further subdivision exists while "\*" and "\*\*\*" indicate that medium/large bore pieces to be bent and long/medium/large bore pieces can be assigned to the same area subdivision, respectively.

Within PPFM, work packages are grouped by similarities in their product aspects at all manufacturing levels in order to facilitate the modularization of the fabrication process and justify expensive but highly

LEVEL	<div> <div>PIPE PIECE JOINING</div> <div>PIPE PIECE ASSEMBLY</div> <div>PIPE FABRICATION</div> </div>					
AREA	MATERIAL	X RAY OR NIL	MAIN OR BRANCH	BORE	STRAIGHT OR BENT?	LENGTH
SUB AREA	STEEL	NIL	MAIN	SMALL	STRAIGHT	
					BENT	
				MEDIUM	STRAIGHT	SHORT
					BENT*	LONG**
				LARGE	STRAIGHT	SHORT
					BENT*	LONG**
			BRANCH			
		X RAY				
	NONFERROUS					
	PVC					
	OTHER					

Figure 2-14. Area Subdivisions of PPFM.(58)

efficient facilities that enhance the fabrication process.

Whether using manual or automated fabrication of pipe pieces, PPFM has distinct advantages that are manifested by less rearrangement of jigs and tools, less variations in the work durations and manhours required among the same type of work package, increased accuracy and significant labor savings.

See Appendix A-4 for an additional detailed description of each of the seven manufacturing levels of PPFM.

#### 2.4.5 Integration of HBCM, ZOEM, ZPTM and PPFM

As stated previously, PWBS facilitates the

integration of the HBCM, ZOFG, ZPTM and PPFM processes by emphasizing expertise in contriving and classifying ideal interim products, i.e., parts and subassemblies. HBCM emphasizes hull parts, sub-blocks and blocks that are manufactured in organized production lines, i.e., work process lanes. ZOFG provides precise zone-by-stage control of outfitting through the three basic stages of on-unit, on-block and on-board outfitting. ZPTM ensures that the painting process is coordinated with HBCM and ZOFG. PPFM provides production-line benefits for the manufacture of many different pipe pieces in varying quantities.

In the construction of a ship the zone/area-oriented processes progress independently at first and later merge. IHOP utilizes zone-oriented scheduling to control and coordinate the flow of work on the different work process lanes so that interim products are completed as they are needed to support the construction schedule. Interim products move along the various work process lanes and merge according to the schedule. The merging of interim products continues through the final erection of the ship in the building dock or on the building ways.

Figure 2-4 shows the simplified integrated processes for simultaneous hull construction and outfitting. The figure includes hull construction, outfitting, integrated hull construction and outfitting, and pipe piece manufacturing work process lanes. Zone painting would

appear as additional processes in additional sub-stages in the various work process lanes, e.g., between block assembly and on-block outfitting. Sub-stages, such as block turnover when outfitting on-block, are also omitted. For clarity "ACCOM" means accommodations, e.g., berthing, messing, laundry, etc. The ship is broken down into the following hull zones:

I - Deck, curved panel block (bow and stern sections),

II - Deck, flat panel block (midship section),

III - Machinery, curved panel block (propulsion and auxiliary machinery section), and

IV - Accommodations, flat panel block (berthing section).

Curved and flat panels refer to the structural configuration of the hull zone. In Figure 2-4 construction proceeds by the HBCM, ZOFC, ZPTM and PPFM through the various work process lanes as numbered (1-11). Interim products then merge in the IHOP work process lanes for assembly and proceed to the four hull zones (I-IV) for final erection that can be either hull erection integrated with on-board outfitting or on-board outfitting integrated with hull erection. The dotted rectangular blocks in the center and lower right of the figure represent hull erection integrated with on-board outfitting and on-board outfitting integrated with hull erection, respectively.



Figure 2-15 is a typical management organization to support integrated hull construction, outfitting and painting. The control of the basic design of a ship by the shipbuilding firm is vital to successful application of PWBS and IHOP. Since IHOP requires unprecedented collaboration between all shipyard departments, production engineers trained in PWBS and IHOP methods are assigned (designated by and "\*" in the figure) to the hull construction and outfitting departments and throughout the shops in the field to increase productivity of the entire shipyard organization. Integrated planning of ship construction is achieved by discussion, trade-offs and ultimately mutual consent.

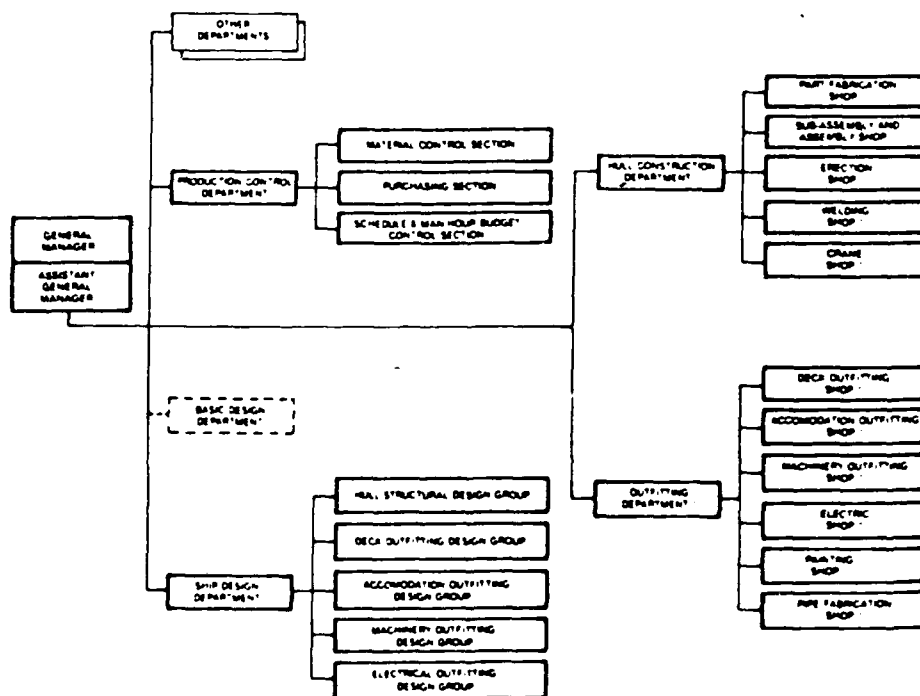


Figure 2-15. Typical IHOP Organization.(59)

In this section the manufacturing levels and product aspects of HBCM, ZOFCM, ZPTM and PPFM were described and illustrated. The section concluded with a discussion of IHOP in the construction of a ship and the management organization to support IHOP.

## 2.5 Traditional vs. Modern Shipbuilding

The final section of this chapter is devoted to a discussion of traditional shipbuilding with that of ships constructed using the Product Work Breakdown Structure and integrated hull construction, outfitting and painting methods.

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, as ventilation, piping, electrical and machinery systems were installed.(60) Traditional shipbuilding results from a systems approach for ship design. Each system has its own drawings, and outfit drawings are generally not issued until hull construction is well underway. Work package contents are relatively large which complicate any attempts to achieve uniform and coordinated work flows. Work teams usually compete with other work teams for access to a work area. This leads to redundant

temporary services, e.g., staging, welding cables, compressed-air hoses and flexible ventilation ducts, leading to unsafe working conditions. Further, most overhead work is still performed by workers reaching over their heads. All of the foregoing result in the traditional shipbuilding method being a slow, laborious, and expensive process.

The antithesis to the traditional shipbuilding method is the modern shipbuilding method utilizing PWBS and IHOP. A ship as a total system/basic design is transformed into a zone-oriented design utilizing a product-oriented design process. Detailed design is complete before construction begins. Integrated hull construction, outfitting, painting and pipe piece work process lanes are established for production of interim products leading to the erection of a ship in a building dock. Zone-oriented scheduling controls the flow of work on the various work process lanes, thus there is essentially no competition by workers for work area access. The majority of the work is done down-hand. Work packages are ideally sized for two workers to complete in a week. Finally, zone orientation provides accurate progress reporting and cost collection which is directly related to work completed. Thus, managers can forecast work remaining and resources required. All of the foregoing contribute to a shipbuilding method that is faster, less labor intensive and less expensive.

Shipbuilders who desire to remain competitive are

incorporating and adapting Product Work Breakdown Structure and integrated hull construction, outfitting and painting based on their facilities capabilities and limitations. The next chapter will look at the application of PWBS and IHOP at Bath Iron Works, Bath, Maine in the construction of the U.S. Navy's DDG-51 class ship.

## CHAPTER 3

### PWBS APPLICATIONS TO CONSTRUCTION OF THE U.S. NAVY'S DDG-51 CLASS SHIP

#### 3.1 Introduction

Bath Iron Works (BIW) has been in the shipbuilding business for over 100 years. Except for the period during World War II when BIW was involved in the modular construction of "Liberty" ships at their South Portland, Maine shipyard annex, BIW continued building ships through the 1960's using conventional methods.

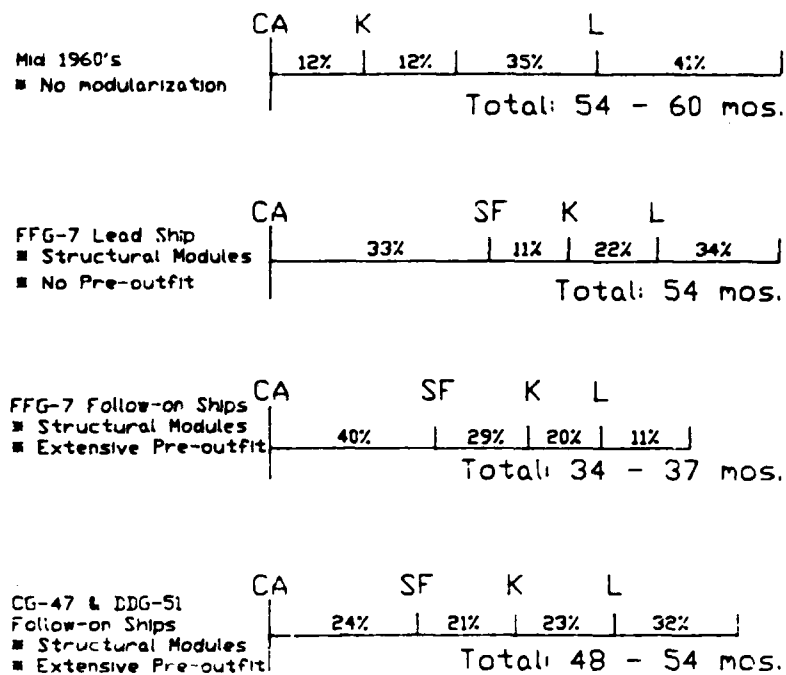
With the advent of the Merchant Marine Act of 1970's National Shipbuilding and Research Program initiatives and the development of the U.S. Navy's new FFG-7 frigate class of ship, BIW began using the modern methods of ship construction based on the Product Work Breakdown Structure (PWBS). The lead ship of the FFG-7 class, USS Oliver Hazard Perry (FFG-7), was built by structural modules using PWBS' Hull Block Construction Method as adapted to BIW's industrial facility capabilities. But, there was no pre-outfitting of the modules. Follow-on construction of

FFG-7 class ships included extensive pre-outfitting of the structural modules based on the PWBS' Zone Outfitting Method. Painting on the lead and follow-on FFG ships was completed at convenient points in the construction schedule.

BIW refined these methods throughout the construction of the follow-on FFG-7 class ships and the follow-on ships of the U.S. Navy's new CG-47 Ticonderoga class cruiser. However, the use of the methods of PWBS and integrated hull construction, outfitting and painting (IHOP) from pre-planning through contract award and subsequent delivery of a ship were not fully realized largely due to the systems based design products, i.e., drawings and material lists.

With the award of the lead ship detailed design and construction contract of the DDG-51 Arleigh Burke class of destroyer in April 1985, BIW management committed to a totally integrated approach to shipbuilding by developing design and engineering documentation to reflect an integrated construction approach.

Figure 3-1 is a percentage comparison of the BIW construction schedules for ships from the mid-1960's to the present. The size and complexity of ships as weapons systems has increased dramatically throughout the time period of Figure 3-1, thus the comparison is somewhat misleading. Yet, the 37 percent schedule reduction in the



Legend: CA - Contract Award  
SF - Start Fabrication  
K - Keel Laid  
L - Launch  
D - Delivery  
% - Percentage

Figure 3-1. BIW Comparative Construction Schedules.(61)

delivery of the FFG-7 lead ship and the follow-on ships of the class demonstrates vividly the advantages of extensive pre-outfitting of structural modules over post-outfitting. The lead ship of the DDG-51 class destroyer has a 54 month schedule from contract award to delivery. Even while the lead ship is now in construction, BIW anticipates reducing

scheduled time for follow-on ship deliveries to approximately 48 months or less.

This chapter will describe and illustrate BIW's integrated hull construction, outfitting and painting production plan and zone-by-stage construction technique for the DDG-51 Arleigh Burke class destroyer which utilizes the technology of the Product Work Breakdown Structure. The methods of PWBS as developed and refined by the Ishikawajima-Harima Heavy Industries Co., Ltd. (IHI) of Japan are compared to BIW's DDG-51 class integrated production plan and zone-by-stage construction technique. The primary references for this chapter are the Bath Iron Works Production Planning and Control Department's presentation papers "DDG-51 - Developing an Integrated Production Plan" (62) and "DDG-51 Production Plan Summary". (63)

### 3.2 Integrated Production Plan for and Zone-by-Stage Construction of the DDG-51

This section describes the Bath Iron Works (BIW) integrated production plan and zone-by-stage technique for construction of the USS Arleigh Burke (DDG-51), lead ship of a new class of U.S. Navy destroyers of the same name. The integrated production plan and zone-by-stage technique for construction of DDG-51 embraces the technology of the Product Work Breakdown Structure (PWBS) and the integrated

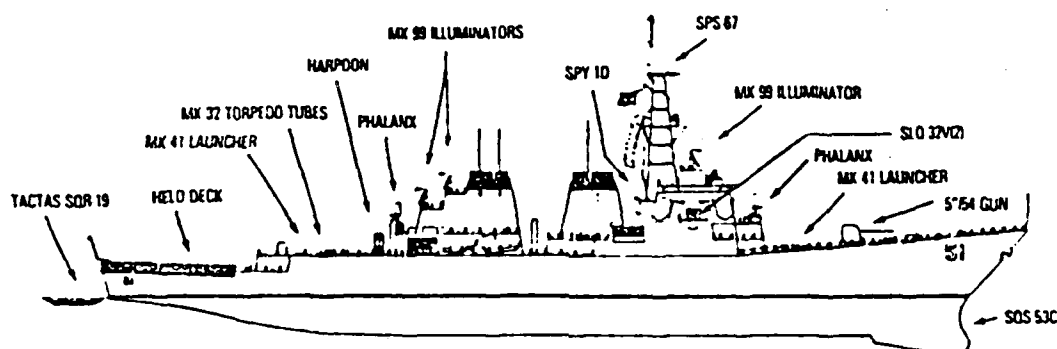


hull construction, outfitting and painting (IHOP) as adapted to BIW's industrial facility capabilities. The DDG-51 is first profiled with its general characteristics for familiarity with the ship. This is followed by detailed discussion and illustration of BIW's development of an integrated production plan for construction of DDG-51 class ships. Finally, the zone-by-stage construction technique is described.

As stated previously, BIW was awarded the lead ship detail design and construction contract of the USS Arleigh Burke (DDG-51) in April of 1985. The DDG-51 is a twin screw gas turbine surface combatant ship displacing 8150 long tons. The ship supports a multi-mission, multi-threat combat system which integrates the requirements of several weapons and sensors with the modern AEGIS radar. Figure 3-2 provides a profile and other characteristics of the DDG-51.

The DDG-51 program represented a significant "cultural" change in the process of developing engineering documentation and the management organization of BIW. Engineering documentation became more representative of the construction approach based on PWBS. Design products, i.e., construction and installation drawings, are now product-oriented, organized by structural unit or outfit design zone. Outfitting material lists are now organized into groups by product (i.e., interim product), stage, trade (i.e., pipefitters, shipfitters, electricians, etc.) and

work family (i.e., similar type of work). BIW management centralized control over all operations, consolidated and focused management/leadership within the production and engineering departments and established a formal production control organization.



### PRINCIPAL CHARACTERISTICS

<ul style="list-style-type: none"> <li>- LENGTH OVERALL = 505 FT. BETWEEN PERP'S = 466 FT</li> <li>- BEAM MAXIMUM = 66 FT WATERLINE = 58 FT 11 5/8 IN</li> <li>- DRAFT = 20 FT 8 1/4 IN</li> <li>- DISPLACEMENT = 8150 TONS</li> <li>- VERTICAL CENTER = 23.80 FT OF GRAVITY (KG)</li> </ul>	<ul style="list-style-type: none"> <li>- STRUCTURE = HS, HY 80 &amp; HSLA 80 STEELS, &amp; ALUMINUM STACKS/MAST</li> <li>- PROPULSION PLANT = 80,000 SHP., TWO SHAFTS &amp; FOUR LM 2500 TURBINES</li> <li>- ELECTRIC PLANT = THREE 2500 KW SHIP SERVICE GENERATOR SETS</li> <li>- COMMAND &amp; SURV. = MULTI-THREAT MULTI-MISSION COMBAT SYSTEM INTEGRATED WITH SPY 1-D</li> <li>- AUXILIARY SYSTEMS = ALL ELECTRIC MACHINERY, SURVIVABLE ARRANGEMENTS</li> <li>- OUTFIT &amp; FURNISHINGS = ACCOMMODATION FOR 26 OFFICERS, 24 CPO &amp; 291 ENLISTED (341 TOTAL)</li> <li>- ARMAMENT = CIWS, 5\"/&gt; </li></ul>
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Figure 3-2. DDG-51 Profile and Characteristics.(64)

In developing the integrated production plan, BIW management was guided by the following objectives to provide

an overall build strategy for DDG-51 construction:(65)

- develop a detailed construction approach by product, stage, trade and work family,
- gain production department consensus on the integrated plan prior to execution of the plan,
- set up an approach to accommodate the DDG-51's specific requirements or other considerations such as schedule and resource availability,
- support requirements for a cost/schedule control system, physical progressing of work and improved work process control, and
- support of a balanced construction approach as reflected in the units (e.g., machinery, innerbottoms, single/multi-deck), zones (e.g., combat systems, machinery, tanks and shells) and systems (e.g., machinery, combat systems, deck/habitability) of the outfitting product structure.

Requirements of the integrated production plan were:(66)

- to provide the production department with clear visibility into construction priorities and work scope,
- to provide the capability to reflect changing production goals for construction of follow-on ships,
- to provide the tool that allows the production department to control construction sequencing problems and project downstream manpower and BIW industrial facility

requirements, and

- to implement a development approach where the planning and engineering departments set the strategy for construction and the production department controls the details of construction.

To develop and execute the integrated production plan BIW established a co-located multi-functional outfit planning team with members from the planning, engineering, and production departments. The multi-functional outfit planning team was formed to accomplish the following:(67)

- establish construction goals for each product and stage,

- develop a DDG-51 class construction plan by identifying installation rationale for components, equipments and distributive systems (e.g., electrical, piping, etc.),

- review the DDG-51 class integrated production plan approach for construction and gain consensus with the production department trades, and

- refine the approach for each individual ship's specific problems such as design or material availability or construction schedule constraints prior to final release of that particular ship's production plan for construction.

With the objectives and requirements of the DDG-51 class integrated production plan established and the formation of the multi-functional outfit planning team, BIW

proceeded with the USS Arleigh Burke (DDG-51) contract by implementing a phased design approach for detailed design to support construction. BIW subcontracted the development of the DDG-51 detailed design to Gibbs & Cox (G&C) Company. Representatives of BIW's engineering and planning departments participated directly on site in New York with the G&C designers. By participating directly with the G&C designers, BIW derived the following benefits of the detailed design effort:(68)

- continuous daily contact and communications with G&C designers,
- promotion of BIW's familiarity with the design,
- G&C familiarity with the construction approach,
- ensuring that the design was compatible with BIW industrial facility capabilities,
- prudent deviations from BIW/U.S. Navy standards of design/construction when required (e.g., BIW decreased the weight of the DDG-51 by using non-standard pipe hangers that were lighter yet still met U.S. Navy shock test requirements),
- ensuring economic use of materials (i.e., minimizing non-standard or one-of-a-kind usage), and
- early, parallel (with design) material definition and control.

BIW's phased design approach was guided by the ship's specifications, contract guidance drawings and BIW standards

for ship design and construction. The phased design utilized four phases for development as follows:(69)

- functional design,
- outfit transition design,
- zone design, and
- production design.

The phased design approach provided:(70)

- separate design phases that developed the appropriate level of details required to support the next design phase,
- planning and production department inputs to the design prior to each phase of design development,
- detailed production shop planning data input to the design, and
- improved quality, accuracy and timely release of design drawings through extensive use of computer aided design (CAD).

During the functional design, system diagrammatics, space arrangements and structural scantling (e.g., frames, plates and girders) drawings were developed. The second design phase, outfit transition design, developed preliminary system arrangement drawings to support the start of design control. Zone design followed which developed detailed system arrangements in composite layers, performed interference checks of equipment and piping, and developed structural assembly unit drawings. Finally, the production

design phase provided detailed fabrication sketches for structure, piping and hull outfit as well as installation/assembly drawings.

Using the G&C zone design products for the various assembly units, BIW developed selected structural and non-structural product-oriented stage drawings. Design documentation along with the associated material definition and planning data was tailored to suit production products, work processes and stage of the DDG-51 construction. Further, the detailed design considered the limitations and needs of potential follow-on shipbuilders (e.g., Ingalls Shipbuilding of Pascagoula, Mississippi) and is essentially a "universal design".(71)

After completion of the detailed design, the multi-functional outfit planning team prepared an integrated production plan work package for every outfit design zone. The team produced the following items for each outfit design zone:(72)

- a DDG-51 class product structure pictorially describing the product, stage and material group breakdown,
- a DDG-51 class outfit work description to serve as the input document for loading the product structure into BIW's Advanced Manufacturing Accounting and Production System (AMAPS) computer program,
- marked outfit design zone composite drawings to serve as the primary guideline for routing installation

material,

- special instructions for material grouping as required to identify deviations from BIW general guidelines for material grouping, and

- outfit material work family scope estimates to verify construction schedules and work content.

Additionally, the team provided general material grouping guidelines to the design division to describe the normal material breakdown by product, stage, trade and material group.

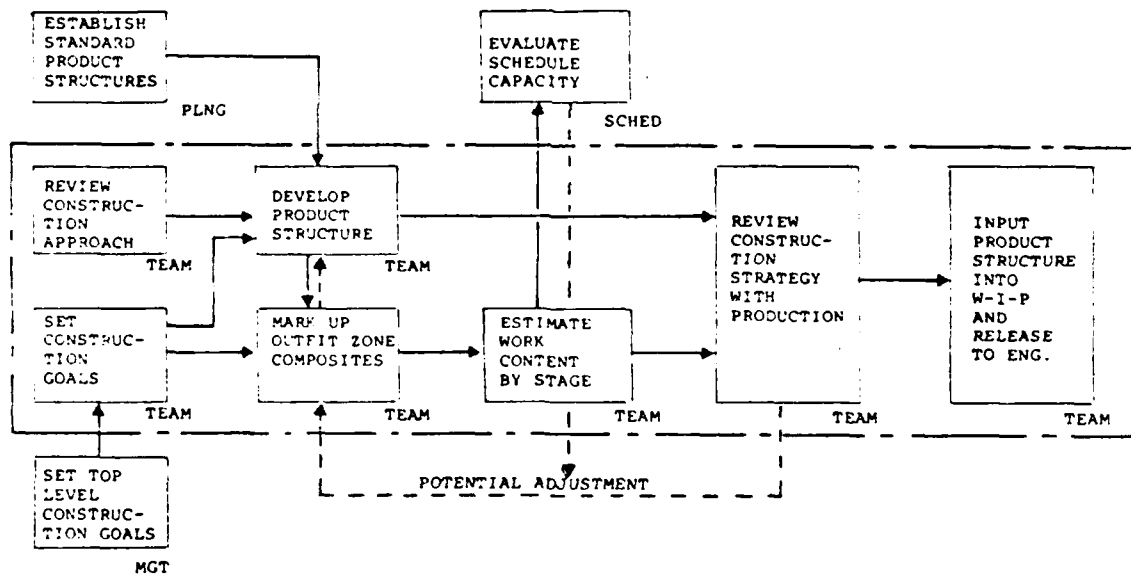


Figure 3-3. DDG-51 Class Integrated Production Plan Preparation Process.(73)



Figure 3-3 is a block diagram of how the multi functional team prepared the integrated production plan for the DDG-51 class of ship as a whole, i.e., an integrated production plan applicable to the construction of every ship of the class. With top level management's construction goals and the planning department's establishment of standard product structures (by units, zones and systems), the team set construction goals and developed the product structures. The team reviewed the construction approach (which is zone-by-stage, to be described later) as applied to the product structures. After developing the product structures, the team marked up outfit zone composite drawings based on the construction goals. Marked up outfit zones were assessed by the team for potential adjustments to the product structure. When satisfied with the marked up outfit zone composite drawings, the team provided estimates of the work content of the outfit zone by stage for evaluation of schedule capacity. If the work content was beyond the schedule capacity, additional adjustments to the marked up composite drawings and the product structures could be accomplished at that time. The reiterative process continued until the evaluated schedule capacity was considered satisfactory. At this point the integrated production plan strategy, work content summaries by stage and the construction schedule were reviewed with production department trade (i.e., shop)

representatives. Based on the comments, further adjustments were made until the trades were satisfied with the construction strategy. Product structures were then input into BIW's Work-In-Process (W-I-P) control system and released to the engineering department for final review and completion of the construction and installation drawings.

Figure 3-4 is a block diagram for adjusting the DDG-51 class integrated production plan for construction of an individual ship.

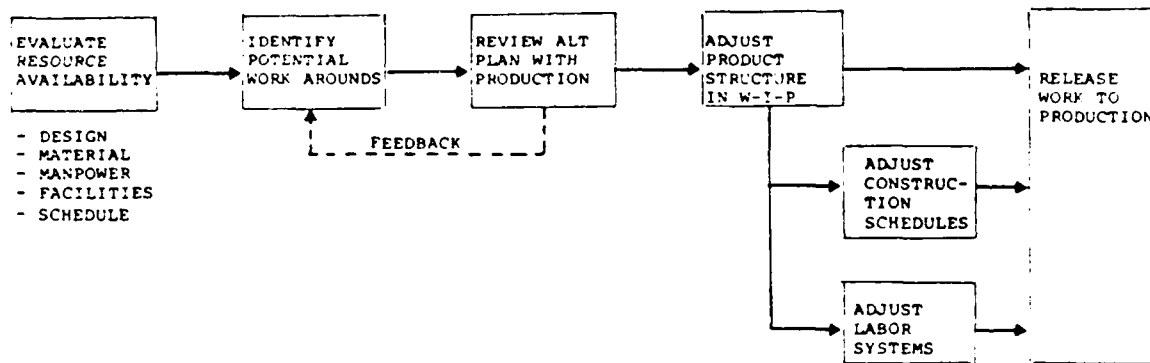


Figure 3-4. Adjusting the DDG-51 Class Plan.(74)

The shipyard production control group now has the ability to evaluate a ship specific plan based on design, material, manpower, facilities and scheduling inputs. After an evaluation is completed, potential work arounds are identified and reviewed with the production department trades. Finally, based on feedback from the trades, an

alternative integrated production plan is defined.

Adjustments to the product structure can be made in the W-I-P control system. Construction schedules and labor control systems can also be adjusted to reflect the revised work packages being released to the production department for construction of a specific ship.

BIW is using the zone-by-stage production approach for construction of the DDG-51. Zone-by-stage organizes the total production effort into precise interim products, i.e., parts and subassemblies, for fabrication and assembly. Work is assigned to specific work stations utilizing continued application of proven construction techniques such as repeating work stations and extensive multi-stage pre-outfitting. The zone-by-stage production approach facilitates the total integration of design, planning, material procurement and program management activities as defined by the integrated production plan. It establishes a one-for-one relationship between design and production work packages. Structural assembly units and outfit design zones have the same PWBS coding number with boundaries of units and zones coinciding except at transverse unit breaks. Figures 3-5 and 3-6 illustrate the design zone breakdown and structural assembly unit breaks and "super unit" boundaries, respectively.

Construction of the DDG-51 started in July 1987 with the shop fabrication of structural, outfitting and pipe

piece interim products in their associated work process lanes.

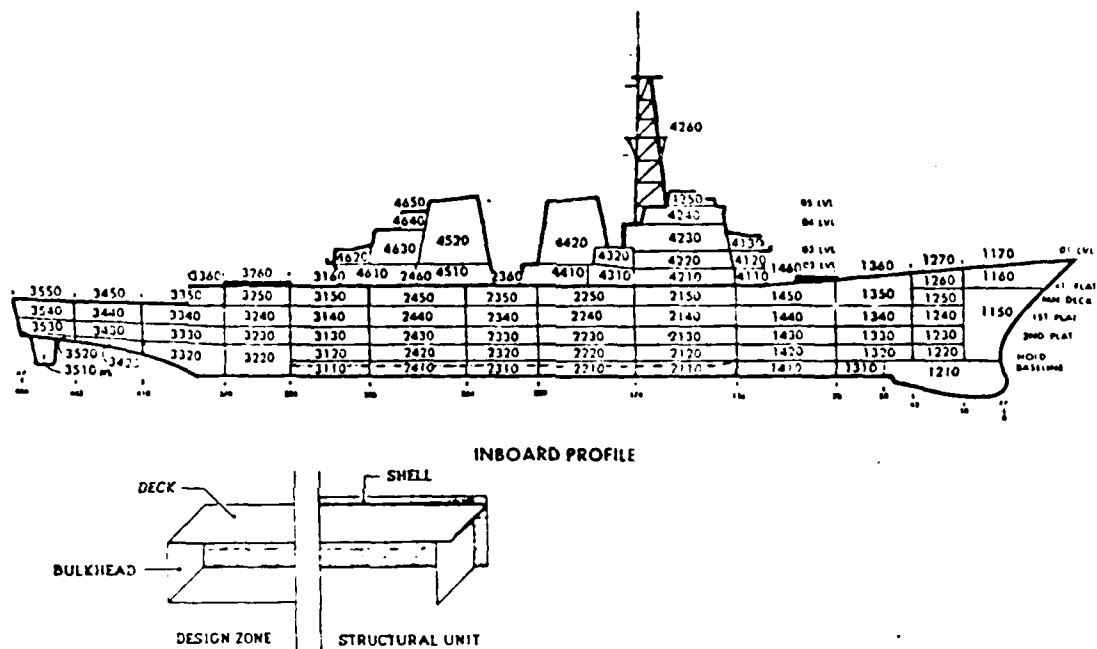


Figure 3-5. DDG-51 Design Zone Breakdown. (75)

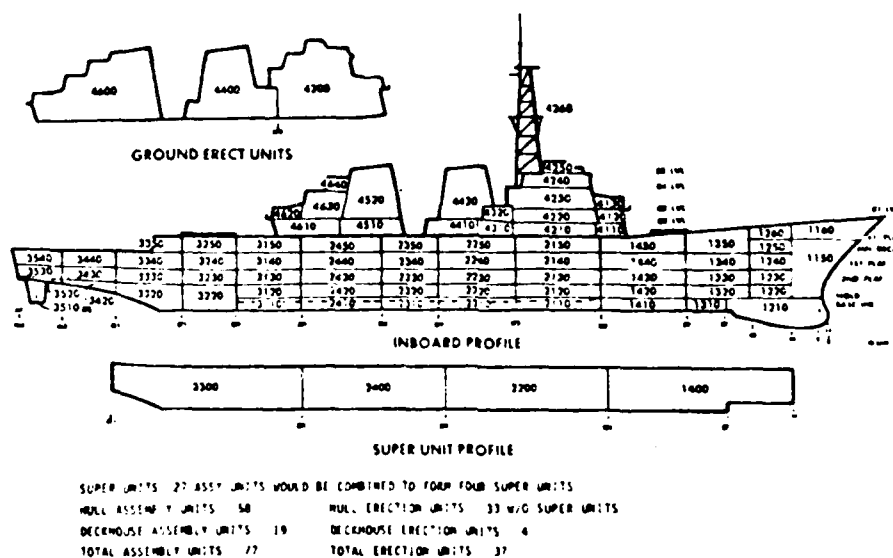


Figure 3-6. DDG-51 Structural Assembly Unit Breakdown.(76)

The work process lanes provide refined material flow lanes and dedicated work stations for specific types of interim products (e.g., curved plates, main reduction gear foundations). In-process material buffer storage areas are used to hold construction material in queues near the work

stations. Thus, material "neating" supports the production process at lower cost because of less movement of material from one work station to another. Further, use of work process lanes provides improved shop scheduling that supports unit pre-outfitting and on-board outfitting.

Production continues along the work process lanes with the joining of subassemblies to form structural assembly units (e.g., deck, machinery, accommodations). The structural assembly units are one-deck high (analogous to one floor height in the home) and form the basic building blocks for other unit assembly and the pre-outfitting process. Use of these one-deck high structural assembly units is:

- to provide continuity between design zones and assembly units,
- to provide a larger number of units that are assembled using similar procedures, and
- to provide greater flexibility for other shipyards when they construct a DDG-51 class ship.

Repeating work stations are utilized for similar groups of structural units. This use of repeating work stations yields "learning curve" benefits within a single hull due to the similarities of size and complexity as noted above. Additionally, dedicated work areas for specific types of construction products and in-process material buffer storage areas to hold the interim construction products in sequence

near the the assembly and pre-outfit work stations are utilized. Emphasis has been placed on shifting significant quantities of outfit work to earlier stages of the construction process. Therefore, outfit work packages are fabricated and assembled in parallel with structural assembly unit construction. BIW is considering the use of "super units" where feasible. The work process for these super units would entail ground erection, joining and extensive pre-outfitting of up to six lower hull assembly units in a controlled environment, i.e., in the assembly or preoutfit buildings. By using super units, BIW could shift up to 50 percent of on-board outfit work on the ship ways within these lower hull units to the final pre-outfit period that is conducted in the controlled environment of the pre-outfit building. This shift would allow significant reductions in production manhours and construction schedule by increasing cost effective pre-outfitting as compared to the more manpower intensive on-board outfitting.

It is important to note at this point that the painting of parts, subassemblies and assemblies is coordinated with the work process flow lanes as the interim products move along the flow lanes. BIW uses controlled environment buildings for the painting process for better adhesion of paint coating systems as required by the U.S. Navy. As a result of this interim painting step, it is extremely important that all primary structural work and

welded outfit attachments be completed prior to the blast and paint step.

BIW's largest crane capacity is 220 tons.

Therefore, the structural units brought to the ship ways on the shipyard's 250 ton transporter are sized according to the 220 ton limit. Structural assemblies with extensive pre-outfitting are joined on the ship ways. On-board outfitting proceeds as the ship takes form on the building ways. The following on-board outfit work is scheduled for completion prior to launch:

- completion of painting and testing of all tanks and voids,
- completion of all main electrical cable pulls to allow early activation of electrical systems,
- completion of electrical switchboard hookups to support shore electrical power through the switchboards, and
- completion of the 5"/54 gun ammunition and vertical missile launch foundations to allow early weapons loading.

Before launch, the final painting of the hull's underwater body is completed.

On-board outfitting after launch continues with the final hookups and testing of machinery, electrical, accommodation and combat systems equipments. Sea trials are scheduled at the completion of testing. After going through



the successful completion of three sets of sea trials, the U.S. Navy formally accepts the completed ship by her commissioning into the fleet.

This section described and illustrated the integrated production plan and zone-by-stage construction technique for the DDG-51 class ship.

### 3.3 PWBS/IHOP Applications at BIW and IHI -

#### A Comparison

Bath Iron Works' (BIW's) integrated production plan and zone-by-stage technique for construction of the DDG-51 class ship are based on the Product Work Breakdown Structure (PWBS) and the integrated hull construction, outfitting and painting (IHOP) methods as developed and refined by the Ishikawajima-Harima Heavy Industries Co., Ltd. (IHI) of Japan. The PWBS and IHOP methods as practiced by IHI have been modified to suit BIW's industrial facility capabilities and labor organization. Yet, the same objectives exist - to construct ships more efficiently with better quality at less cost. This section will compare BIW's integrated production plan and zone-by-stage technique for construction of the DDG-51 class ship to the PWBS and IHOP methods as practiced by IHI.

The reorganization of the BIW management organization to support the integrated production plan and zone-by-stage construction technique is similar to the

typical IHOP organization as depicted in Figure 2-15 of Chapter 2. The only exception is that the ship design department of the IHOP organization is a division within the engineering department at BIW.

BIW's formation of the co-located multi-functional outfit planning team with members from the planning, engineering and production departments for development of the DDG-51 class integrated production plan reflects the philosophy of having the entire shipyard organization involved in the planning of ship construction. The objectives and requirements of the integrated production plan for the DDG-51 as discussed in the previous section of this chapter are simply an outgrowth of that philosophy. The reiterative process used by BIW in analyzing the work packages of the integrated production plan as depicted in Figures 3-3 and 3-4 is similar to the reiterative process for analyzing IHI work packages (see Figure 2-1 of Chapter 2).

The phased design approach for detailed design of the DDG-51 was accomplished in the four phases - functional design, outfit transition design, zone design and production design. This design approach by BIW is product-oriented and similar to the product-oriented design process as depicted in Figure 2-3 of Chapter 2.

BIW's "universal design" for the DDG-51 class considered the limitations and needs of potential follow-on

U.S. shipbuilders. This universal design is unique in that it is available for use by BIW's competitors in the shipbuilding business. The U.S. Navy required that the universal design be developed as part of the DDG-51 contract. Obviously, the universal design would have to be adapted to another shipbuilder's industrial facility and labor organization, but having the basic design completed eliminates reinvention of the design by other shipbuilders and saves the U.S. government money. Further, competition forces competitive shipbuilders to become more intelligent in their application of PWBS and IHOP in order to obtain the follow-on contracts for building DDG-51 and future U.S. Navy ships.

The zone-by-stage approach for construction of the DDG-51 is synonymous with IHOP. Zone-by-stage organizes the total production effort into precise interim products, i.e., parts and subassemblies, for fabrication and assembly. The hull construction and pre-outfitting work process lanes progress independently at first and merge based on the zone-oriented schedule that controls and coordinates the flow of work. Painting occurs as the schedule directs and is completed in controlled environments. Buffer storage areas are provided for interim products near the appropriate work station that will use them. BIW "super units" would be similar to IHI's "grand blocks". All of the foregoing represent similarities to the IHOP as used by IHI. Some

differences are:

- the pipe piece family manufacturing area-oriented work process as used at IHI is a part of the outfitting work process lanes of BIW,

- BIW erects ships on building ways while IHI uses graving docks.

Figure 2-4 of Chapter 2 depicts the integrated work process lanes for construction of a typical tanker ship. By combining the pipe piece manufacturing process lane into the outfitting process lanes, the BIW integrated work process lanes would be depicted.

This chapter has described and illustrated BIW's integrated production plan and zone-by-stage technique for construction of the DDG-51 class ship. The PWBS and IHOP methods as used at BIW are comparable to those as practiced at IHI. The next chapter will look at the implementation of PWBS and IHOP at the Avondale Shipyards, Incorporated of New Orleans, Louisiana and compare the Avondale Shipyards' ship construction methods to those of BIW.

## CHAPTER 4

### IMPLEMENTATION OF PWBS AT AVONDALE SHIPYARDS

#### 4.1 Introduction

Avondale Shipyards, Incorporated (ASI) of New Orleans, Louisiana, and the Maritime Administration (MarAd), in cooperation with the Ishikawajima-Harima Heavy Industries Co., Ltd. (IHI) of Japan, conducted a technical evaluation of ASI's production operations and organization during fiscal year 1980. The goal was the development of a long-range facilities plan that would significantly improve productivity at ASI. Many recommendations for changes were offered by IHI based on the Product Work Breakdown Structure (PWBS). Not all changes could be implemented at one time because many non-shipyard related areas (e.g., vendors) outside ASI's control were affected. Therefore, ASI selected four of the IHI recommendations for implementation that would improve productivity with the least disruption to ASI. The four recommendations were:(77)

- Production Planning and Scheduling,

- Design Engineering for Zone Outfitting,
- Use of Process Lanes, and
- Production Control.

Since each of the four recommendations contained many elements, ASI selected only specific elements that:

- promised significant improvement in productivity with the least amount of disruption during the integration period,
- could be tailored for ASI and used as an Americanized version of Japanese technology, and
- were measurable so that comparisons could be made between old and new methods adopted.

An important aspect of the joint efforts of ASI/MarAd and IHI was the dissemination of information to other U.S. shipbuilders via technology transfer seminars.

This chapter describes and illustrates the implementation of the four recommendations of the IHI technical evaluation of ASI that have decreased production time, increased productivity and materially reduced costs. ASI's methods are compared to Bath Iron Works' application of PWBS to the construction of the DDG-51 class ship. The primary reference is the National Shipbuilding Research Program (NSRP) publication "Manufacturing Technology for Shipbuilding - Project Condensation".(78) This publication is based on the four technology transfer seminars conducted by ASI for U.S. shipbuilders over a period extending from

May 1982 through June 1984 and is a condensation of the four volumes of lecture materials from those four seminars.

#### 4.2 Production Planning and Scheduling

This section describes and illustrates ASI's implementation of IHI's recommendations for production planning and scheduling. The section begins with a brief discussion of production planning and scheduling practices before implementation of PWBS technology. This is followed by the detailed description and illustration of ASI's implementation of the modern methods of planning and scheduling based on PWBS. This includes contract planning requirements, organizational changes, planning for work process lanes and zone outfitting, planning instruments and procedures, production outfit planning procedures and the development of construction schedules.

Prior to the implementation of PWBS technology, Avondale Shipyards' traditional and conventional methods of production planning and scheduling for shipbuilding were normally undertaken after contract award and continued up to launch of the vessel. Production planning and scheduling was low profile and performed by the production department shops because basic planning developed by the planning department did not provide sufficient detail during development of the initial plan for construction. ASI accepted these conditions because of the lack of detailed

plans that assured production of each unit of a ship with predictable accuracy on a reliable schedule.

ASI recognized the need to improve the methods, controls and predictability of construction. After completing a study of the PWBS, ASI managers developed a basic approach to planning and scheduling that provides integration of division responsibilities/functions and specifies relationships and dependencies among hull, outfitting and facility requirements. The approach also included all requirements for construction beginning early during the marketing stage through final delivery of the ship. It further provided for top milestone meetings essential for visibility and control.

By adopting the principles of PWBS, engineering and production departments realized improvements in communications and delivery of design documentation, i.e., design drawings and material lists. Top managers now require that a construction plan be developed up-front to ensure that the engineering department is fully aware of construction methods that must be included in preliminary engineering development before contract award.

Total contract requirements are now planned in advance of hull construction at ASI by a planning team. Top management is involved with the planning team to assure the visibility of the total contract requirements and their relationship to other contracts.



Organizational changes were necessitated in order to support the PWBS technology. Engineering planning and production planning organizations changed to accommodate the IHI technology. ASI organizational changes included:(79)

- new groups established by the moldloft to implement line heating and unit control manuals (UCM),
- a new department, "Operation Services", created to handle all the various lifting devices and turning methods needed to implement work process lanes,
- reorganization of production planning into two divisions - Hull and Outfit Planning,
- new groups of skilled burners formed to create a "line heating crew" for shaping shell plates,
- an accuracy control team of four people under a qualified engineer to improve dimensional control, and
- a new production department group, Shop Planners, formed to reinforce the work process lane concept at the shop level.

Planning for work process lanes provided a method to control and handle materials quickly, efficiently and economically. By incorporating work process lanes, ASI management was able to control the detailed work process lane schedules based on volume and quantity of work for each process lane work center. A direct result of use of work process lanes is that work center cost and efficiency could now be determined by management.

Use of work process lanes require the hull units of a ship to be divided into categories based on size, shape, weight and method of construction. ASI categorized hull units into six basic categories:

- flat panel units (e.g., mid part, double bottom, side shell, longitudinal bulkheads),
- curved shell units (e.g., aft and fore part side shells),
- superstructure units (e.g., pilot house, decks, flats, bulkheads),
- large and heavy modular units (e.g., fore and aft peak tanks, engine room innerbottoms),
- engine room and inner bottoms, and
- special units (e.g., rudders, skegs, bulbous shapes, stern castings).

This categorization of hull units allows planning department, shop and work center planners to develop basic and detailed planning and scheduling for construction of a ship. Further, hull unit categorization provides for orderly flow of materials and determination of where a component will be constructed, construction time and production control through a particular work process lane. Figure 4-1 illustrates the categories of hull units. These hull units are further divided into assemblies, subassemblies and partial subassemblies down to individual pieces.

ASI established planning control guidelines to support the work process lane concept and overall planning development. These guidelines included:(80)

- determining present work platen loading,


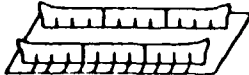

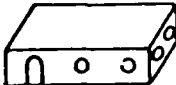


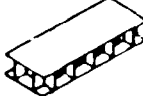
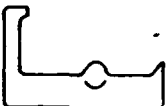

CATEGORY	UNIT NAME	SHAPE
No. 1 FLAT PANEL UNIT	MID PART DOUBLE BOTTOM SIDE SHELL LONG BHDS	 
No. 2 CURVED SHELL UNITS	AFT & FORE PART SIDE SHELLS	
No. 3 SUPERSTRUCTURE UNITS	DECKS FLATS BULKHEADS HOUSES ETC.	 
No. 4 FORE PEAK AFT PEAK	LARGE AND VERY HEAVY 3 DIMENSION UNITS	
No. 5 ENGINE ROOM INNER BOTTOMS	LARGE AND HEAVY INTRICATE UNITS	
No. 6 SPECIAL UNITS SKEGS RUDDERS ETC.	BULBOUS SHAPES STERN CASTINGS	 

Figure 4-1. Categories of Hull Units.(81)

- establishing key construction dates,
- dividing the hull into units and developing an erection sequence for the units,
- categorizing hull units,
- establishing weight calculations by hull unit (rough calculation),

- loading work platens to capacity,
- establishing the erection schedule,
- preparing assembly schedules,
- ensuring key construction dates are compatible with the assembly and erection schedules, and
- refining weight estimates and all schedules as detailed drawings become available.

ASI's basic procedures for hull planning are:(82)

- to divide a hull into units to meet the best requirements of the erection sequence, and
- to assemble each unit with high productivity and quality using the PWBS.

ASI considers the following in the basic planning for hull unit production sequence and unit erection:(83)

- the choice of the first units to be put down (as a rule these are the engine room units to allow complicated outfitting to start early in construction),
- the capacity of the cranes in the assembly and erection areas of the ASI facility,
- the ASI area facilities in the assembly yard,
- maintaining the accuracy (i.e., not bending out of shape) of the unit when turning the unit for the best position for welding, which is normally the downhand position,
- the lengths of fittings and welds required on each unit which will determine the length of stay at each

construction work station on the work process lane,

- the required on-unit outfitting, and

- the size of the unit, which should be determined and adjusted with the outfitting schedule so that the merits of both hull construction and on-unit outfitting can be achieved.

Figure 4-2 is a flow diagram for planning and scheduling of hull unit construction. Lead hull planners begin development of the construction methods by hull unit early during the key planning stage. This is followed by hull unit planning, unit assembly planning, etc., along with scheduling and associated material requisitions through the working stage. Units are broken down into partial subassemblies to the minimum level, i e., an individual part. The detailed breakdown is completed early in the preliminary stage and assigned to a work process lane. Issue of detailed drawings allow refinement of the work process instructions which are contained in the Unit Control Manual (UCM) and preparation of the unit parts list (UPL) prior to final issue of drawings to the moldloft.

Zone outfitting, as practiced at ASI, utilizes three types of zones based on PWBS technology:

- package unit pre-outfitting,
- on-unit outfitting, and
- on-board outfitting.

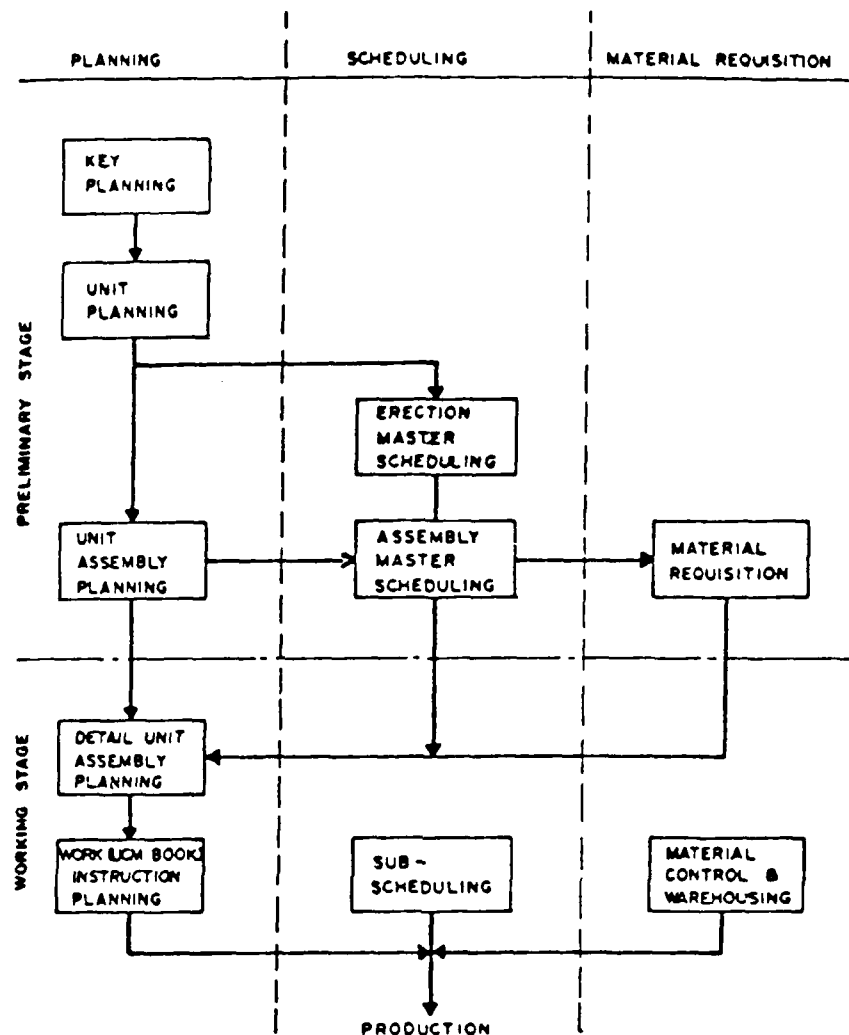


Figure 4-2. Flow Diagram for Hull Unit Construction.(84)

In package unit pre-outfitting components/parts are assembled into package units that do not require temporary reinforcements or supports to maintain the package's stability and rigidity. Two types of package units are produced - machinery and zone. Machinery package units are assemblies of machinery that is combined with adjacent components such as the foundation, pipe pieces, valves, gratings, ladders and supports. Zone package units

(sometimes called pipe package units) are assemblies of pipe pieces and pipe racks.

On-unit outfitting is the outfitting of various components on the ceilings, floors and inner bottoms of a hull unit before hull unit erection.

On-board outfitting is the outfitting of:

- items or package units too heavy or big to load onto the unit prior to erection,
- fragile components and water-vulnerable components that are impractical to be fitted on-unit (e.g., joiner panels, insulation and other items subject to damage from handling and weather), and
- connection components between package and hull units (e.g., pipe makeup pieces, cable, etc.)

Figure 4-3 is an illustration of the three types of zone outfitting.

ASI goals to support outfit planning are:(85)

- to maximize the pre-outfitting of components of all systems in zones of the on-board divisions into sub-zones of hull units,
- to maximize the assembling of components of systems in the zones of on-board divisions into the sub-zones of machinery and pipe package units,
- to minimize the amount of outfitting after hull erection,
- to orient assemblies requiring steel fitting and

foundation work to an easy work position assisted by gravity rather than opposing gravity, avoiding difficult overhead work, and

- to transfer work environments from closed, narrow, high or unsafe locations, to open, spacious, low and safe locations, and also to facilitate transportation of materials.

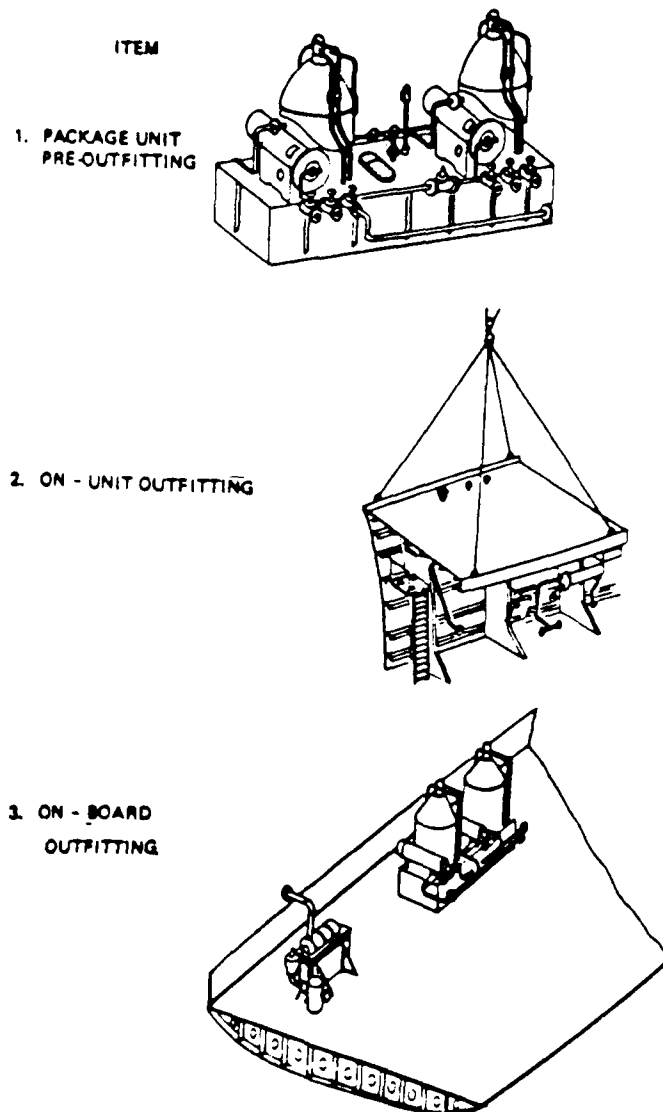


Figure 4-3. Three types of Zone Outfitting. (86)



ASI's approach to hull planning and scheduling begins before contract signing by the use of the ASI document entitled "Job Description At Each Stage in New Hull and Outfitting Engineering Procedure at ASI" which is referred to more simply as the "Job Description At Each Stage Schedule".(87) This document provides the guidelines to ASI planners in the development of a construction plan and schedule. Figure 4-4 is a simplified flow diagram of a hull and outfitting engineering schedule. It consists of five stages:

- marketing stage,
- preliminary stage,
- key plans stage,
- engineering drawings stage, and
- moldloft stage.

These stages for total contract requirement resolutions and work process lanes development are phased to ensure sufficient lead time is provided to all departments of the ASI organization in order to complete their required work within each stage.

Early during the marketing stage meetings are conducted to review marketing stage development. Items of importance that are required during the marketing stage include contract specifications, ship's lines drawings and contract drawings. Midship sections, scantling plans, shell expansions and machinery arrangements/diagrammatics are

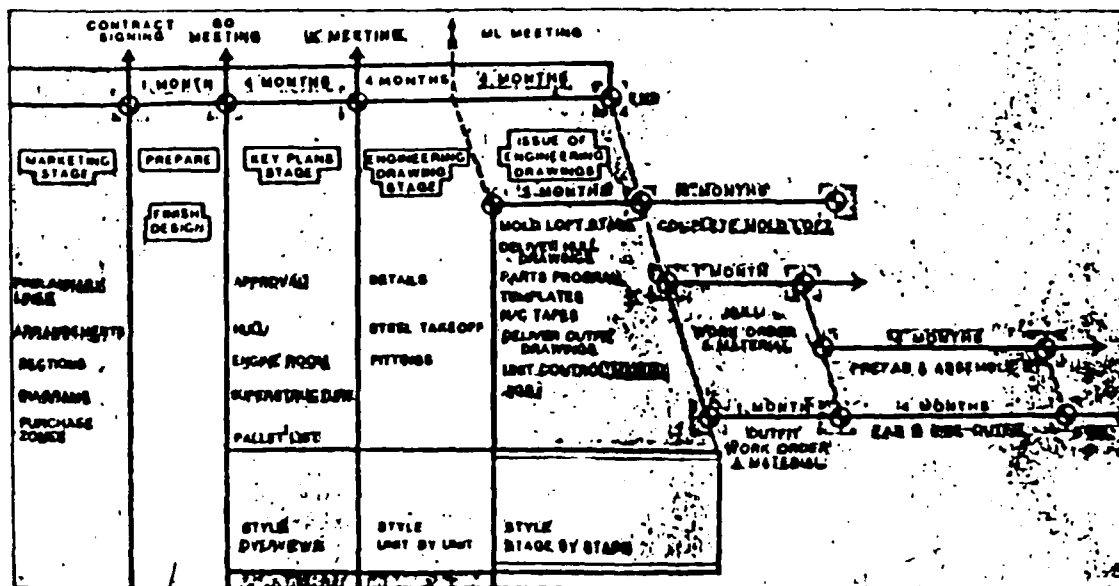


Figure 4-4. Hull and Outfitting Engineering Scheduling.(88)

used for outfitting and hull planning development. All of the technical data and engineering calculations that are developed for the ship are important to follow-on engineering stages. Procurement specifications for material and parts are started for resolution at contract signing. Preliminary hull unit arrangements are developed prior to contract signing.

A "GO" meeting is held one month after contract signing with the engineering and planning departments and top management to assess development of the preparation stage. Items discussed at this meeting include labor and material estimates, purchase requests for major items (e.g., reduction gears), budget, adjustment of ship specifications

and drawings, basic hull unit arrangement, drawing issue schedule, faired ship's lines drawings and preliminary outfit pallet lists (pallet refers to specific products gathered together in one place for outfitting).

Four months after the "GO" meeting at the end of the key plan stage the "K" meeting is held with the same personnel in attendance as the "GO" meeting. By the time of this meeting key plans (e.g., frame body plan, fore, hold, engine room, aft and superstructure construction plans) are completed and reviewed. A pallet schedule is issued for all outfitting material for on-unit and on-board outfitting. Seventy to seventy five percent of the required steel for construction is requisitioned during this period. The order of sequence of unit erection is established and charted on an erection sequence master diagram. The erection sequence is ordered to provide an evenly distributed grouping of units that fall into a regular pattern of erection. This ordered sequence of erection allows the use of the same workers and equipment in a predetermined, production line type of erection (analogous to the automobile assembly line). Further, this allows for the efficient movement of workers performing the same jobs from one ship to another in a multiple ship construction effort. Unit Breakdown Summary Sheets are completed and sent to the mold loft along with the unit parts list (UPL). Unit Breakdown Summary Sheets contain the routing and work process instructions for

producing a unit from the start of construction to blast and paint. This document takes into consideration the following:(89)

- classification of parts (i.e., partial subassemblies, subassemblies, assemblies, pieces),
- lines and type of weld connections,
- beveling of welded edges,
- extra stock for adjustment,
- provisions for accuracy control, and
- pre-outfitting and blast and painting.

The Unit Breakdown Summary Sheets are the work process instructions for the hull engineers and draftsmen to make the detailed unit-by-unit plans that are sent to the mold loft.

The "ML" (mold loft) meeting is held four months later. Top management reviews the schedule of hull drawings issue to the mold loft. Unit Control Manuals (UCM), which are work process instruction booklets, are started by the moldloft with receipt of the hull drawings along with the unit parts list (UPL).

The mold loft stage follows for the next three months. Near the end of the three months the production department starts to receive parts programming, templates, numerical control tapes for machining of parts, outfitting drawings and jig instructions.

The next eight months between the "ML" meeting and

laying of the keel of the ship includes the following:

- completion of mold loft work,
- issue of work process orders and assembly of material, and
- fabrication, subassembly and assembly of hull units by the production department.

Assembly stage planning involves the planning for joining of assemblies from the various work process lanes into larger and complete hull units. The grouping of these hull unit assemblies is by category, as described previously, and is dependent on the supporting facilities of the construction area (e.g., flat jigs for flat units, fixed and pin jigs for curved units) and the construction time in the work process lane as determined by outfitting lengths, welding lengths and pre-outfitting.

Erection stage planning and scheduling is the key to the previous steps because any delays at this stage can affect the ship's launch and delivery dates. Planning for erection involves the joining of hull units together in zones according to an erection schedule. Erection stage planning is divided into a series of substages that include:(90)

- unit erection,
- shipwrighting,
- scaffold erecting,
- main structure fitting and welding,

- substructure fitting and welding,
- cleaning,
- internal visual inspecting,
- scaffold removal,
- air test of tanks and compartments,
- painting of coated tanks,
- water testing of tanks, and
- completion.

Shipwright, rough fitting, finish fitting, welding, inspection, testing and painting crews perform the work in the substages as scheduled for each tank, zone and subzone.

The planning and scheduling of the paint coating system is done in conjunction with the hull and outfitting stage planning. The goal is to accomplish as much surface preparation and undercoating as possible during the hull unit construction and prior to the ship's erection. The PWBS' Zone Painting Method is used by ASI.

Production outfitting planning is done concurrently with the hull planning and scheduling. Outfit planning at ASI describes the planning and scheduling necessary to install, test and operate all the components of a ship, excluding the hull. The Production Outfit Planning team develops the information, documents and schedules required to implement zone outfitting. Outfit planning begins early before contract signing. Interaction between outfit planners, hull planners, engineering planners and other

departments of ASI is essential to successful outfit planning.

Outfit planning is done in two stages - precontract and contract. During the contract negotiating period, i.e., precontract, the Production Planning Department establishes the major milestone dates for keel laying, launch and delivery of the ship. Production Outfit Planning uses these dates along with the contract specifications, midship and scantling plans, general equipment and machinery arrangements and key systems diagrams for starting outfit planning development. The ship is divided into large purchasing zones for advance ordering of material and equipment. The Production Outfit Planning and Engineering Outfitting divisions decide on the preliminary applications of machinery and pipe package outfitting units and on-unit/on-board outfitting.

After contract signing, the Production Outfit Planning team develops the detailed zone arrangement and preliminary pallet lists. A Master Milestone Construction/Zone Outfitting Schedule is then developed and finalized after review by Production Operations, Production Engineering and Production Planning via joint meetings. Top management reviews and approves the Master Milestone Construction/Zone Outfitting Schedule. Production Outfit Planning begins publication of the "Unit Outfitting Lists of Material" and "Zone Outfitting Lists of Material".

Production Engineering then issues work process orders for fabrication, sorting, collection and the packaging of outfit materials. As construction of hull units and zones proceed the on-unit, package unit, and on-board outfitting proceed in parallel based on the schedule. Production Outfit Planning issues a Compartment Completion and Machinery Testing Schedule to closeout all compartments and test all tanks and machinery prior to the final delivery of the ship.

ASI uses three basic types of schedules:(91)

- master yard schedule,
- long-term schedule, and
- short-term schedule.

In developing these schedules ASI ensures participation by all levels of the shipyard organization. This is to ensure that schedules are realistic (i.e., within the capability of the facility and personnel), recognized (i.e., the schedules are official documents of top management and can be changed only by top management) and resolute (i.e., the schedules are regarded by all employees as unwavering work guides).

The master yard schedule defines the long-term scheme of the construction for all contracts in progress and being negotiated. It contains the following items for each contract:

- keel laying,
- launching, and



- delivery.

Additionally, it contains projected erection and assembly production weight per month and accumulative erection and assembly weight curves for each ship. Finally, the master yard schedule provides management with the following:(92)

- an understanding of the necessary manhours and required assembly areas,
- the ability to make adjustments to the assembly platform (i.e., platen) capabilities, and
- the ability to adjust manpower to support ship construction schedules.

The long-term schedule functions are:(93)

- to support smooth relationships between the production stages (e.g., the relationship between fabrication, pre-fabrication and assembly stages), and
- to level-load the work volume at each assembly stage.

With the long-term schedule established the short-term (monthly, weekly, daily) schedule is established. Production shop planners use the long-term schedule to prepare the short-term schedule based on the capacities of each machine and work process area. These short-term schedules are issued regularly to:(94)

- give an understanding of the work progress status for prior and subsequent construction stages, and
- indicate exceptions to normal routine working

methods for particular items.

Short-term schedules provide precise material and production process control, accuracy/safety/manufacturing method control and production efficiency control. Shop planners control the daily schedule, looking ahead six to eight weeks. These short-term schedules are used by the foremen to determine their weekly work load in order to maintain the schedule dates.

This section described and illustrated the implementation of Production Planning and Scheduling at ASI. Past planning and scheduling prior to implementation of the IHI technology was briefly discussed. This was followed by a detailed description of ASI's implementation of Production Planning and Scheduling that is based on the PWBS.

#### 4.3 Design Engineering for Zone Outfitting

This section discusses and illustrates the implementation of ASI's design engineering for zone outfitting which is based on IHI's PWBS technology. The section begins with the impact of zone outfitting on the overall engineering design effort. This is followed by the effects of zone outfitting on ASI's engineering department. The section concludes with ASI's philosophy that must be adopted by an engineering organization that is going to implement zone outfitting techniques.

The implementation of design engineering for zone

outfitting had an effect on all engineering department sections and disciplines. Six major innovations were:(95)

- modifications to the engineering approach (fabrication/installation drawings are no longer system oriented),

- more data displayed on each drawing,
- the number of drawings produced significantly increased,

- establishment of a package unit team,
- schedule adherence becomes critical, and
- the overall work scope increased.

The modifications to the engineering approach consisted of shifting the detailed design for engineering drawings from a systems orientation to a zone orientation. During the detailed design phase, ASI uses three basic design processes:

- final system level design,
- selection of equipment, and
- fabrication and installation design.

The time periods for the first two processes greatly overlap while the last process follows the other two. Also, the first two processes for detailed design are essentially the same as those for conventional shipbuilding since they are system oriented. It is the fabrication and installation design process that incorporates the PWBS technology because it is zone oriented. The zone oriented drawings describe

the units to be built. Designers configure the systems within each unit to simplify installation. This is accomplished by having the production department provide detailed, written, unit-by-unit descriptions of how each unit will be built. Engineering and production department personnel meet weekly to discuss the best timing for installation of each system within a unit with joint agreements reflected in the engineering drawings. Fabrication drawings (e.g., pipe details, vent ducting) are developed unit-by-unit and are part of the installation drawing package. Components are identified by coding to reflect the unit the component will be installed in and the stage of assembly or subassembly of that unit. This in turn relates to the building site where the installation will take place. Thus, the installation drawings are a material control document as well. ASI installation drawings are produced in booklet form for the production worksites.

More data are displayed on installation drawings. Because the engineering department is intimately involved with the methods and sequences of the production department (via the Unit Breakdown Summary Sheets), the various engineering sections (e.g., mechanical, electrical, etc.) must reflect the methodology of production in the drawings they produce. Thus, the information required by production relative to when equipment and components are to be installed must be shown on each drawing. Material control

is reflected on these drawings. Additionally, work that was left for field accomplishment (i.e., not done on a unit in a work process lane) is now reflected on the installation drawings (e.g., 3/4" to 2" diameter small bore pipe).

The zone outfitting approach requires use of approximately twice as many drawings as the conventional method. The major reason for this increase is in the method for presenting piping work because there are about three times as many piping plan drawings for a zone outfitted ship. A piping arrangement drawing that applies to two units is accompanied by two pipe detail drawings and two lists of material, one for each unit. Pipe is fabricated by unit and stored by pallet code to await installation.

Zone outfitting necessitated some organizational changes within the engineering department. A Package Unit Team was established in the mechanical engineering section for developing complete machinery package units for machinery spaces. The team details equipment foundations, gratings, handrails, piping and instrumentation.

Under zone outfitting each drawing has a more critical issue date since work on a portion of a system within a unit is closely knit into the pre-outfitting plan. Therefore, the Engineering Planning and Scheduling section must effectively plan the issue of drawings.

Zone outfitting has increased the scope of the engineering department's work and consequently the

engineering department's costs. However, it has been demonstrated by ASI that this increase has been more than offset by savings in manhours and time in production.(96) Further, ASI expects to reduce engineering department costs as the shipyard becomes more familiar with the zone outfitting method.

Some of the effects of zone outfitting on the engineering department include:(97)

- the engineering effort must begin and be completed earlier than in conventional design methodology,
- the role of the engineering and production departments as partners must be stressed; thus, meaningful dialogue is essential,
- engineering drawings are developed as units, not as systems,
- structural "key plans" are used in drawing development,
- material on drawings must be "pallet coded", and
- advance ordering of long-lead material is emphasized.

"Engineering essentially complete" (98) is the phrase ASI uses to illustrate the overall goal at the time of starting prefabrication. The mutual engineering effort is far greater in zone outfitting and must be accomplished in a far shorter time. Figures 4-5 and 4-6 illustrate the impact of unit outfitting on overall scheduling and the intensity

of engineering effort as compared to conventional methods.

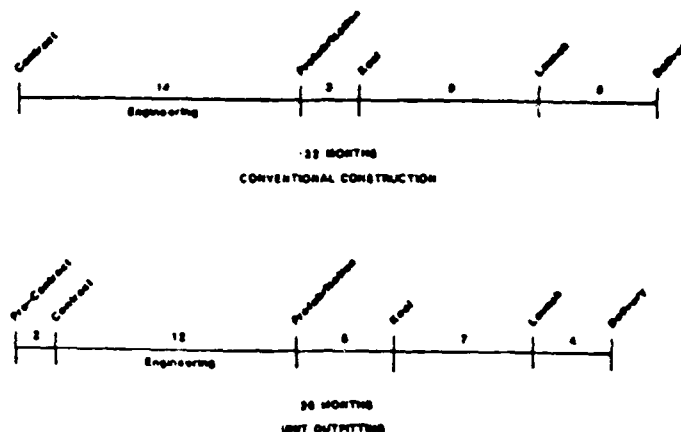


Figure 4-5. Impact of Unit Outfitting on overall scheduling.(99)

#### CONVENTIONAL CONSTRUCTION

- Total Engineering Manhours - - - - - 350,000
- Percent Complete At Pre-Fabrication - - - - - 80%
- Months From Contract To Pre-Fabrication - - - 14
- Manhours Per Month (avg) Prior To Pre-Fabrication- 15,000

#### UNIT OUTFITTING

- Total Engineering Manhours - - - - - 500,000
- Percent Complete At Pre-Fabrication - - - - - 80%
- Months From Contract To Pre-Fabrication - - - 12
- Manhours Per Month (avg) Prior To Pre-Fabrication - 33,333

Figure 4-6. Intensity of Engineering Effort.(100)

Therefore, the precontract effort must maximize the definition of design parameters, contract requirements, construction methods, scheduling and long lead time material needs so at the time of contract signing the intense engineering effort can begin. The engineering effort that

follows typically results in 80 percent completion of design drawings at the time of start of prefabrication.

Unit outfitting places an increased burden on the engineering and planning activities of ASI because of the early intense engineering effort. A clear and concise understanding of the design task is realized through the engineering and production departments working closely as partners.

As discussed, zone outfitting at ASI requires that the engineering drawings be developed for units vice systems. Structural key plans are used in drawing development. The key plans are detailed scantling plans that show all aspects of the ship's structure. The primary purpose of the key plans is to provide engineering and production with a document that depicts details related to the ship's major structural components for their use. For example, the Hull Drafting section uses the data shown on the key plans to develop unit drawings. The Piping section uses the key plans to locate major interferences of piping runs. Production Planning uses the key plans to aid in the unit breakdown development. Material on drawings are pallet coded to reflect when material or components are to be installed in the outfitting process. The Material Control section of production uses the pallet code information to assemble all material to be installed at a particular time and routes the material to its exact location for



installation. Figure 4-7 is an example pallet code.

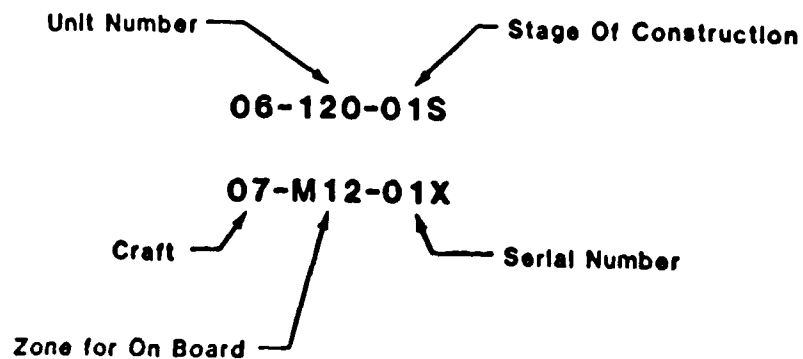


Figure 4-7. Example of Pallet Codes.(101)

The advance ordering of long lead time material is critical to implementation of zone outfitting. The design effort requires early receipt of vendor information and the zone outfitting production schedule requires earlier-than-conventional receipt of material and equipment.

ASI's implementation of zone outfitting has been most satisfactory. The philosophy that must be adopted by an engineering organization that is going to implement zone outfitting techniques could be condensed into the following key items:(102)

- START ASAP, before contract signing, if at all possible,
- COMMUNICATE with Production from the start,
- MATERIAL SPECIFIED AND ORDERED ASAP: Have vendors ready to go upon contract signing. The sooner purchase

orders are issued, the sooner vendor information required for drawing development will be received,

- PLAN AND SCHEDULE ENGINEERING WORK: With all the drawings needed and the short amount of time to do them, a good plan and a good schedule are crucial, and

- REMEMBER TO MAKE IT HAPPEN: With zone outfitting there is no time to sit around and wait for the "other guy" to call. If something is needed, get it.

This section discussed the implementation of design engineering for zone outfitting at ASI. The section included discussions of the impact and effects of zone outfitting implementation on the ASI engineering department organization and concluded with ASI's philosophy for implementation of zone outfitting techniques in any engineering organization.

#### 4.4 Process Lanes

This section discusses and illustrates the implementation of work process lanes at ASI. The work process lanes concept is discussed first. This is followed by the requirements for implementation of work process lanes and a discussion of the physical aspects of ASI's work process lanes. The section concludes with a discussion of facility capacity loading at ASI.

The work process lanes concept categorizes and separates similar kinds of work. Work centers are formed

and specifically designed to efficiently and economically produce these similar kinds of work. Further, the work process lanes establish a "learning curve" efficiency because the same workers in the same work centers are doing repetitive types of work every day which is supported by an organized and efficient flow of material.

Using the PWBS technology as the basis for work process lane implementation, ASI emphasized the following requirements for the evolution of work process lanes:(103)

- the physical aspect of the process lanes within ASI's industrial facility,

- hull unit breakdown,
- material flow,
- coding systems,
- cost system,
- planning systems,
- scheduling systems, and
- control systems.

Discipline and attention to detail in every phase of design and construction and to all interim products were the factors that have led to successful development and execution of the process lanes system at ASI.

Developing the process lane schedule provided ASI management the controls and visibility for determining work center cost and efficiency during production. ASI emphasizes the flexibility and control afforded by work

process lanes to achieve uniform work flow within each work center and coordinated outputs from all work centers. ASI's Production Planning monitors and reports schedule progress on each work center. Shop planners provide daily detailed attention to each work center's progress. Additionally, Production Engineering monitors and reports work center cost and actual manhour cost per ton versus projected cost per ton efficiency allowing management to take corrective actions as necessary to improve productivity.

In implementing work process lanes ASI analyzed the physical shipyard platform layout required to support the new concept. Area requirements, crane capacities and material flow were major considerations for implementation. The volume of work for each hull category and the method of construction of each hull unit was considered in the selection of assembly, subassembly and fabrication work sites. The percentage of hull weight for a typical tanker ship by hull category was calculated. Using the foregoing, ASI selected and laid out the assembly platforms, i.e., work process lanes, for construction of each of the six hull unit categories along with the prefabrication work process lanes. As in the PWBS technology, the process lanes start out independently in production of interim products and merge at appropriate points as required by the production plan and schedule. Figures 4-8, 4-9, 4-10 and 4-11 represent the work process lanes at ASI for prefabrication, subassembly

and assembly stages of construction.

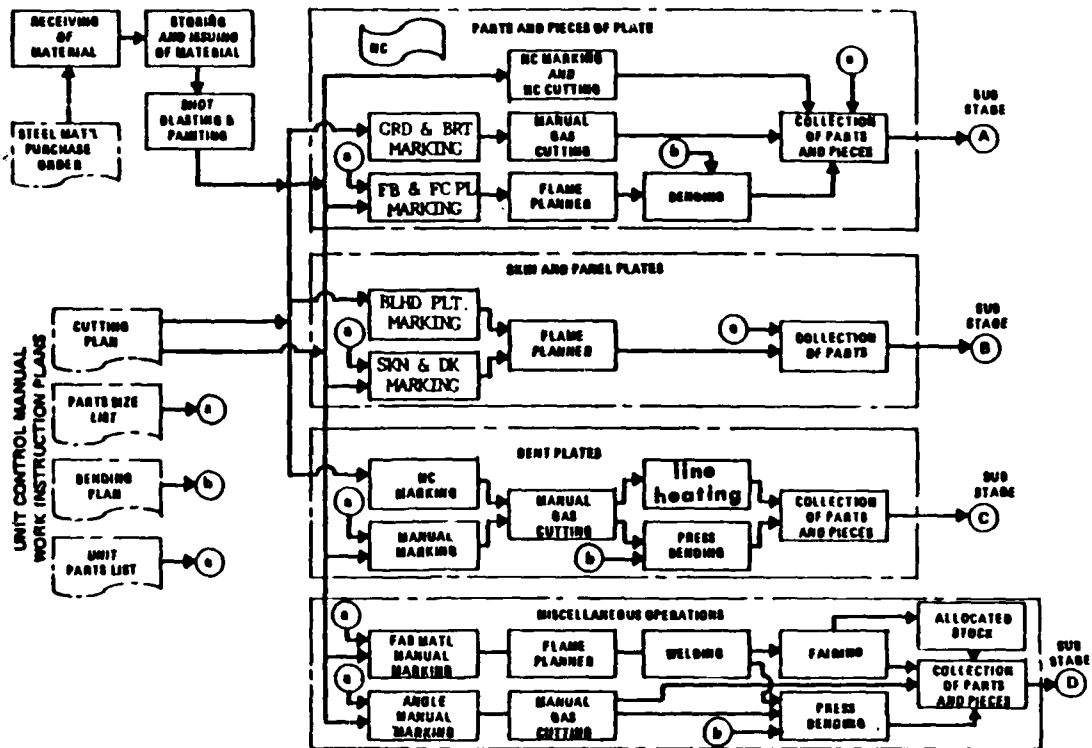


Figure 4-8. Prefabrication Process Lane. (104)

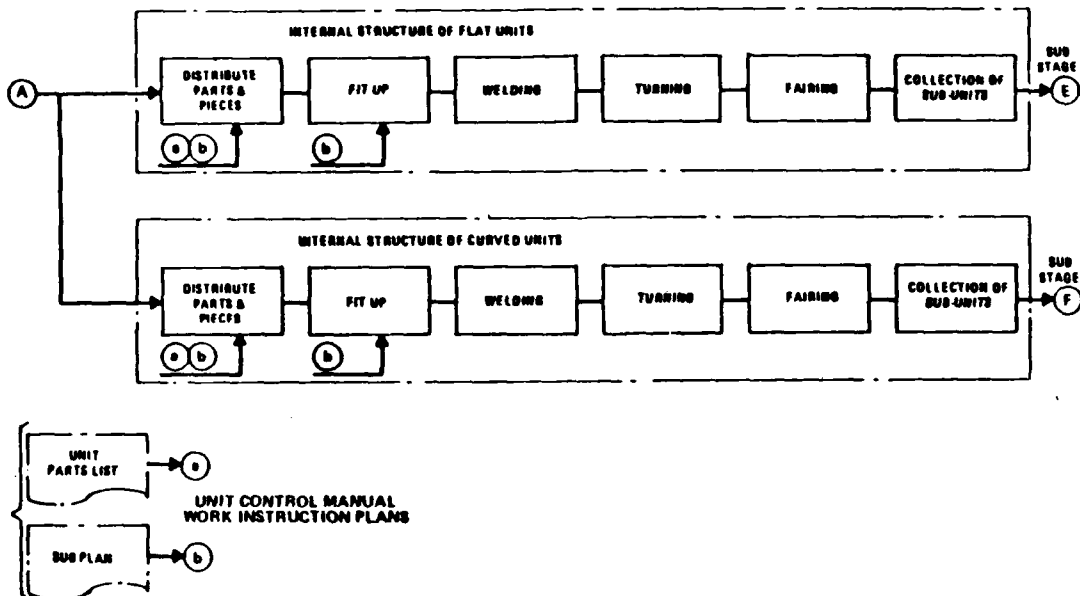


Figure 4-9. Subassembly Process Lanes. (105)

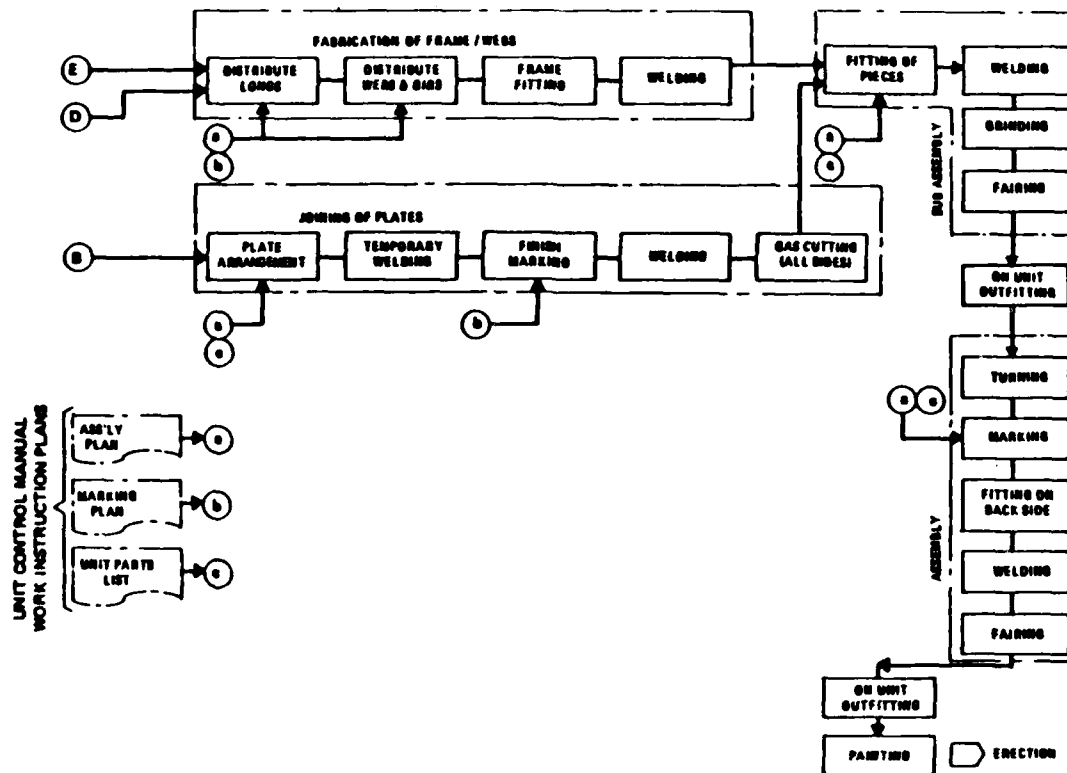


Figure 4-10. Assembly Process Lanes (Flat Units).(106)

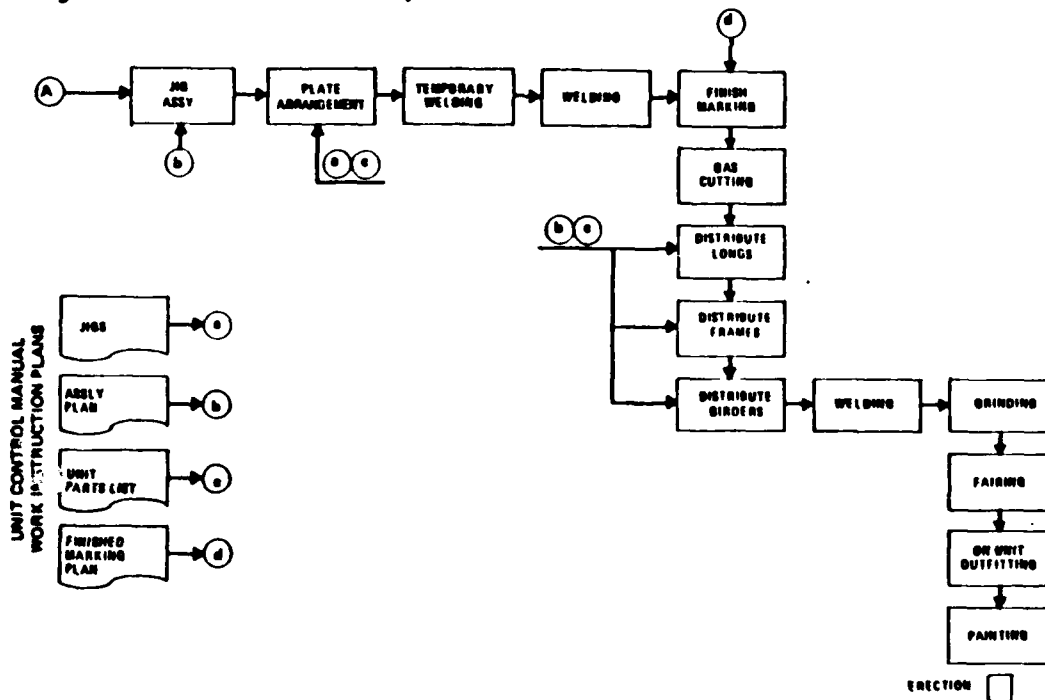


Figure 4-11. Assembly Process Lanes (Curved Units).(107)

Avondale plans current and prospective workloads to ensure full industrial facility capacity (4,200 short tons per month) without creating overloads within the facility. Work currently in progress and known future work is plotted according to key events of the contracts using erection tonnage as a base line. Additionally, multiple or multi-hull contracts scheduling considers the erection sequence and category of hull units to be erected for each hull in order to load the ASI industrial facility to capacity.

The objective is to prevent the overloading of assembly work centers, which is the ASI control point of hull construction, while remaining as close as possible to the total shipyard assembly capacity of 4,200 short tons per month. The task of level loading and placing fabricated components/hull units in storage or work queues is the means to that end. This detailed level of planning is a constantly changing process which creates the flexibility to accommodate variations between actual progress and the project plan and to absorb the impact of additional work created by new contract signings.(108)

This section discussed and illustrated the implementation of work process lanes at ASI. The concept of process lanes and the requirements for implementation along with the physical aspects of ASI's work process lanes was discussed. The section concluded with a discussion of ASI

facility capacity loading.

#### 4.5 PRODUCTION CONTROL

This section describes the implementation of production control at ASI. The role of the Production Engineering Department in implementing production control is discussed. Discussion of material control follows. The establishment of the Accuracy Control Department concludes the section.

The implementation of work process lanes required changes to ASI's production engineering policies and techniques. The Production Engineering Department document, Production Estimate, that production engineers use as a guide for issuing budgets to the various work centers changed format. The format incorporates a cost code system for each work center that now allows management to monitor work center efficiency and job cost. This cost code system is a result of the categorization of hull structures into similar kinds of work and the subsequent work centers developed to produce the similar kinds of work, i.e., the work process lanes.

ASI's production engineers are experienced in solving production problems of the various trades and disciplines. The three sections of Production Engineering - Hull, Outfitting and Mechanical - have common responsibilities which are:(109)



- to prepare direct labor cost estimates,
- to prepare work orders for the various manufacturing process lanes in accordance with the Production Plan and the various hull, outfitting, machinery and testing schedules,
- to assist the planning engineers in the preparation of schedules and information regarding the most economical and practical manufacturing areas in which to place construction,
- to monitor the production progress of the ship and to ensure its completion in a timely and economical manner,
- to work closely with the Design Engineering Department to ensure that economical production techniques and practices are used,
- to study cost reports to stay abreast of the direct labor expenditures,
- to prepare cost projections as may be required by management,
- to monitor work as required to determine production efficiency and to verify work standards, and
- to make and/or propose changes in the production effort where cost overruns are projected.

Production engineers provide the leadership and initiative by persuading all ASI departments to give their best efforts toward maximum efficiency.

Work orders are prepared by production engineers and

are management's primary instrument for production control. The work order initiates production work and monitors cost, work progress and efficiency. Work orders are of two forms - shop order and work order. Shop orders are used primarily for packages of prefabrication work to be accomplished at a specific machine (e.g., a lathe or numerical control burning machine) within the work center. Work orders are used primarily for work that has progressed to fabrication, assembly, erection or installation. The work order serves as the vehicle for accumulating daily direct labor costs expended at each work/cost center.

Copies of work orders released to work centers by production engineers are transcribed by key punch operators into the ASI computer data base. Actual direct labor manhours charged to the work order are entered directly into the computer data base by work/cost center superintendents at local terminals which are located throughout the shipyard. Manhour charges are accumulated by the computer and are printed out on sheets and forwarded to the cognizant production engineer for monitoring of progress (percent completion) and cost (actual vs. estimated). The printouts can be sorted in various ways to facilitate overall job monitoring. For example, "active" work orders, i.e., those in progress, can be listed on one report while all "closed" work orders can be put on another report. These various reports are used to monitor individual work order efficiency

and progress, overall percent completion and projected work remaining. Actual accumulated manhours and actual completed tonnage are plotted against targeted values determined prior to construction for continual monitoring of actual cost of work compared to the budget.

A Hull Efficiency Report is generated for every work process lane work center and is updated and reviewed weekly by the production engineers for control purposes. Based on the overall actual direct labor manhours spent by a work center versus those issued, a manhour per ton efficiency being experienced is computed. This document also serves as the source document for subsequent forecasting analyses.

The benefits of the work/cost center data collection effort are:(110)

- fewer work orders to prepare, issue and monitor,
- less paperwork for field supervision and Data Processing to manage, and
- the manhour per ton efficiency ratio thus established for each category is usable for all construction of similar types of ships.

Management can thus observe the progress of the job and its projected cost and determine the overall efficiency of the work center and its supervision.

The total engineering and production effort is a finely meshed system which centers around, contributes to, and coordinates with the work process lane concept. From

initial planning, drawing preparation, scheduling, work center loading, budgeting, order release, cost control, to cost analysis and projections, the systems all complement and enhance the work process lanes concept.

Material control is an essential activity in productive shipbuilding. Material costs account for approximately 60-70 percent of all shipbuilding costs. Thus, material control directly affects handling costs and storage area along with the potential disruptions to the production schedule and the cost of material. The implementation of material control based on IHI technology has created significant cost savings for ASI.

In conjunction with implementation of work process lanes ASI developed a plant layout for the effective flow of material. The objective was to minimize the number and length of routes and elimination of any unnecessary movements (e.g., backhauls, crosshauls, transfers, etc.). Factors affecting material flow are:(111)

- external transportation facilities,
- the number of items to be moved,
- the number of hull units to be produced,
- material storage locations, and
- location of manufacturing service areas.

ASI performed a material flow analysis for past methods and process lanes. The past method analysis employed flow diagrams (i.e., yard maps on which material

flow routes were indicated) to determine distances involved. Using comprehensive logs of material movements and mobile crane servicing area reports, "From-To" charts were constructed to tally and sum the number of pieces moved between each of 39 origins and destinations. Plates and structural and fabricated pieces between platens and other sites were the materials tracked. The Process Lanes committee rerouted the same materials to the work sites of the process lanes. Figures 4-12 and 4-13 compare the past and process lanes methods.

DESCRIPTION	PAST METHOD	PROCESS LANES	DIFFERENCE
Pieces/week	9,174	6,571	- 2,603
Pieces To - From Fabrication Storage	5,584	532	- 5,052
Percent To - From Fabrication Storage	60.7	8.0	
Trips/week	170.5	145.2	- 25.3
Pieces/trip	53.8	45.3	- 8.5
Trips/week To - From Fabrication Storage	81.5	9.3	- 72.2
Percent To - From Fabrication Storage	47.8	6.4	

Figure 4-12. ASI In-Yard Material Movement.(112)

An overall savings of approximately 30 percent has been realized in the handling of steel as a result of the implementation of the work process lanes concept. The appropriate cost savings are evident for manpower,

	PAST METHOD	PROCESS LANES	DIFFERENCE
Material Handling Distance week (Miles)	66.6	43.4	23.2
Material Handling Distance To-From Fab. Storage	39.3	5.9	33.4
Percent M. H. Distance To-From Fab. Storage	60.0	13.6	
Trips / week from Plate Shop	42.3	62.3	(20.0)
Trips/week from Platen 18	5.3	11.4	( 6.1)
Trips/week from A-Crane Storage	31.3	7.7	23.6
Distinct Moves	177	119	58

Figure 4-13. ASI In-Yard Material Movement.(113)

equipment and energy reductions from the 30 percent reduction in handling of steel.

Unit construction and zone outfitting enhances material control because it involves smaller increments of material to be handled with much less storage time. ASI now requests and procures material to the unit and zone level. The basic instrument for zone outfitting is the pallet and the associated pallet coding for grouping of outfit material as a package. The pallet for zone outfitting consists of:(114)

- a work package or kit of outfitting material to be installed in the hull of a ship in a specific place at a specific time during construction,

- the manhours allowed for its installation which is approximately 100 manhours, one week's work for two men, and

- a pallet number which identifies the material.

ASI has implemented an overall Material Marshalling Plan to record, expedite, pallet and deliver the various categories of material to the work process lanes. The categories include:

- prefabricated steel,
- fabricated preoutfitting items (e.g., manholes, water tight doors, deck fittings, foundations),
- warehoused (purchased) materials,
- raw piping material input to the pipe shop, and
- fabricated pipe from the pipe shop.

ASI has found that unit and zone outfitting is a valuable management tool with respect to material control. It provides the capability to review material needs in smaller, more controllable packages and in a much more timely manner. The returns from a reduction of lost material alone has been significant. The savings obtained from standardization of pieces including lifting lugs and padeyes greatly reduces the overall cost.

During the manufacture of parts and assemblies

absolute accuracy in dimensions and tolerances and shape is an unrealistic goal. Measurements show that there is no such thing as absolute accuracy because variations from specified dimensions of a work piece are always measurable and normal. ASI formed the Accuracy Control Department to establish realistic goals within the normally achieved ranges of accuracy within which the Production Department could operate. Thus, the Accuracy Control Department established realistic goals in the area of accuracy and developed proper procedures and controls to achieve the accuracy goals. Implementation of successful accuracy control requires that a job be completed right the best way possible the first time.

ASI's Accuracy Control Department activities spans all phases of ship construction from the burning of plate and structurals to the final erection. The activities are divided into three categories:

- checks,
- controls, and
- statistics.

Checks are utilized to isolate specific problems of inaccuracy that require controls, monitor construction to ensure proper controls and identify and assist in minimizing human errors. At ASI accuracy control engineers spend a great amount of time measuring. Measuring is slow, methodical, painstaking and tedious yet necessary. Careful



measurements that are methodically recorded and statistically analyzed allows development of proper controls. As an example, a web frame is measured before butts are welded, after butts are welded and after stiffeners and face plates are welded. These measurements are used to determine shrinkage factors that will be used in the cutting of the plating that makes up the web frame and to develop assembly procedures that minimize deformation of the component.

The development of controls results in an improved product. ASI employs controls in master/datum lines, burning procedures, uniform shrinkage factors and construction and erection procedures.

Master/datum lines are water lines, frame lines or buttocks that are laid out on various components of hull units to facilitate building and erection of the units. These lines are on the design engineering drawings in the Unit Control Manual. The mold loft produces steel tapes of these lines for transfer to structural elements.

Pieces of units, subunits, and partial subunits require accurate burning procedures or else there will be rework. Tolerances of 1/32" in burning are not unlikely.

Uniform shrinkage factors are required for accurate burning. Specific shrinkage factors are developed for all components of a hull unit. Data gathered and analyzed by accuracy control engineers are used to determine shrinkage

factors for each type and stage of construction.

Construction and erection procedures require proper fitting and welding sequences in the fabrication and erection of a ship's hull units. The key is to prevent deformations due to the high heat introductions caused by welding. Erection is the principal beneficiary of the use of control lines. When laid out with predictable accuracy, control lines are an invaluable aid in setting units at erection.

The accuracy control engineer is really a statistical engineer. He determines the goals and the controls to achieve accuracy. Accuracy control engineers at ASI use basic statistical principles for calculating mean values and standard deviations of measurements taken from all work processes involved with shipfitting work (i.e., marking, cutting, bending and welding steel) to develop standards for shrinkage factors and excess material allowances. Unit histories are developed for the manufacture of specific units. These histories are simply the methodical recording of all problems encountered in the production of a specific unit from the design engineering stage through final welding and handling of the unit.

Checks, controls and statistics are thoroughly interrelated with one another. Checks identify inaccuracies but cannot alone improve end products. Controls result in improved products for immediate work but not for future

work. Statistics provides the potential for improvements to future work. By implementing these three accuracy control procedures and forming the Accuracy Control Department, ASI has dramatically improved the quality of the hull units and the erected ships produced.

This section has described the implementation of production control at ASI. The Production Engineering Department's role in production control, material control and accuracy control were discussed.

#### 4.6 Bath Iron Works and Avondale Shipyards -

##### A Comparison of PWBS Applications

Avondale Shipyards, Incorporated (ASI) and Bath Iron Works (BIW) have studied and incorporated the basic technology of the Product Work Breakdown Structure (PWBS). ASI and BIW modified the technology to suit their industrial facility capabilities. This section will compare important aspects of BIW's integrated production plan and zone-by-stage technique for construction of the DDG-51 class ship to ASI's implementation of production planning and scheduling, design engineering for zone outfitting, work process lanes and production control for ship construction.

Both ASI and BIW management changed their organizations to support the PWBS technology. Both shipyards centralized control over all operations, consolidated and focused management/leadership within the

production and engineering departments and established a formal production control organization.

BIW's integrated production plan and zone-by-stage construction technique for the DDG-51 class ship is synonymous with ASI's production planning and scheduling, design engineering for zone outfitting, work process lanes and production control. The minor differences in the terminology may be somewhat confusing, but the objectives for shipbuilding remain the same.

Both BIW and ASI plan the construction of ships as early as possible in order to provide the opportunity for all shipyard departments to have a hand in the development of a production plan and schedule. Up front detailed design via a phased design approach and the associated design documentation, i.e., drawings and material lists, are product oriented in order to support the work process lanes concept of PWBS as practiced at both shipyards. Work process lanes development at both shipyards is designed around the facilities' physical plant layout. Material flow is routed to buffer storage areas in small amounts organized in pallets to support hull unit construction and outfitting in sequence on the work process lanes. Repeating work stations along the work process lanes are utilized because the same workers in the same work centers do repetitive types of work everyday. Production controls are used to provide visibility to upper level management on how

construction of a ship is progressing physically and financially. Computer data bases are used to support production control by generating various reports for management. Accuracy control is used to eliminate rework.

All of the foregoing along with their details in this and the previous chapter have one and only one goal in mind - to construct ships more efficiently with better quality at less cost.

This chapter has described and illustrated the implementation of production planning and scheduling, design engineering for zone outfitting, process lanes and production control at Avondale Shipyards, Incorporated. The chapter concluded with a comparison to Bath Iron Works construction techniques. The next chapter will describe a proposed implementation of PWBS to the modular construction of nuclear power plants.

## CHAPTER 5

### A PROPOSED IMPLEMENTATION OF PRODUCT WORK BREAKDOWN STRUCTURE TECHNOLOGY TO MODULAR CONSTRUCTION OF NUCLEAR POWER PLANTS

#### 5.1 Introduction

The development and refinement of the Product Work Breakdown Structure (PWBS) at the Ishikawajima-Harima Heavy Industries Co., Ltd. (IHI) of Japan and PWBS' implementation at Bath Iron Works (BIW) and Avondale Shipyards, Incorporated (ASI) and other shipbuilders worldwide has significantly increased their productivity and quality while decreasing the cost and length of time associated with construction of a ship. The competitive market place required that shipbuilders shift from conventional to these modern methods based on PWBS in order to survive and remain competitive.

The nuclear power plant construction industry has pursued various methods of modularization on a modest scale (e.g., modularizing subsystems, prefabrication of pipes and

pipe ways, condenser units).(115) But, these modest attempts have not significantly reduced capital costs and time for construction and licensing. Modularization would relieve the conventional construction method's congestion problems at the work sites and reduce construction costs and improve quality considerably.(116)

Any implementation of PWBS technology for modular construction of nuclear power plants should start with an in depth study of IHI's methods of PWBS and a technical evaluation of the construction facilities' production operations and organization by IHI representatives. Based on the technical evaluation's list of recommended changes for implementation of PWBS technology, the facilities' management would have to analyze each of the recommended changes for their applicability and/or modification and then establish a plan of action and milestones for implementation. Funding for the study and technical evaluation could be jointly shared by the facility and the U.S. government with the stipulation that technology transfer seminars be conducted for other companies in and out of the nuclear industry.

This chapter describes a proposed generic implementation of the PWBS technology at a nuclear power facility (the acronym "NPF" is used for conciseness) for modular construction of a nuclear power plant. The implementation is based on the BIW and ASI application and

implementation of IHI PWBS technology at their respective shipyards. The assumptions for construction of the nuclear power plant are:

- the NPF will construct and complete testing of all nuclear and non-nuclear modules at its facility;
- the NPF will subcontract all site preparation work for nuclear and non-nuclear module installation;
- the NPF will complete the joining and testing of nuclear and non-nuclear modules at the construction site; and
- after acceptance, the utility will load nuclear fuel and conduct all the associated nuclear power operational testing required for final full power licensure.

The first section discusses the planning and scheduling necessary for construction. Next, the design engineering necessary to support module outfitting is discussed followed by the application of integrated work process lanes. A discussion of the methods for controlling module construction and at-site joining of modules concludes the chapter.

## 5.2 Planning and Scheduling for Module Construction

This section describes the proposed implementation of planning and scheduling for modular construction of a nuclear power plant. The following items are discussed:



- management organization,
- total contract planning,
- planning for work process lanes and module outfitting,
- production outfitting planning procedure, and
- development of construction schedules.

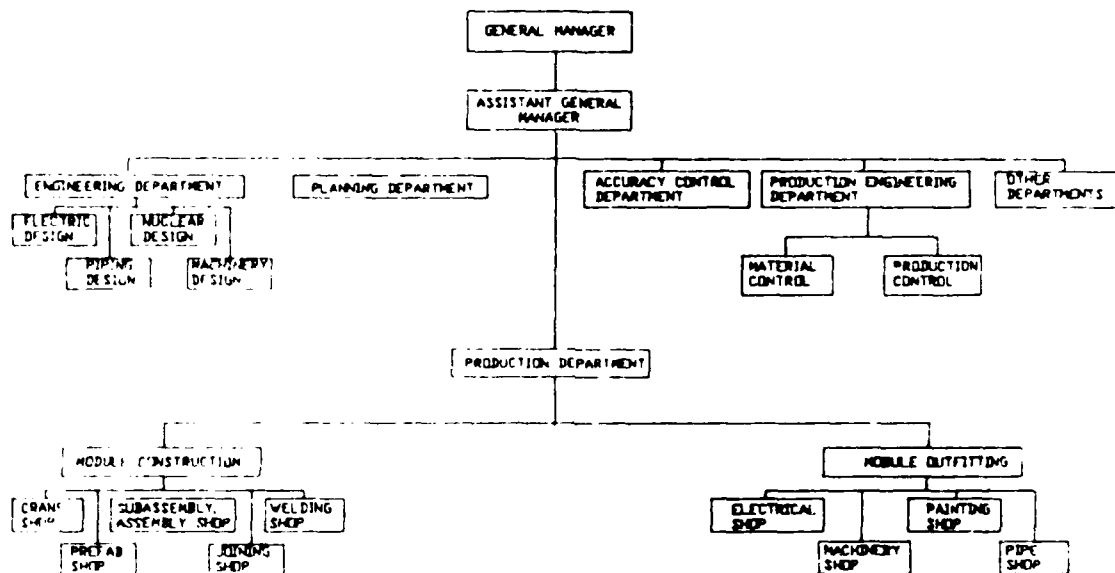


Figure 5-1. Proposed NPF Management Organization.

Figure 5-1 is a typical management structure needed to support PWBS technology implementation at an NPF. Control of the basic design for modularization of the nuclear power plant by the NPF is vital to successful application of PWBS. Since PWBS requires unprecedented collaboration between NPF departments, production engineers trained in PWBS would be assigned to the module construction and outfitting departments and throughout the shops in the

field to increase productivity of the entire NPF organization.

Total contract requirements of a nuclear power plant must be planned in advance of construction. This approach to planning requires a well organized nuclear planning team comprised of members of the engineering, planning and production departments and the involvement of top level management to assure the visibility of the total contract requirements.

Total contract planning would evolve through the following stages:

- contract stage,
- preparation stage,
- key plans stage,
- engineering drawing development and issue stage,
- mold loft stage,
- parts fabrication, module assembly and outfitting stage, and
- site joining and testing stage.

During the contract stage, the utility would provide contract specifications and contract drawings which represent all the various nuclear and non-nuclear systems of the power plant. The contract specifications and contract drawings would include:

- special requirements for safety and radiation shielding,

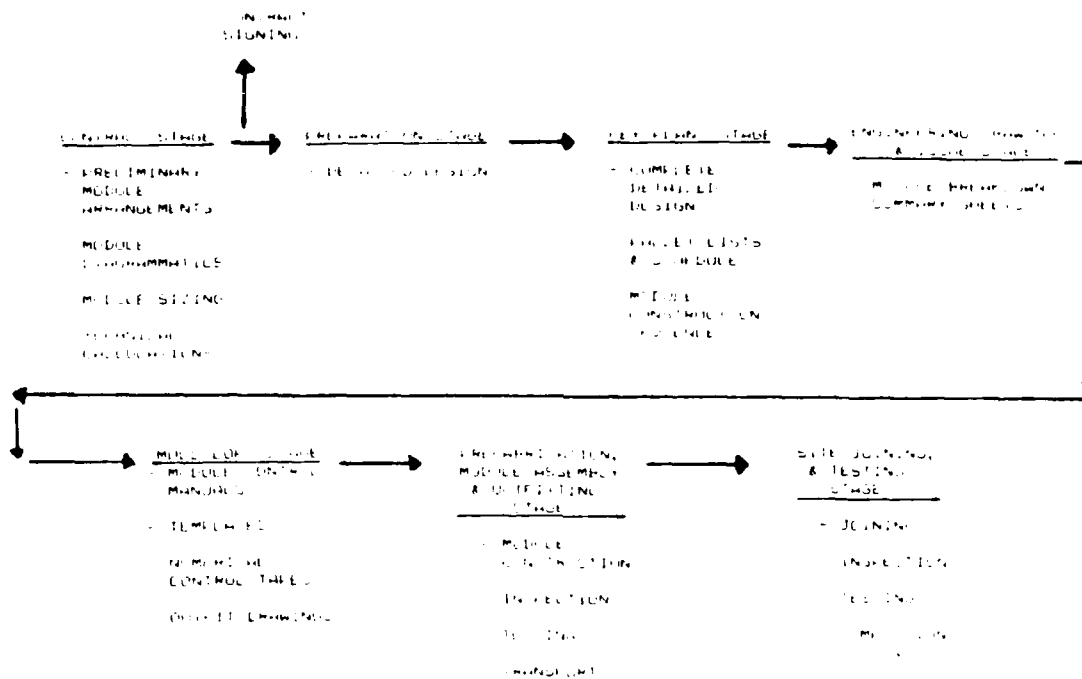


Figure 5-2. Total Contract Planning.

- detailed requirements for inspection and testing (which are based on Nuclear Regulatory Commission regulations),
- requirements for construction and handling of large components (e.g., reactor vessel, steam generators, etc.),
- structural, foundation, piping supports, etc. requirements in order to satisfy postulated accident scenarios, and
- requirements for all emergency equipment and their

locations (e.g., firefighting, decontamination, etc.). Using the information and data of the contract specifications and contract drawings along with the NRC's requirements for licensing, the NPF nuclear planning team begins module and zone outfitting planning development. Nuclear and non-nuclear module structural plans and machinery arrangement and system diagrammatics are developed by the nuclear planning team. Modules would be sized according to the mode of transportation for the modules and the crane capacity at the site's geographical location. All of the technical and engineering calculations for each module and the plant are calculated for the follow-on engineering stages. Procurement specifications for material and parts are initiated. Periodic contract stage meetings are conducted by top management to review module planning and outfitting development. Throughout the contract stage and contract signing the NPF meets with the utility and NRC representatives to discuss and resolve problems associated with the proposed modules' construction and outfitting, on-site joining and licensing. The importance of these and follow-on joint meetings can not be overstated. The sooner potential construction and, especially, potential licensing problems are resolved the earlier that stability will be realized in the remaining stages of the planning and scheduling and construction of the modules.

The preparation stage would start after contract

aigning. During this stage the detailed design of the nuclear power plant would be completed through the following phases:

- functional design,
- transition design, and
- module design.

Functional design, which started during the contract stage, would complete the system diagrammatics, space arrangements and structural drawings. Transition design would transform the systems oriented design to a module oriented design. Module design would develop detailed module drawings in composite layers, perform interference checks of equipment and piping and develop structural assembly module drawings. Additionally, labor and material estimates, purchase requests for major items (e.g., turbine generators), basic plant module arrangements, engineering drawing schedule, preliminary outfit pallet lists and a budget would be completed during this stage. The nuclear planning team and top management would meet periodically throughout the preparation stage to assess development of the foregoing.

The key plans stage would see completion and review of the detailed design of the nuclear and non-nuclear modules. A pallet schedule would be issued for all outfitting material for on-module and at-site outfitting. The majority of the required steel for construction would be requisitioned during this period. The order of sequence of

nuclear and non-nuclear module construction would be established and charted on a module construction sequence master diagram. The sequence of construction would be ordered to provide an evenly distributed grouping of modules that falls into a designated pattern for at-site joining. Top management and the nuclear planning team would meet throughout the key plans stage to monitor its progress.

The engineering drawing development and issue stage starts with the development of Module Breakdown Summary Sheets by the nuclear planning team. Module Breakdown Summary Sheets would contain the material routing and work process instructions for producing a module from start of construction to final outfitting and painting. These sheets are the work process instructions for the engineers and draftsmen to make the detailed module-by-module engineering drawings that are issued to the mold loft along with the associated module parts list (MPL). Throughout this stage top level management meets with the nuclear planning team and the engineering designers and draftsmen to ensure that the established drawing issue schedule is being maintained.

With the issue of the engineering drawings to the mold loft the next stage begins. During the mold loft stage, Module Control Manuals would be developed for issue to the production department. These manuals would contain the work process instructions and module parts list for construction and joining of the modules. Parts programming,

templates, numerical control tapes for cutting steel and machining parts, outfitting drawings and jig instructions are other items developed by the mold loft. Again, top level management would meet with mold loft representatives and the nuclear planning team to review the schedule for issue of the Module Control Manuals to the production department.

Receipt of the Module Control Manuals would signal the start of the parts fabrication, module assembly and outfitting stage. Parts fabrication and module assembly involves the planning for production of interim products and the construction of assemblies on the various work process lanes. The assemblies would be joined together to form the larger and complete modules. The grouping of the modules would be dependent on the supporting facilities of the construction area (e.g., flat jigs for flat units, fixed and pin jigs for curved units) and the construction time in the work process lane as determined by fabrication, outfitting and welding lengths. Testing of individual parts and portions of a system within each module would be scheduled and conducted throughout the work process lane so that when a module is completed it will be ready for shipment to the site for joining and final testing. Transportation to the site would be by barge and/or rail depending on the site's geographical location.

The at-site joining and testing stage would involve

the planning and scheduling of rough module fitting, finish module fitting, welding, at-site outfitting of material and equipment, inspection, testing and final painting of the nuclear and non-nuclear modules.

The planning and scheduling of painting the modules would be done in conjunction with the parts fabrication, module assembly and outfitting stage. The goal would be to accomplish as much painting as possible during module construction and prior to the module's transportation to the joining site. The PWBS' Zone Painting Method as described in Chapter 2 would be used.

In order to support a work process lanes concept the NPF would have to establish the following planning control guidelines:

- establish key construction dates,
- divide the nuclear power plant into modules and develop an at-site joining sequence,
- categorize and subcategorize modules,
- load work process lanes to capacity,
- establish the module assembly schedule,
- establish the at-site joining schedule, and
- ensure key construction dates are compatible with the assembly and joining schedule.

Planning for work process lanes would provide the NPF with the ability to control and handle materials quickly, efficiently and economically. NPF management would



be able to control the detailed work process lane schedules based on the volume and quantity of work for each process lane work center and determine work center cost and efficiency.

NPF work process lanes would require that the modules of the nuclear power plant be divided into nuclear and non-nuclear categories. Each category would then be subcategorized based on size, shape and method of construction. Categorizing modules in this manner would allow planning department, shop and work center planners to develop basic and detailed planning and scheduling for construction of each module.

Module outfitting planning would utilize three types of zones based on PWBS technology:

- module package preoutfitting,
- on-module outfitting, and
- at-site module outfitting.

In module package preoutfitting, components and parts would be assembled into packages that do not require temporary reinforcements or supports to maintain stability and rigidity. Two types of preoutfitting module packages would be used - machinery and piping. Machinery module packages would be assemblies of machinery that are combined with adjacent components such as the foundation, pipe pieces, valves, gratings, ladders and supports. Piping packages would be assemblies of pipe pieces and pipe racks.

On-module outfitting would be the outfitting of various components and equipment on the ceilings and floors of the module.

At-site module outfitting would be the outfitting of items or preoutfit packages too heavy or too big to load onto the module prior to joining, fragile components that are impractical to be fitted on-module and connection components between modules.

Production outfitting planning would describe the planning and scheduling necessary to install, test and operate all the components of a nuclear power plant prior to acceptance by a utility and loading of nuclear fuel. The nuclear production planning outfitting team would develop the information, documents and schedules required to implement the module outfitting. The goals of the nuclear production outfit planning team would be:

- to maximize module package preoutfitting of components of all systems in the on-module zones,
- to maximize the assembling of components of systems in the on-module zones,
- to minimize the amount of at-site outfitting,
- to orient assemblies requiring steel fitting and foundation work to an easy work position assisted by gravity rather than opposing gravity, avoiding difficult overhead work, and
- to transfer work environments from closed, narrow,

high or unsafe locations to open, spacious, low and safe locations and also to facilitate transportation of materials.

Outfit planning would begin early before contract signing. Interaction between outfit planners, module planners, engineering planners and other departments of the NPF would be essential to successful outfit planning. It should be done in two stages - precontract and contract. During precontract the planning department establishes key milestone dates for module construction, joining and testing. The nuclear production outfitting planning team would use these dates along with contract specifications, general equipment and machinery arrangements and key systems diagrams for starting outfit planning development. The nuclear power plant would be divided into large purchasing zones for advance ordering of material and equipment. The nuclear outfitting production planning team and engineering planners would decide on the preliminary applications of machinery and piping package preoutfitting and on-module/at-site outfitting. After contract signing the team would develop detailed module arrangement and preliminary pallet lists. From this a Master Milestone Construction and Module Outfitting Schedule would then be developed, finalized and approved by top level management and other NPF departments. The nuclear production outfitting planning team would then publish a "Module

Outfitting Lists of Material" document.

The Production Engineering Department would then issue work process orders for parts fabrication, sorting, collection and packaging of outfit materials. As construction of modules proceeds the module package preoutfit, on-module and at-site outfitting would proceed in parallel based on the module construction schedule. The nuclear production outfitting planning team would develop a Module Completion and Machinery Testing Schedule to closeout all compartments of the module and test all machinery and equipment prior to acceptance of the power plant by the utility.

The NPF would use three basic types of schedules:

- master NPF schedule,
- long-term NPF schedule, and
- short-term NPF schedule.

All departments of the NPF would participate in the development of these schedules to ensure that they are realistic, recognized and resolute.

The master NPF schedule would define the long term plan of construction for the nuclear power plant and all other contracts in progress or being negotiated by the NPF. In the case of the nuclear power plant the master NPF schedule would contain the start of prefabrication of parts and module construction, at-site start of joining of modules and completion of the plant. Other key dates from other

contracts, which are not necessarily other nuclear power plant projects, would also be included in the master NPF schedule. This master NPF schedule would contain projected module production weights per month and an accumulative module production weight curve for the plant and other contracts in progress. The master NPF schedule would provide management with:

- the understanding of the necessary manhours and required assembly areas,
- the ability to make adjustments to the assembly areas, and
- the ability to adjust manpower to support module construction schedules.

The long-term NPF schedule would function to:

- support smooth relationships between the production stages, and
- level load the work volume at each assembly stage of the work process lanes.

The short-term NPF schedule would be comprised of the monthly, weekly and daily schedules for production. Production shop planners would use the long-term NPF schedule to prepare the short-term NPF schedules based on the capacities of the machines in the work centers on the work process lanes. The short-term NPF schedules are issued regularly to reflect scheduled work, progress status of construction and exceptions to normal routine for particular

interim product manufacture. Further, these schedules would provide precise material, work process lane, accuracy, safety, and efficiency control. Shop planners control the schedule and the foremen execute the schedule based on their weekly work load.

This section described the proposed implementation of planning and scheduling for modular construction of a nuclear power plant. Management organization, total contract planning, planning for work process lanes and zone outfitting of modules, production outfitting planning and development of construction schedules were discussed.

### 5.3 Design Engineering for Module Outfitting

This section describes the proposed implementation of design engineering for module outfitting at the nuclear power facility (NPF). The impact of module outfitting on the overall design engineering effort and effects of implementing module outfitting on the NPF's engineering department will be discussed.

The implementation of design engineering for module outfitting would require the NPF to shift detailed design for engineering drawings from a systems to a module orientation. As discussed in the previous section, the detailed design would be completed through the three design phases - functional, transition, and module design. The module design drawings describe the modules to be built.

Design engineers would configure the systems within each module to simplify installation. In developing these detailed module drawings the production department would provide detailed written, module-by-module descriptions of how each module would be built. Engineering design and production department personnel would then meet periodically to discuss the installation of each system within a module. Joint agreements would be reflected in the final engineering drawings and parts lists used for construction. Parts fabrication drawings (e.g., pipe details, vent ducting, etc.) would be developed module-by-module and become part of the module installation drawing package. Components are identified by coding to reflect the module the component will be installed in and the stage of assembly or subassembly of that module and what building site in the work process lanes where the installation will occur. Thus, these installation drawings become a material control document and are part of the Module Control Manual. More data would be displayed on the module installation drawings because of the detailed methodology of production incorporated in these drawings. Their number would be greater too because of the methods for presenting piping plans. For example, a piping arrangement drawing that applies to two modules would be accompanied by two pipe detail drawings and two lists of material, one for each module.

The engineering department would establish module package teams within the mechanical and nuclear design sections, respectively, for development of complete nuclear and machinery module packages. These teams would provide details for equipment foundations, gratings, handrails, piping, instrumentation, etc.

Under module outfitting each installation drawing has a more critical issue date since work on a portion of a system within a module would be incorporated in the module package preoutfitting. Thus, the engineering planning and scheduling section must effectively plan the issue of drawings.

The costs for implementing design engineering for module outfitting would be high because of the large scope of the engineering department's work. However, it can be anticipated that these initial higher costs would result in significant savings in manhours and time of production.

The ASI phrase "engineering essentially complete" must be the same goal for the NPF at the time of starting prefabrication. The precontract effort must maximize the definition of design parameters, contract requirements, construction methods, scheduling and long lead time material needs in order to start the intense engineering effort after contract signing. Typically, an 80 percent completion of module installation design drawings would be achieved by start of prefabrication. The engineering and production



departments must work closely together to achieve this high percentage completion of drawings.

This section discussed the implementation of design engineering for module outfitting. The section included discussions of the impact and effects of module outfitting on the NPF engineering department organization.

#### 5.4 Work Process Lanes to Support Module Construction

This section describes the proposed implementation of work process lanes at the NPF. First, the work process lanes concept is reviewed. The procedures for implementation of work process lanes follows. The section concludes with a discussion of work loading of the process lanes.

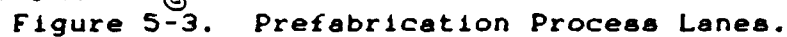
As discussed in the previous chapters, the work process lanes concept categorizes and separates similar kinds of work. Work centers are formed and specifically designed to efficiently and economically produce the similar kinds of work. The work process lanes establish a learning curve efficiency because the same workers in the same work centers of the work process lanes are doing repetitive types of work everyday which is supported by an organized and efficient flow of material.

The NPF would start implementation by analyzing the physical plant layout required to support the work process lanes. Module construction area requirements, crane

capacities and material flow would be important considerations. The volume of work for each nuclear and non-nuclear module and the method for construction of those modules would be analyzed in order to select module prefabrication, subassembly and assembly work sites on the work process lanes. As described in the PWBS chapter, construction on the work process lanes would start out independently with the prefabrication of parts and structurals, i.e., interim products. The work along the work process lanes would continue independently and merge at the appropriate points as required by the production plan and schedule. Figures 5-3, 5-4 and 5-5 represent the proposed work process lanes for the NPF. Figure 5-6 represents the work process lane for at-site joining and testing of modules.

Based on the production plan and schedule the work process lanes would be loaded to full industrial capacity without creating overloads in any one particular process lane. All of the work currently in progress and future work would be tracked by management by plotting the actual versus the projected tonnage. Other contracts would be tracked in the same manner. Level loading work process lanes and placing prefabricated components, subassemblies and assemblies in buffer storage areas along the work process lanes in accordance with the production plan and schedule would allow the orderly construction of the nuclear and

WORD INSTRUCTION PLANS



MODULE CONTROL MANUALS  
WORK INSTRUCTION PLANS

- ASSEMBLY PLAN - (a)
- MODULE PARTS LIST - (b)

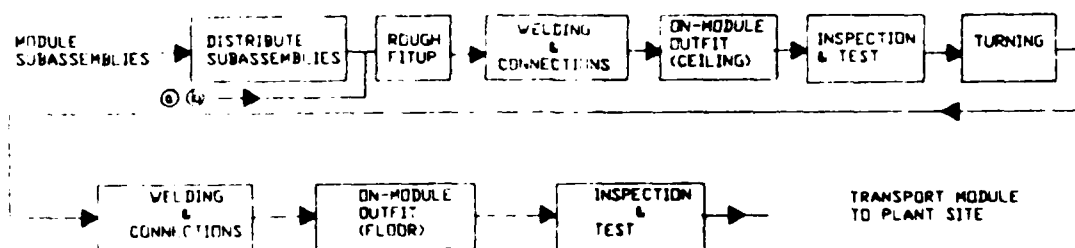


Figure 5-5. Module Assembly Process Lanes.

MODULE CONTROL  
MANUALS  
WORK INSTRUCTION PLANS

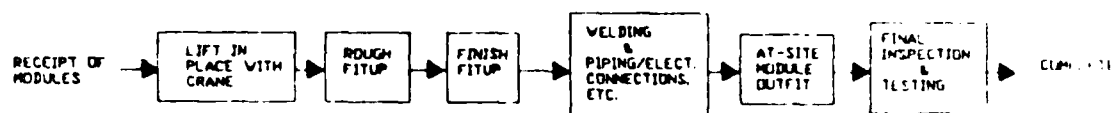


Figure 5-6. At-site Joining Process Lanes.

The completed modules would come off the work process lanes of the NPF fully tested and ready for transport to the at-site location. Transport would be by barge and/or rail. Once the modules are at the site, an at-site work process lane for the joining of modules would be used for the rough fitting, finish fitting, welding and connection of all systems of one module to another module.

By monitoring the progress of the modules on the work process lanes any variations between actual progress and scheduled progress would be accommodated by shifting manpower accordingly. These variations could be caused by delays in delivery of vendor furnished components and materials, late design changes necessitated by the NRC and other contracts.

This section described a proposed implementation of work process lanes to support module construction. The work process lanes concept was reviewed and the implementation and work loading of the process lanes discussed.

#### 5.5 Production Control

This section describes the proposed implementation of production control for module construction and joining at the nuclear power facility (NPF) and the geographical site, respectively. Production and material control by the Production Engineering Department will be discussed. A discussion of the establishment of an Accuracy Control

Department will conclude the section.

The implementation of work process lanes would require the Production Engineering Department to establish a guide for issuing budgets to the various work centers. The guide would establish a cost code system for all work centers to allow management to monitor work center efficiency and cost. The cost code system would be a direct result of the work process lanes' categorization of module work into similar kinds of work.

The NPF's production engineers would be experienced in solving various production problems of the trades and disciplines of the Production Department. The Production Engineering Department would be responsible for the following:

- preparing direct labor costs,
- preparing work orders for the work process lane work centers in accordance with the production plan and schedule,
- assisting the nuclear planning team in the preparation of schedules and information regarding the most economical and practical manufacturing areas in which to place construction,
- monitoring the progress of module construction and ensuring its completion economically and as scheduled,
- working with the design engineers in developing production techniques,

- studying cost reports to stay abreast of labor expenditures,
- monitoring work to determine production efficiency and verify work standards, and
- making and/or proposing changes in the production effort where cost overruns are projected.

Work orders would be prepared by the production engineers. These work orders for the work centers of the work process lanes would be management's primary tool for production control. Work orders would initiate work and monitor cost, work progress and efficiency. The NPF would use prefabrication work orders and module work orders. Prefabrication work orders would be issued for prefabrication of parts and components that would be accomplished by a specific machine or group of machines in a work center. Module construction work orders would contain the orders for the production of the module subassemblies, assemblies and outfitting.

These work orders would serve as the device for accumulating daily direct labor costs expended at each work/cost center. Copies of work orders issued would be transcribed by key punch operators into the NPF's computer data base program. Actual direct labor manhours charged to a work order are entered directly into the computer data base by work/cost center superintendents daily. The manhour charges would be accumulated by the computer and printed out

on spread sheets and forwarded to the cognizant production engineers for monitoring of progress and cost. Various sorts of the information contained in the data base could be used for monitoring the overall progress of module construction. A Work Center Module Construction Report would be generated for every work center along with a cumulative Overall Module Construction Report. These reports would show active and closed work orders status and update them weekly or as required. Production engineers and top level management would review both reports to monitor work center progress, overall contract completion percentage and projected work remaining. Based on the overall actual direct labor manhours spent by a work center versus those issued, a manhour per ton efficiency would be computed. Combining these reports with actual physical progress reports by production department progressmen and production engineers would provide the basis for production control by top management. Management would be able to observe the progress of jobs in the work center, their projected cost and the overall efficiency of the work center and its supervision.

At-site joining of the modules would be monitored in a similar manner as construction of the modules at the NPF. An At-site Module Joining Report would be generated along the same lines as the two NPF reports in order to monitor individual work center and overall job progress, cost and



efficiency.

Material control would be an essential activity in the productive construction of nuclear power plant modules. Since material costs would probably account for over 50 percent of the construction costs, material control is critical to successful implementation of production controls on the work process lanes. Thus, material control directly affects handling costs and storage area along with the potential disruptions to the production schedule and the cost of material.

The implementation of material control would coincide with the implementation of work process lanes at the NPF. The plant would be laid out in such a manner as to promote effective flow of material along the work process lanes. The objective is to minimize the number and length of routes and the elimination of unnecessary moves.

Module construction and outfitting enhances material control because smaller amounts of material would be handled with less storage time in buffer storage areas. The basic instrument for module outfitting would be the pallet with an associated pallet coding for grouping of the outfit material as a package. The pallet for module outfitting would consist of:

- a work package or kit of outfitting material for installation in a module in a specific place at a specific time on the work process lane,

- the manhours allowed for installation, and
- a pallet number which identifies the material.

The NPF would establish a Master Material Plan for recording, expediting, palleting and delivery of the various categories of material to the work process lanes.

Material control would be an invaluable management tool at the NPF because it provides the capability to review material needs in smaller, more controllable packages with a significant reduction in lost material.

The NPF's formation of an Accuracy Control Department would establish realistic goals in the area of manufacturing accuracy and develop proper procedures and controls to achieve NRC regulated accuracy requirements for the nuclear modules. The Accuracy Control Department's responsibilities would span all construction phases of the nuclear and non-nuclear modules. Accuracy control engineers would be involved in checks, controls, and statistics. Checks would be utilized to isolate specific problems of inaccuracy that require controls, monitor construction and assist in minimizing human errors. Accuracy control engineers would take measurements methodically, record them and statistically analyze them in order to develop proper control procedures for construction. All facets of construction would be measured from structural steel to alignments of equipment.

Developing control procedures in manufacturing would

improve the quality of interim products and ultimately the modules. Uniform shrinkage factors and module construction and joining procedure controls are two examples. Uniform shrinkage factors are required for accurate burning and welding. Data gathered by the accuracy control engineers would be used to determine shrinkage factors for all stages of module construction. Module construction and joining procedures would require proper fitting and welding sequences in order to prevent deformations due to high heat introductions caused by welding.

Acting as a statistical engineer, the accuracy control engineer would use statistical principles for calculating mean values and standard deviations of measurements taken from all work processes of module construction and joining in order to develop standards for shrinkage factors.

By establishing the Accuracy Control department the NPF would dramatically improve the quality of module construction and joining.

This section described the proposed implementation of production control and material control for the NPF. The Production Engineering Department's role in production control and material control along with the establishment of the Accuracy Control Department were discussed.

This chapter proposed a generic implementation of

PWBS technology at a nuclear power facility for modular construction of a nuclear power plant. The planning and scheduling for construction, design engineering of module outfitting, application of work process lanes and production control methods were discussed.

The next chapter discusses specific conclusions for the application of PWBS to the construction of a light water reactor nuclear power plant.

## CHAPTER 6

### SPECIFIC CONCLUSIONS FOR THE APPLICATION OF PWBS TO CONSTRUCTION OF A LIGHT WATER REACTOR NUCLEAR POWER PLANT

#### 6.1 Introduction

Several proposals for modularization of light water reactor (LWR) nuclear power plants have been offered by the nuclear power industry and the Electrical Power Research Institute. The Westinghouse 600 MWe NUPACK pressurized water reactor nuclear power plant design is based on fabricating nuclear and non-nuclear modules in a shipyard and transporting them to the plant site for installation on a conventional foundation.(117) Modules and the plant site would be constructed in parallel and the systems in each module would be pretested prior to transport to the plant site. The Electrical Power Research Institute's study on Advanced Light Water Plants, which is based on a plant of about 600 MWe, is considering the advantages which can be achieved by modularization of the LWR.(118)

Modularization requires that the detailed design be essentially complete prior to the start of construction. The engineering and design effort for the first of a "standard design" plant would be considerable, but the reduction in cost and construction time for follow-on plants would far outweigh the initial costs.(119)

This chapter discusses specific conclusions for the application of the Product Work Breakdown Structure (PWBS) to the construction of an LWR nuclear power plant (specifically, a pressurized water reactor). Section 6.2 discusses the division of the LWR plant into nuclear and non-nuclear modules for construction, outfitting and joining at the plant site based on PWBS technology. Section 6.3 concludes the chapter with general remarks. The description of the proposed implementation of PWBS to modular construction of nuclear power plants would be applied to construction of these modules.

## 6.2 Nuclear and Non-nuclear Modules

This section describes the application of PWBS technology to the division of the LWR plant into nuclear and non-nuclear modules for construction, outfitting and joining at the plant site. The importance of the management organization is first discussed. The nuclear and non-nuclear modules for construction are then described. The section concludes with a discussion of nuclear and

non-nuclear work process lanes for construction, outfitting and joining of modules.

First, the construction, outfitting and joining of nuclear modules using the techniques of the PWBS requires a management organization that is based on the organization depicted in Figure 5-1. All departments of the management organization must be trained in the methods of PWBS. Specifically, nuclear and non-nuclear production engineers trained in PWBS technology must be assigned to the departments and shops cognizant of module construction, outfitting and joining in order to provide the leadership and maintain communications among the departments and shops that is so vital to high productivity.

Four basic nuclear module types would be constructed. The reactor vessel module would contain the reactor vessel and all associated piping, foundations, valves and electrical cabling. The steam generator modules would contain the steam generators and associated piping, foundations and valves. Main reactor coolant pump modules and the pressurizer module would contain the coolant pumps and pressurizer, respectively, along with associated piping, foundations, valves and electrical cabling. Large plants (e.g., 1200 MWe) would require that the reactor vessel and steam generators be subdivided into sub-modules due to constraints on size/weight for shipping and crane handling. The nuclear modules and/or sub-modules would be joined at

the plant site inside the containment building.

Five basic non-nuclear modules would be constructed. The turbine generator modules would contain the turbine generators and all associated piping, foundations, valves and electrical cabling. The electrical distribution module would contain all the necessary equipment (e.g., distribution control panels, circuit breakers, etc.) to handle the electrical power generated by the turbine generators. The condensate module would contain the main condenser, condensate pumps, condensate polisher, condensate storage tank and associated piping, foundations, valves and electrical cabling. The feedwater module would contain the feedwater booster pumps, feedwater pumps, feedwater heaters and associated piping, foundations, valves and electrical cabling. Finally, the power plant control operating room module would contain all the control equipment and monitors to operate the LWR plant. Again, based on the LWR plant's size, the non-nuclear modules would be subdivided into sub-modules to meet transportation and crane handling requirements. The non-nuclear modules and/or sub-modules would be transported to the plant site and joined in the non-nuclear buildings. Eventually, the secondary coolant loop between the containment building and the non-nuclear buildings would be joined along with the sensors and monitors of the power plant control operating room.

Each of the nuclear and non-nuclear modules and/or



sub-modules would be broken down into assemblies, subassemblies and parts using the PWBS techniques for detailed design. Specifically, the detailed design would proceed through functional, transition and module design phases. Functional design would involve developing systems drawings and material lists for the LWR plant. Transition design transforms from a systems orientation to a module orientation. Module design provides the detailed module structural drawings, composite drawings for outfitting and material lists that incorporate all systems of the module and shows module boundaries. Finally, module design subdivides the modules into assemblies and subassemblies down to the minimum level, i.e., components to be purchased and material requirements for the fabrication of parts.

The pre-contract and contract execution for construction, outfitting and joining of the LWR plant's nuclear and non-nuclear modules would proceed based on the proposed methods for implementing PWBS for construction of nuclear power plants. Specifically, the procedures for planning and scheduling construction, design engineering for module outfitting, work process lanes and production control would be utilized.

The work process lanes concept of PWBS categorizes and separates similar kinds of work and develops work centers on the work process lanes that are specifically designed to produce that kind of work efficiently and

economically. Nuclear and non-nuclear work process lanes would be used for construction, outfitting and joining. Dividing the work process lanes in this manner is necessitated because of the complexity involved and quality work required when building reactor vessels, steam generators, main coolant pumps and pressurizer modules and containment buildings. This is not to say that the non-nuclear modules are not more complex. The fact that nuclear modules will eventually be carrying radioactive material necessitates their individualism within the work process lane.

Prior to the start of prefabrication of parts and subassemblies on the nuclear and non-nuclear work process lanes and parallel construction of the containment and non-nuclear buildings at the plant site, the design engineering effort must be essentially complete. This is fundamental to the application of PWBS. The nuclear and non-nuclear modules would then be constructed and outfitted on the work process lanes in accordance with the work process instructions/drawings and the construction schedule. Completed modules' systems would be tested and certified by the Nuclear Regulatory Commission prior to transport to the plant site. Joining of the modules at the plant site would be based on the joining sequence established during the planning and scheduling for construction. Nuclear and non-nuclear modules are joined and tested and the at-site

work is completed (e.g., closing up the containment building after nuclear modules are installed).

This section described specific conclusions for application of PWBS technology to nuclear and non-nuclear module construction, outfitting and joining at the plant site. The importance of the management organization, description of nuclear and non-nuclear modules construction and nuclear and non-nuclear work process lanes for construction were discussed.

### 6.3 General Remarks

The construction and outfitting of nuclear and non-nuclear modules presupposes that one nuclear industrial facility will build all the modules. For construction control this would be the optimal situation. However, it can be anticipated that several industrial facilities will build the various nuclear and non-nuclear modules via subcontracting by the primary contractor. If this is the case, the control of the design for all modules must be maintained and closely monitored by the prime contractor. The subcontracted facilities would have PWBS technology implemented to suit their particular facilities' capabilities. The ultimate goal would be to build the LWR plant at less cost, more efficiently and in a shorter time period.

This chapter discussed specific conclusions for the application of the Product Work Breakdown Structure to the construction of an LWR nuclear power plant. The division of the LWR plant into nuclear and non-nuclear modules for construction, outfitting and joining at the plant site based on PWBS technology was discussed. The chapter closed with a general remarks section.

## CHAPTER 7

### SUMMARY AND CONCLUSION

The Product Work Breakdown Structure (PWBS) technology for shipbuilding as developed and refined by the Ishikawajima-Harima Heavy Industries Co., Ltd. of Japan has been successfully applied and implemented at Bath Iron Works and Avondale Shipyards, Incorporated. PWBS classifies components to be purchased, parts to be fabricated and planned subassemblies in order to achieve coordinated work flows on the work process lanes. PWBS also incorporates integrated hull construction, outfitting and painting along with coat centers which exactly match a zone-oriented organization.

The nuclear power plant construction industry has tried various methods of modularization on a modest scale. The implementation of PWBS technology at nuclear industrial facilities would significantly reduce costs and time for construction and improve the quality in construction of nuclear power plants.

This thesis questioned the feasibility of using the PWBS technology as applied to shipbuilding in Japan and the U.S. to modular construction of nuclear power plants. The proposed implementation of PWBS technology to the construction of nuclear power plants described in this thesis answered the foregoing question. Areas that require further study are designing nuclear and non-nuclear modules for ease of maintenance and repair, life extension and decreased decommissioning costs.

## APPENDIX A

### DESCRIPTIONS OF MANUFACTURING LEVELS

This appendix contains the detailed descriptions of the manufacturing levels of Hull Block Construction Method (Appendix A-1), Zone Outfitting Method (Appendix A-2), Zone Painting Method (Appendix A-3) and Pipe Piece Family Manufacturing (Appendix A-4). The descriptions come directly from the National Shipbuilding and Research Program publication "Product Work Breakdown Structure". No attempt has been made to rearrange or paraphrase these descriptions.

## APPENDIX A-1 (120)

### MANUFACTURING LEVELS OF HBCM

#### A.1.1 Part Fabrication

Part fabrication is the first manufacturing level of HBCM. It produces components or zones for hull construction which cannot be further subdivided. Typical work packages are grouped by zone and:

by area, for associating raw materials, finished parts, fabrication processes and relevant facilities separately for:

- parallel parts from plate,
- non-parallel parts from plate,
- internal parts from plate,
- parts from rolled shape, and
- other parts, e.g., from pipe, etc.

by stage, after having performed groupings by zone, area and similarities in part types and sizes as follows:

- plate joining or nil,
- marking and cutting, and
- bending or nil.



For large quantities of parts to be bent, problem area can be subdivided by the resources available such as:

- universal press (single-axis shallow curvature),
- press with die (small parts, e.g., bracket flange),
- mechanized line-heating (double-axis shallow curvature), and
- manual line-heating (double-axis deep curvature and correction of any part).

A face plate for example, is marked and nested on a plate with other such parts that can be cut in one pass by a multiflame planer. Those which require different curvatures are then grouped together provided they can be processed by a press without the need to change dies. Face plates, including those that are to remain straight, are then grouped per block and distributed to succeeding work packages.

Typical groupings of work packages for parts fabrication are illustrated in Figure A-1.1.

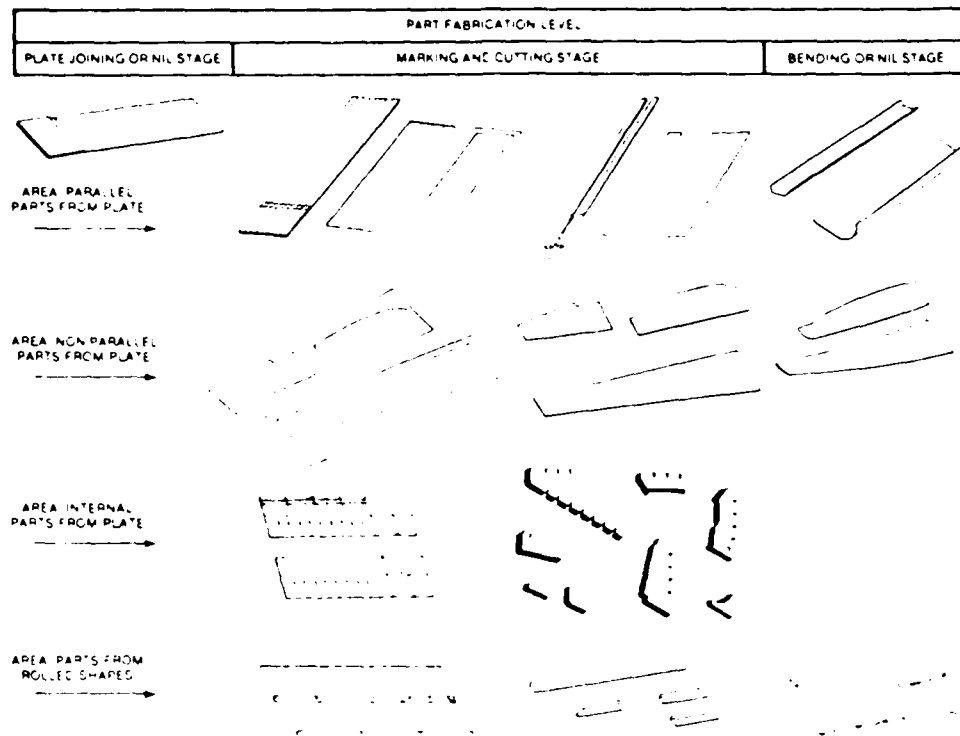


Figure A-1.1. Part Fabrication.

#### A.1.2 Part Assembly

The second manufacturing level is special and outside the main work flow. Its typical work packages are grouped by area as:

- built-up part, e.g., tee- or el-section
- longitudinals of large or unusual sections not rolled by

mills, and,

- sub-block part, e.g., a part which is a weldment, typically consisting of a bracket fitted with a face plate or flat bar, as shown in Figure A-1.2.

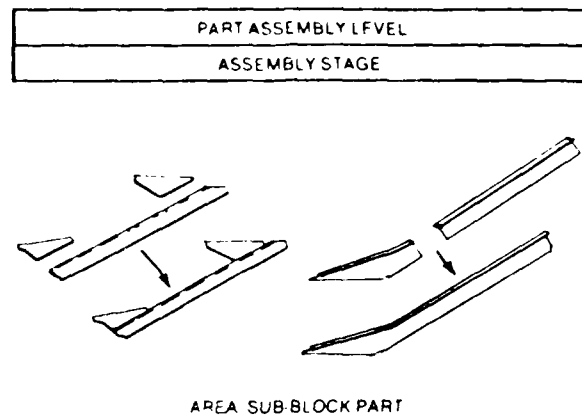


Figure A-1.2. Part Assembly.

The sub-block "part" concept is a planning technique for shifting work from the sub-block assembly level, where excessive work volume is otherwise probable, to an earlier level outside the main work flow. Undertaken with simple facilities as compared to those required for sub-block assembly (e.g., mechanized conveyors), manufacturing sub-block "parts" in the part assembly level is a means of balancing work and conserving resources. Further, as such "parts" are only used in sub-blocks, zone identification employs the same code as for sub-blocks; see Figure 2-7.

Stage is divided into:

- assembly, and

- bending or nil.

#### A.1.3 Sub-block Assembly

Sub-block Assembly appears in the third manufacturing level of Figures 2-6 and 2-7. A zone is generally a weldment, consisting of a number of fabricated and/or assembled parts, which will eventually be fitted on a panel during block assembly.

Typical work packages are grouped by area for:

- similar size in large quantities, e.g., large transverse frames, girders, floors, etc., and
- similar size in small quantities.

Subassemblies falling within the first problem area regardless of their design differences can be mass-produced size-by-size on process lanes with appropriate facilities, e.g., conveyors. Those in the second category require a job-shop approach because of:

- insufficient numbers for any one size, and
- different working times required for the different sizes that are normally encountered.

Stage classifications are:

- assembly, and
- back assembly or nil.

During back assembly, parts and/or assembled parts are fitted on the opposite side of a marked surface of a main part (it is additional fitting after overturning).

Examples are shown in Figure A-1.3.

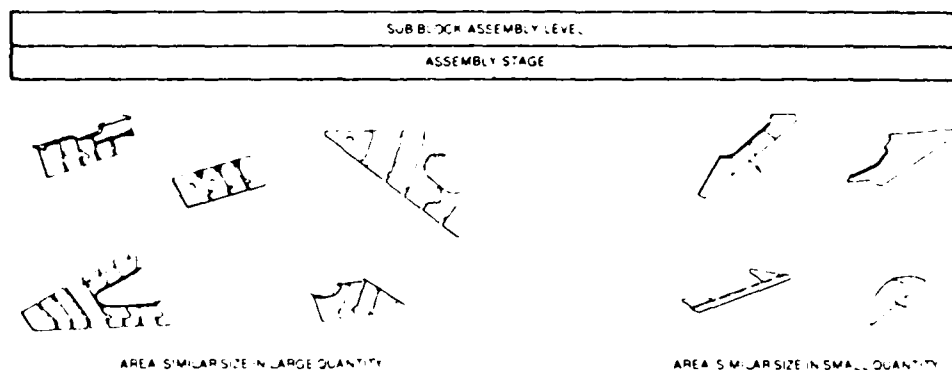


Figure A-1.3 Sub-block Assembly.

#### A.1.4 Semi-block and Block Assembly and Grand-block Joining

A block is the key zone for hull construction and as indicated in Figures 2-6 and 2-7 it may, depending on circumstances, be planned in three assembly levels, i.e.:

- semi-block assembly,
- block assembly, and
- grand-block joining.

Only block assembly is in the main work flow. The other levels provide useful planning alternatives. All are planned in accordance with the concept of grouping work packages by area and stage.

A semi-block serves the need to assemble a partial zone separate from a key zone (block) whenever a block would

otherwise disrupt work flow. When a semi-block is employed, the block assembly level is where it joins its "mother" block which was processed in the main work flow.

Grand-block joining, i.e., the combining of a few blocks to create a larger block at a site near a building dock:

- reduces the working time needed for erection in a building dock,

- produces a shape that is more stable for erection purposes, and

- provides more spacious area and volume which facilitates further on-block outfitting and painting.

This level, which is outside the main flow, is needed when zone divisions from a large ship are applied to a small ship in order to quickly achieve a nearly uniform work balance. The ensuing smaller-size blocks are joined into grand blocks in order to minimize the working time needed in a building dock for erection.

The zone of the three levels ranges from block to ship as shown in Figure 2-7.

The semi-block assembly level is divided by problem area in the same manner as for the sub-block level. Most semi-blocks are rather small in size and two dimensional so that they can be produced in a sub-block assembly facility. In planning work, this should be the point of divergence for separating semi-block assembly from block assembly. The

grouping by stage for semi-blocks is also the same as for sub-blocks as also shown in Figure 2-7.

The block assembly level is divided by problem area using:

- distinguishing features of the panel needed as a base for attaching parts, assembled parts and/or sub-blocks, and

- uniformity of working times required.

These characteristics determine whether:

- platens or pin jigs are required, and whether
- blocks are to be assembled in a flow where work starts and completes in unison.

Because of their uniqueness, superstructure blocks are addressed separately.

Pertinent problem area divisions and necessary definitions are:

- flat (working time is uniform and there are no projections from panel underside which require special jigs or which would interfere with platens equipped with conveyors),

- special flat (sometimes called semi-flat; working time is non-uniform and/or unique jigs or supports are needed),

- curved (working time is uniform),

- special curved (working time is non-uniform and/or unique jigs or supports are needed), and

- superstructure.

Special-flat and special-curved blocks, because of variations in working times and/or needed jigs, are not assembled in facilities designed for work flow where starts and completions are in unison. Thus, they require a job-shop approach.

If the quantity of blocks to be produced is small, less than five problem area classifications should be considered.

As shown in Figure 2-7, the block assembly level is phased by stage as follows:

- plate joining or nil,
- framing or nil,
- assembly, and
- back assembly or nil.

The assembly stage at the block level is for combining a panel with parts, assembled parts and/or sub-blocks and sometimes a semi-block. When many blocks are required it could be useful to add further classifications by problem area based upon internal framing, i.e.:

- egg box,
- longitudinals attached before webs,
- longitudinals attached after webs, and
- other.

At the grand-block joining level only three classifications by area are normally required:



- flat panel,
- curved panel, and
- superstructure.

Stage at this level is subdivided into:

- joining or nil,
- pre-erection or nil, and
- back pre-erection or nil.

For very small ships, the pre-erection stage provides for joining grand blocks in order to create grand-grand blocks. Back pre-erection provides for further assembly work after turnover, e.g., attaching bulwarks, chain pipes, etc.

Figures A-1.4 through A-1.14 show relationships between semi-blocks, blocks and grand blocks that were actually employed for construction of a 22,000 deadweight-ton general-cargo carrier. It was purposely selected as the basis for illustration because it is one of a type, i.e., it was not a ship of a standard series.

#### A.1.5 Hull Erection

Erection is the final level of the hull construction where the entire hull is the zone. Problem areas at this level are:

- fore hull,
- cargo hold,
- engine room,
- aft hull, and

- superstructure.

Stage is simply divided into:

- erection, and
- test.

Tests at this level, such as tank tests, are independent of erection and are distinguished by the size of their work packages as compared with the tests and inspections of other levels. The latter tests and inspections are included in the packages of each level and respectively implemented at the time when each interim product is being finished.

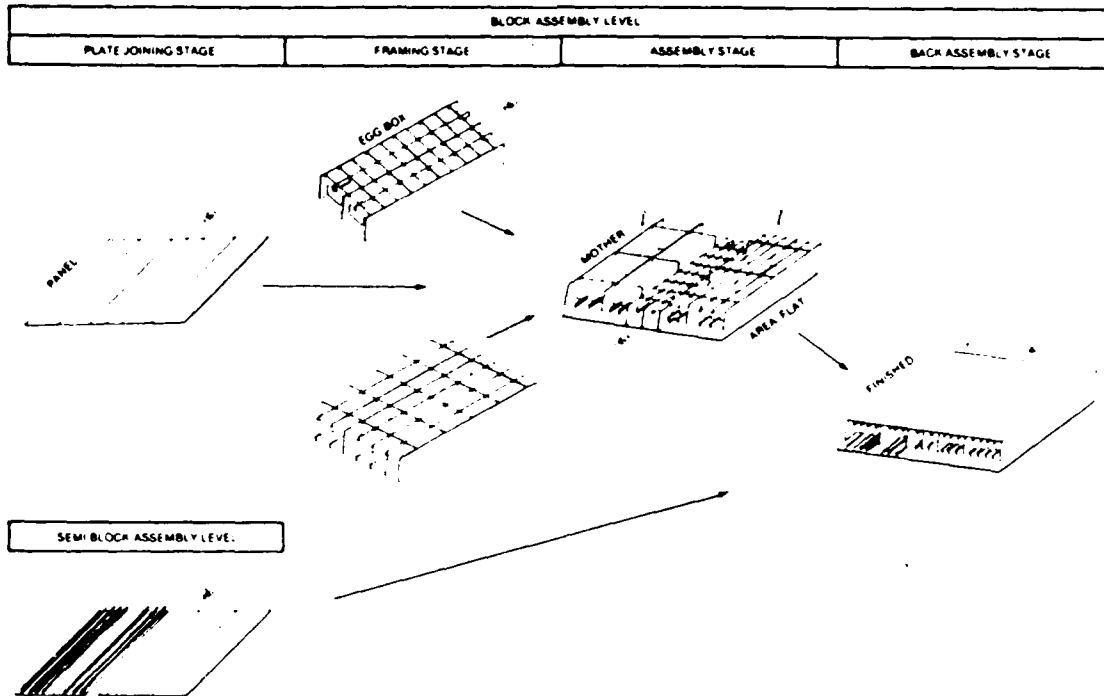


Figure A-1.4. Semi-block and Block Assembly - Bottom Center Block of Cargo Hold. Work content of the finished block exceeds norm. A semi-block was designed so that work for the mother block could progress in a uniform work flow. The problem area classification is FLAT.

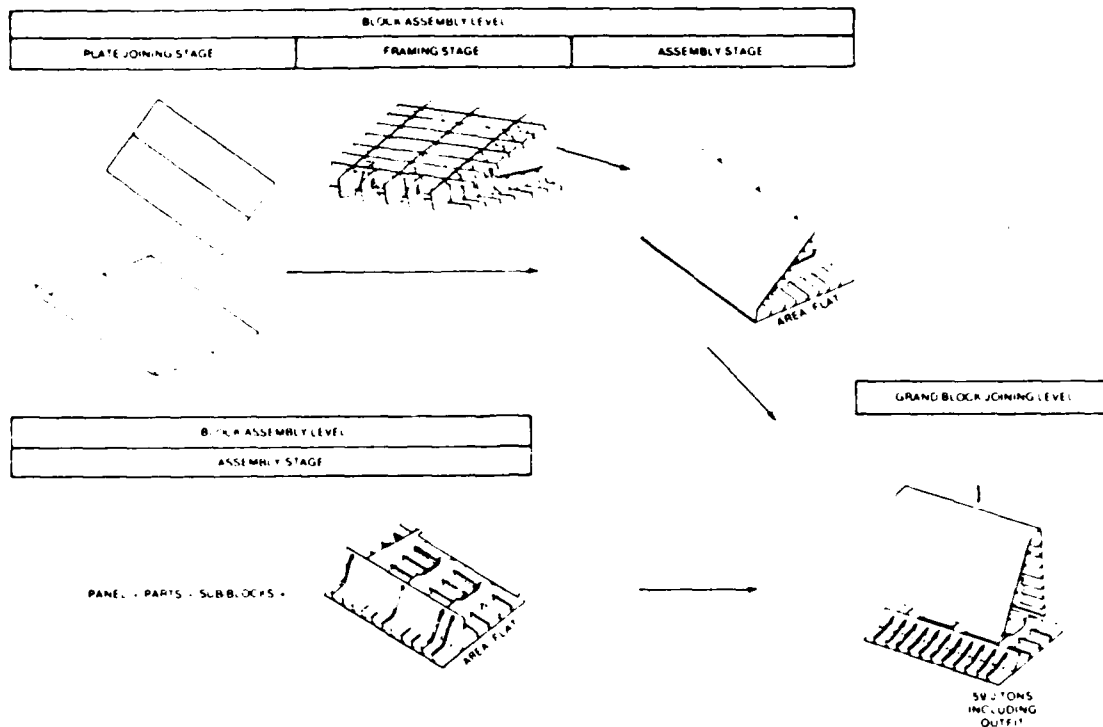


Figure A-1.5. Block Assembly and Grand Block Joining - Top Wing-tank. Both blocks are classified by problem area as FLAT.

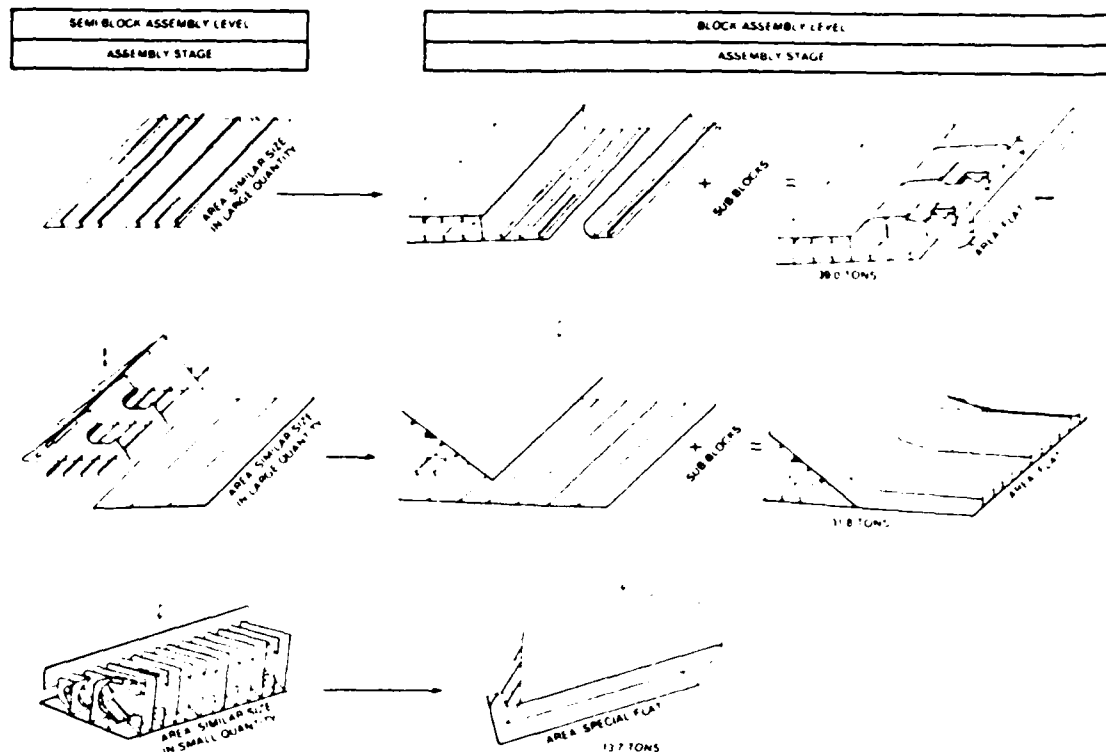
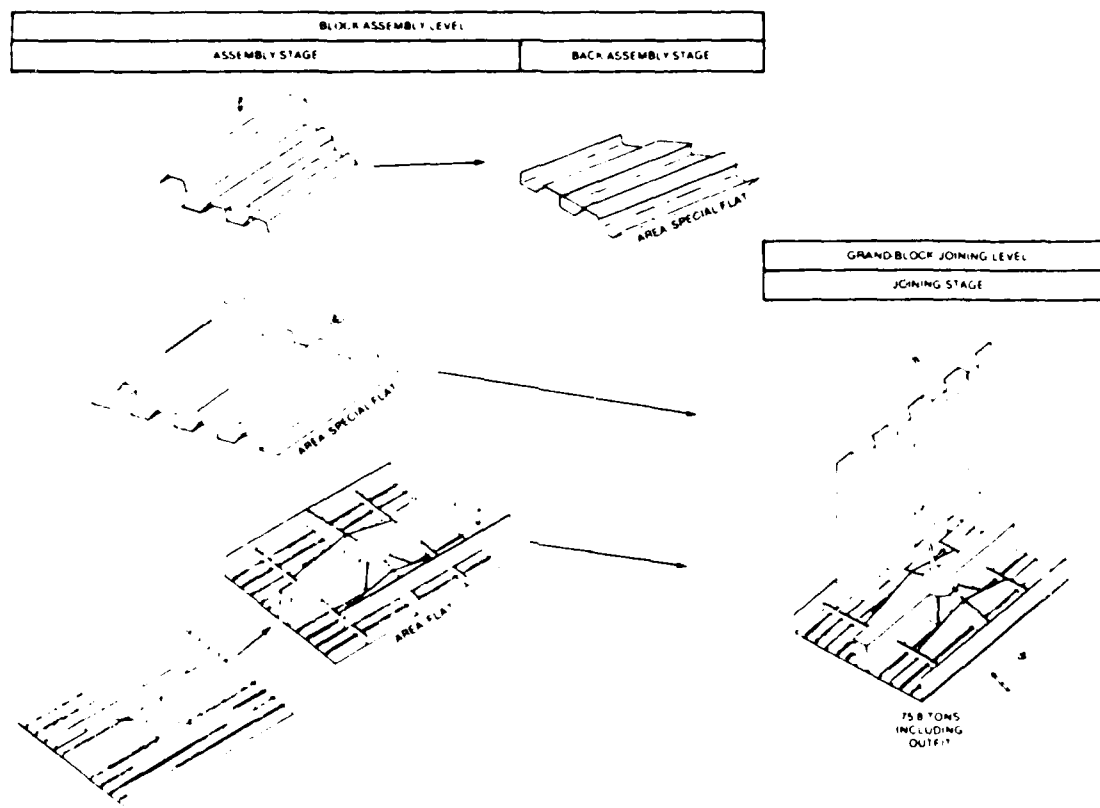


Figure A-1.6. Semi-block and Block Assembly - Bottom Wing, Side Shell with Hopper, and Transverse Hopper in Cargo Hold. Problem area classifications SIMILAR SIZE IN LARGE QUANTITY and FLAT designate work for assembly lines (on-flow). SIMILAR SIZE IN SMALL QUANTITY and SPECIAL FLAT designate job-by-job work (off flow) because there are too few of them or because their work content is not uniform.



**Figure A-1.7. Block Assembly and Grand-block Joining.**  
**Corrugated Transverse Bulkhead and Deck Center Between Cargo Holds.**

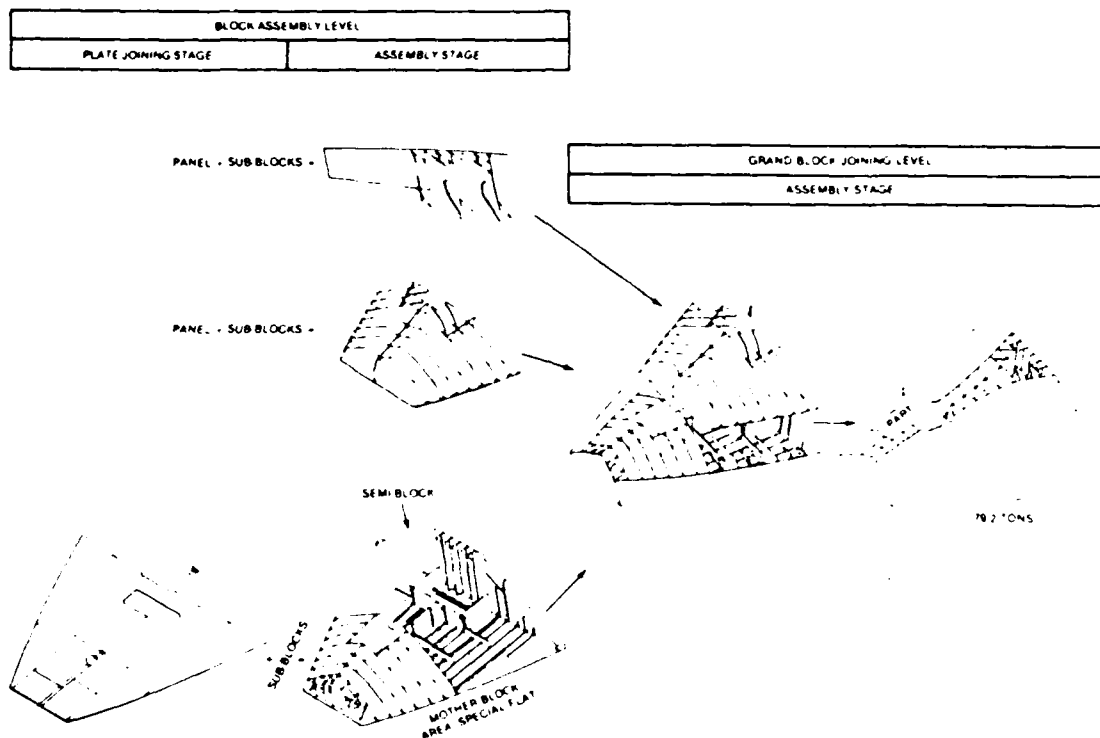


Figure A-1.8. Block Assembly and Grand-block Joining - Cant Block. Attaching a semi-block to a mother block which is classified by area as SPECIAL FLAT is an exception. Also, providing for a part during grand-block joining is planned as an exception.

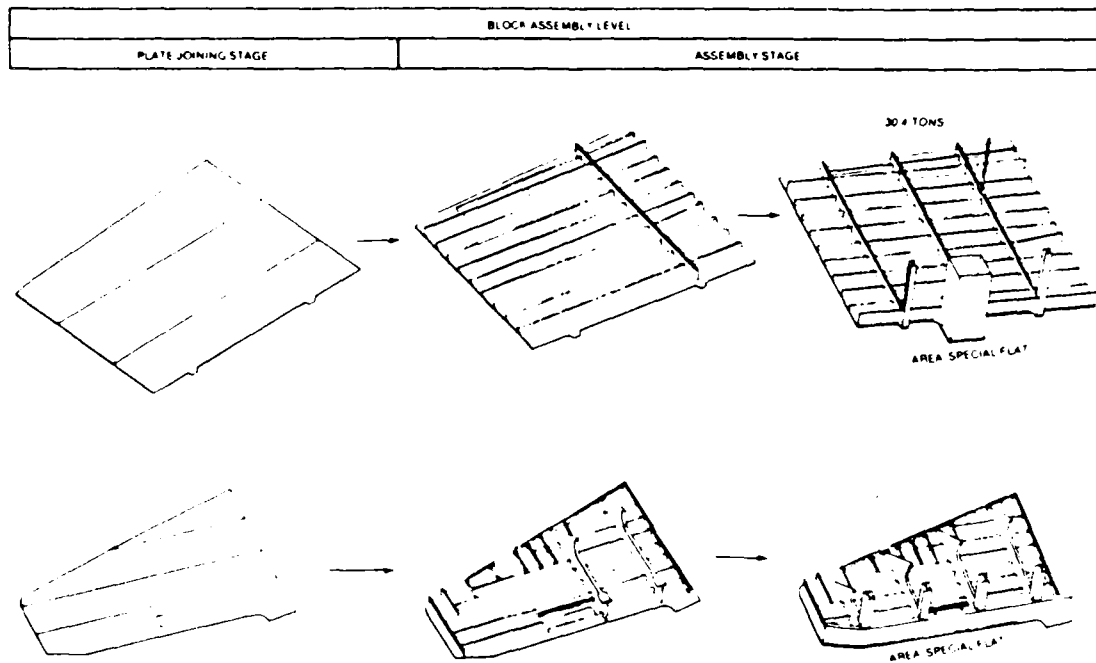


Figure A-1.9. Block Assembly - Upper Deck and Engine-room Flat.



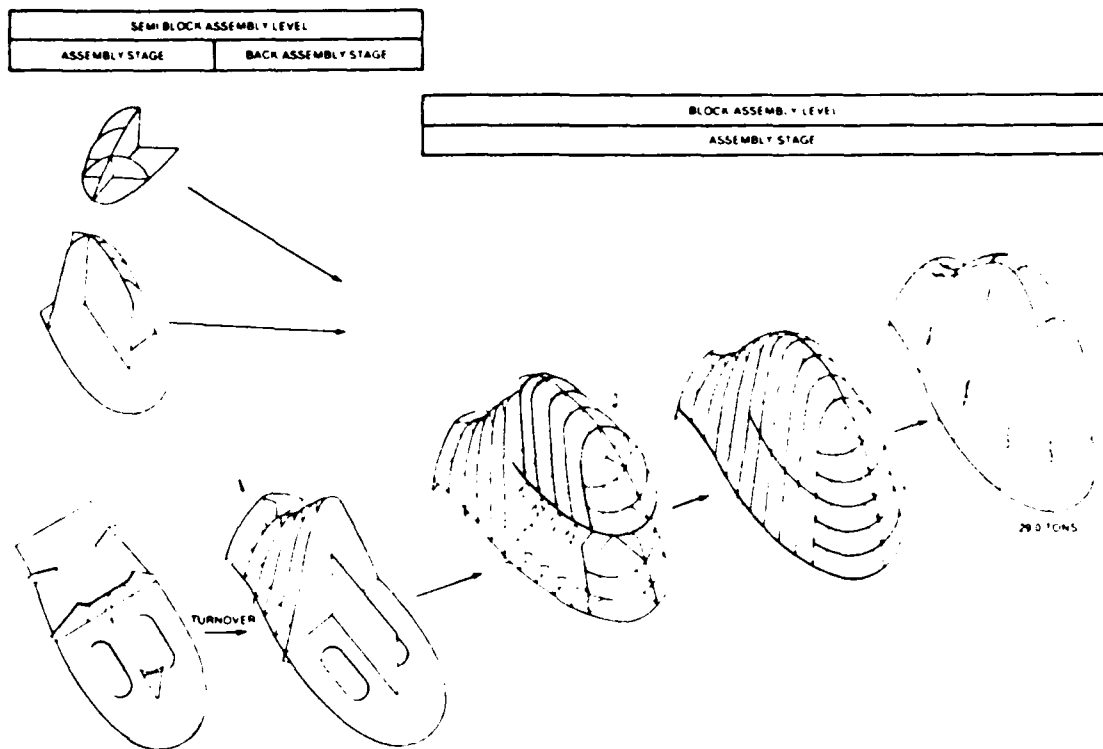


Figure A-1.10. Semi-block and Block Assembly. The three semi-blocks are classified by problem area as SIMILAR SIZE IN SMALL QUANTITY. The block, regardless of its work content, is classified as SPECIAL FLAT because the projections beneath require that it be assembled on a special jig.

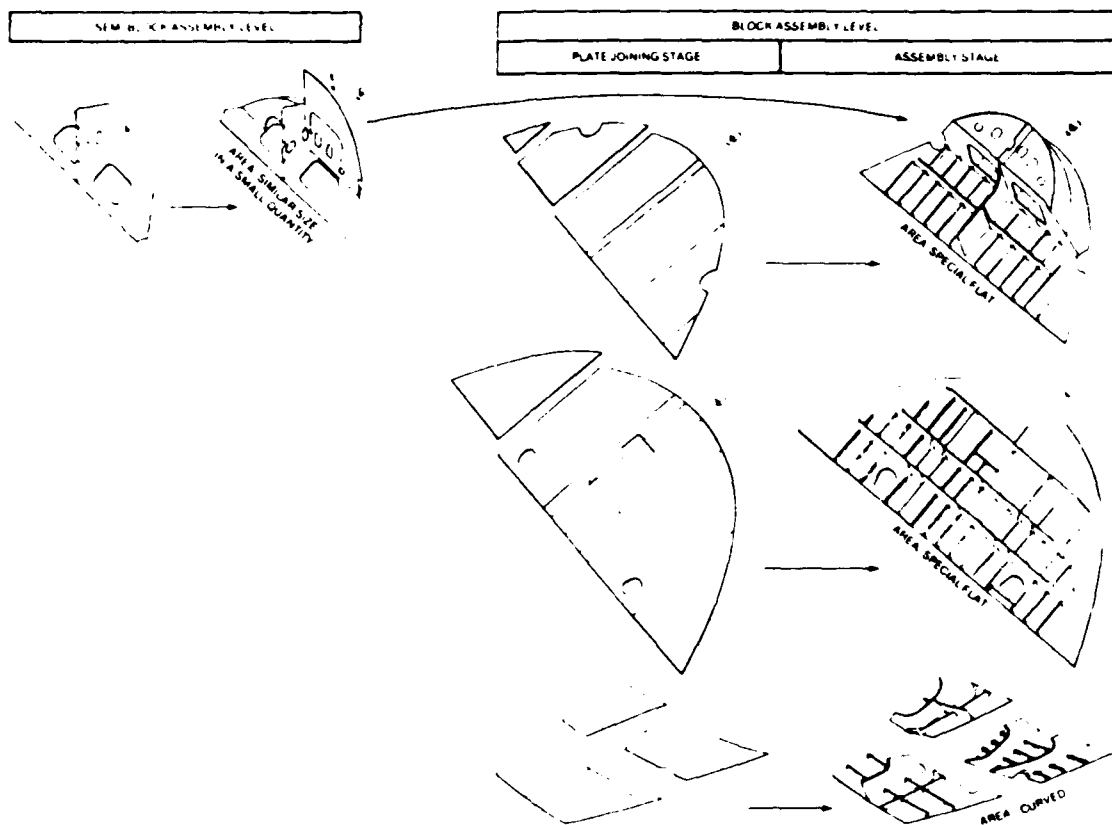


Figure A-1.11. Semi-block and Block Assembly - Fo'c'sle and Upper Deck of Fore-body.

GRAND BLOCK JOINING LEVEL		
JOINING STAGE	PRE ERECTION STAGE	BACK PRE ERECTION STAGE



Figure A-1.12. Grand-block Joining - Fo'c'sle and Upper Deck of Fore-body.

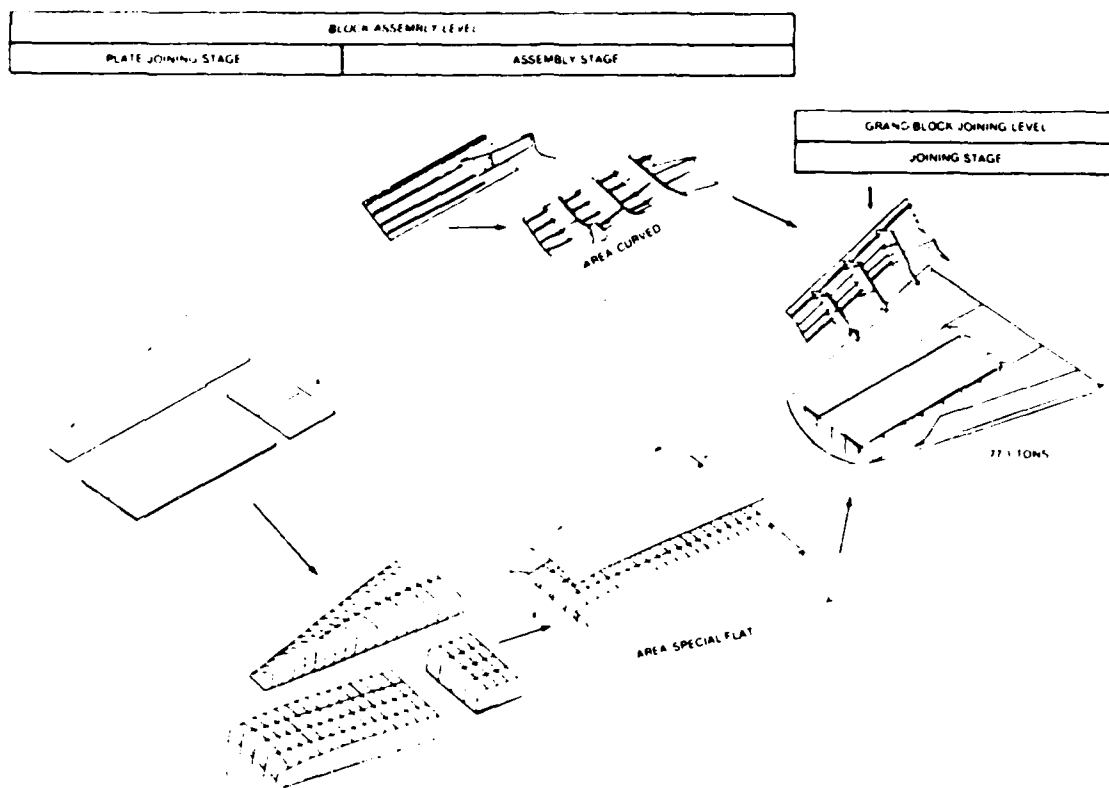


Figure A-1.13. Block Assembly and Grand-block Joining - Bottom of Engine Room. The engine-room bottom block is classified by area as SPECIAL FLAT because of its work content and the projection of the main-engine foundation.

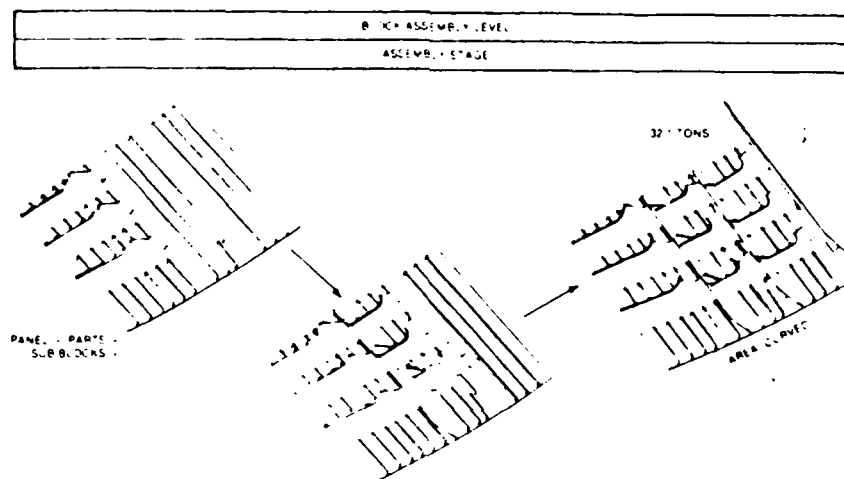


Figure A-1.14. Block Assembly - Side Shell of Engine Room.

## APPENDIX A-2 (121)

### MANUFACTURING LEVELS OF ZOFM

#### A.2.1 Component Procurement

As shown in Figures 2-8 and 2-9, component procurement is the initial manufacturing level. It produces interim products or zones for outfitting for which no further subdivision is needed by the shipyard. Typical work packages and material requisitions are grouped by zone and by area to address the separate procurement problems, i.e.,

- in-house manufacturing,
- outside manufacturing, and
- purchasing.

These problem areas are further classified by requirements for manufacturing drawings, purchase order specifications and raw materials as shown in Figure A-2.1.

After having performed groupings by zone, area and similarities in component types and sizes, further grouping is made by stage as follows:

- design and material preparation or nil,
- manufacturing or nil, and

- palletizing.

AREA	AREA SUBDIVISIONS	
	DESIGN TO FURNISH	MATERIAL TO BE FURNISHED
IN HOUSE MANUFACTURING	MANUFACTURING DRAWING	YES
OUTSIDE MANUFACTURING	MANUFACTURING DRAWING	YES/NO
PURCHASING	PURCHASE ORDER SPECIFICATION	SELDOM NO

Figure A-2.1. Area Subdivisions for Design and Material Preparations.

The palletized components are assigned to their respective work packages for subsequent manufacturing levels.

#### A.2.2 Unit Assembly and Grand-unit Joining

Just as a block is a key zone for hull construction, a unit is a key zone for outfitting which, as illustrated in Figures 2-8 and 2-9, may only require a single manufacturing level. Productivity is enhanced when units are planned which have similarities in working hours needed for assembly, numbers of components, volume, weight, design standards, etc. Grouping by such similarities facilitate organizing and uniformly loading process flow lanes.

Unit sizes vary significantly. Therefore, two problem areas are designated at the unit assembly level, i.e.,:

- large size, and
- small size.

The distinction is by lift capacity, e.g., units that weigh more or less than one ton. If many small units are planned for assembly of larger units, another manufacturing level may be included for sub-unit assembly.

Problem areas at the unit level could be further subdivided into:

- machinery unit (machinery combined with all adjacent components including foundation, pipe pieces, valves, supports, walkways, ladders, etc.),
- pipe unit (no machinery, just pipe pieces combined with valves, supports, walkways, etc.), and
- other (hatch covers with coaming, masts, etc.).

Stage for unit assembly is divided as:

- assembly, and
- welding or nil.

The welding stage applies when extensive or special welding requirements exist as welding incident to routine unit assembly is performed by fitters during the preceding assembly stage.

Machinery units have been developed into standard arrangements which are often adapted for various types and sizes of ships. As required design and material definition is already available, much planning for a standard machinery unit can progress just as if it was a single component. Pipe units are generally unique because they reflect the pipe passages and details peculiar to each type and/or size



ship even among standard series ships that are for different owners.

The grand unit joining level primarily provides for combining two or more units in order to:

- reduce the working times needed for fitting on-block and on-board, and
- produce more stable entities for erection purposes.

Classification by area is limited to:

- large size unit or nil.

Phasing by stage is:

- joining, and
- welding or nil.

The welding stage applies only if there are special or extensive welding requirements.

#### A.2.3 On-block Outfitting

Outfitting components, units and grand units are sometimes fitted in a block zone defined for hull construction. However, when they are to be fitted to ceilings, blocks should be inverted because fitting down hand enhances safety and efficiency. Therefore, the outfit zone for a block set upside down encompasses everything fitted to the ceiling. Following block turnover, the outfit zone encompasses the components, units and/or grand units fitted to the floor. Turnover represents a change in stage.

Specifying a zone per stage for each side suffices for absolute control of on-block outfitting.

Similarly, outfit items should be fitted in the zone of a double-bottom block before its tank top panel is installed. Then at a later stage, a different outfit zone encompasses everything to be fitted to the tank top. Clearly, the primary goals of this manufacturing level are to outfit ceilings and double-bottoms when blocks can be manipulated to provide ideal access.

Typically, the divisions by area address problems which are inherently different so that each work package for outfitting on-block can be assigned to the appropriate team of assembly specialists for deck, accommodation, machinery or electrical. These classifications are further subdivided by the quantities of items to be fitted resulting in the following eight problem area divisions:

- deck: large quantity or small quantity,
- accommodation: large quantity or small quantity,
- machinery: large quantity or small quantity, and
- electrical: large quantity or small quantity.

When the items to be fitted comprise a small quantity per block, outfit work can be performed at the site where the block is assembled. When a large quantity is planned, the completed block should be transferred to an indoor or outdoor region designated for outfitting in accordance with an on-flow concept, i.e., where work

packages start and complete in unison.

Separation by stage is in accordance with the following sequence which reflects block turnover:

- on-ceiling fitting,
- on-ceiling welding or nil,
- on-floor fitting, and
- on-floor welding or nil.

The welding stages apply only for special or extensive welding requirements. On-ceiling fitting and welding usually is optimum for blocks. However, most on-floor fitting and welding takes place after on-ceiling outfitting is completed, blocks are turned over, and blocks are joined to create grand-blocks. In order to simplify the erection schedule and minimize duration in the building dock, such on-floor outfitting should include all grand units, units and components to the maximum extent possible.

#### A.2.4 On-board Outfitting

Outfitting on-board seems at first to be the same as conventional outfitting. However, the work required is susceptible to the same analyses as for on-unit and on-block outfitting. As a consequence, zone/area/stage control is applicable.

Much outfit work at this level progresses simultaneously with hull erection as shown schematically in Figure 2-4. Ideally, outfitting on-board should be limited

to:

- fitting components, units and/or grand units that are too large or too heavy to fit, on-block (e.g., main engines, diesel generators, most units and grand units for engine room tank top, etc.),

- fitting fragile and weather-vulnerable components that could be damaged if installed before compartments are enclosed (e.g., joinery, insulation, electronic equipment, etc.), and

- connecting between components, units and grand units that are either fitted on-block or on-board.

One useful method of classifying work packages by problem area simultaneously addresses the teams of specialists needed, work volume sizes, and skill requirements in accordance with the following twelve categories:

- deck: similar work in small volume, high volume or high skill,

- accommodation: similar work in small volume, high volume or high skill,

- machinery: similar work in small volume, high volume or high skill, and

- electrical: similar work in small volume, high volume or high skill.

Variety work in small volume should be encompassed in an on-board zone for execution by a team having the

needed variety of skills. Variety work in large volume should be divided by similarities in components and units or sets of components and/or units. Zones for such problem areas should not be too long, wide, scattered or otherwise unfavorable for execution and supervision of work. At the same time planners must regard the need for high-skill fitting work required in many ship compartments. In such cases, large zones grouped by specific problem areas could be most beneficial.

Stage for on-board outfitting could be divided into:

- open-space (blue sky) fitting,
- open-space (blue sky) welding or nil,
- closed-space fitting, and
- closed-space welding or nil.

The welding stages apply only if there is special or extensive welding to be done. Open-space fitting and welding should be completed before closures imposed by the continuing erection of blocks in order to take full advantage of ideal access. Therefore, such work should be incorporated in the erection schedule. Closed-space fitting and welding activities should be minimized as much as practicable as they require more working hours, more transportation services, longer durations, etc.

The on-board outfitting level uses on-board divisions as zones which are subdivisions of the ship as a

zone for the erection level in the hull construction work.

#### A.2.5 Operation and Test

The operation and test level applies to work necessary for assessing the performance of each ship's functional systems. At this level zone is the entire ship.

Problems are grouped to match teams of specialists for the following areas:

- deck,
- accommodation,
- machinery, and
- electrical.

Further, operation and test is regarded as a single stage. Thus, at this level, work is packaged by one or more systems within each of the problem areas defined for the specialist teams. It is the traditional method for planning operation and test work.

## APPENDIX A-3 (122)

### MANUFACTURING LEVELS OF ZPTM

#### A.3.1 Shop Primer Painting

This manufacturing level applies to surface preparation for and application of shop primer to raw materials before they are processed to create structural parts or outfit components. Items which are to be pickled after their manufacture are usually excluded. Thus, useful divisions by problem area are:

- plate, and
- shapes and other.

The applicable stage categories are:

- shot blasting, and
- painting.

#### A.3.2 Primer Painting

This level is for the application of an anti-corrosive, including epoxy and inorganic zinc-silicate, which is the first coat applied to a component or an on-board division (as defined in ZOFM), or a block (as

defined in HBCM). These constitute the zone categories.

Problem area is grouped by:

- paint type, i.e., conventional, epoxy, inorganic zinc-silicate, etc.,
- number of coats, and
- type of zone.

The latter further classifies each component, block or on-board division, by problem area to anticipate:

- burn or wear damage of painted surfaces during HBCM and ZOFM succeeding manufacturing levels,
- difficulty if there is a change in painting conditions, e.g., downhand to overhead, low to high, spacious to confined, etc., and
- need to maintain appearance.

These considerations again demonstrate that ZPTM, ZOFM and HBCM planning must be coordinated. Painting planners have to consider the foregoing for each zone at all ZOFM and HBCM manufacturing levels.

Stage at this level is separated into the following phases:

- surface preparation,
- cleaning,
- touch up,
- painting,
- surface preparation after block turnover or nil,
- cleaning after block turnover or nil,



- touch up after block turnover or nil, and
- painting after block turnover or nil.

The work at this manufacturing level is coordinated with ZOFM so that primer is applied just before the on-ceiling fitting stage and, following block turnover, just before the on-floor fitting stage. "Nil" applies to blocks that are not turned over.

#### A.3.3 Finish Under-coat Painting

This is the semi-final manufacturing level for paint application. Useful zone classifications are:

- components (big in size or which become relatively inaccessible after fitting on-board such as masts, cargo booms, undersides of hatch covers, etc.),
- units which are to be fitted on-board,
- outfitted blocks,
- on-board divisions, and
- nil (applicable if epoxy specified).

Problem area divisions are:

- paint type,
- number of coats,
- type of zone (as described in Part A.3.2 for the primer painting level), and
- scaffolding required only for painting or not.

The classification of work packages by stage is the same as for the primer level.

#### A.3.4 Finish Painting

Finish painting is the final manufacturing level in ZPTM. Zone, area, and stage classifications are the same as in the final under-coat level except that:

- stages associated with block turnover are not applicable, and
- "nil" in the final stage "painting or nil" means a finish coat will not be applied, as in the case of epoxy.

## APPENDIX A-4 (123)

### MANUFACTURING LEVELS OF PPFM

#### A.4.1 Material Receiving

Material receiving is the preparation, or first manufacturing, level as shown in Figures 2-12 and 2-13. Problem area is grouped by types of material in accordance with the following:

- pipe, and
- flanges, elbows, tees, sleeves, etc.

Stage is simply:

- material receiving.

#### A.4.2 Pipe Fabrication

Pipe fabrication, the second manufacturing level, applies to processing of pipe only, i.e., processing of the main part of the finished pipe-piece zone. Problem area is grouped by:

- pipe material (steel, non-ferrous, polyvinylchloride, etc.),
- main pipe or branch, and

- bore (small, medium or large).

These area divisions and further subdivisions are incorporated in Figure 2-14.

Stages are phased for this level as:

- marking or cutting,
- bending of cut pipe or nil, and
- machining or nil.

Preferably, bending should be deferred for the next manufacturing level because it is easier to attach flanges or sleeves to straight pipe. The bending stage at the pipe fabrication level is only for those exceptional cases where flanges would lose their required orientations during bending. The machining process applies to the preparation of pipe ends for welded or threaded joints.

#### A.4.3 Pipe Piece Assembly

At this level flanges, sleeves, etc., are attached to cut pipe. The finished assembly is the zone for a pipe piece except for main and branch subassemblies which are to be joined to create a branch pipe piece during the next manufacturing level.

Area is subdivided as follows:

- x-ray test or nil,
- short straight (5.5 meters or less) or bent, and
- long straight (over 5.5 meters).

Stage is phased in accordance with the following

sequence:

- cut pipe joining or nil,
- assembling,
- welding or nil,
- finishing (grinding or machining) or nil, and
- bending or nil.

Cut pipe joining is for producing a cut pipe longer than a standard length of 5.5 meters. The welding and finishing stages for main and branch subassemblies are deferred until after they are joined to create a branch pipe piece during the next manufacturing level. Grinding on non-tested pipe pieces and machining on pipe pieces to be x-ray tested or on pipe for hydraulic systems are deferred for accomplishment during the next manufacturing level.

#### A.4.4 Pipe Piece Joining

The pipe piece joining level is for performing all joining not previously accomplished. Typically, it would apply to joining a main pipe subassembly to a branch pipe subassembly or to other parts such as elbows, tees, sleeves, etc. Thus, the pipe pieces finished at this level are neither simple or straight.

Area is grouped identical to that for the previous manufacturing level except that the "main or branch" subdivision shown in Figure 2-14 is not required.

Stage is phased as:

- marking and cutting or nil,
- joining,
- welding, and
- finishing (grinding or machining).

The marking and cutting stage at this level pertains to boring a hole in a main pipe subassembly as preparation for joining a branch.

#### A.4.5 Testing and Coating

Testing and coating are performed at the places where each pipe first constitutes a zone. This means places where final work for pipe piece assembly (straight or simple) and pipe piece joining (branches, etc.) are performed.

Area for testing is grouped by the different test processes required.

Stage is simply:

- testing or nil.

Area for coating is grouped by the different coating processes required.

Stage is phased as:

- pickling or nil, and
- coating or nil.

#### A.4.6 Palletizing

Palletizing is the final manufacturing level and

provides for the sorting of all pipe pieces (including electrical conduit) in accordance with structured material lists. Each list establishes the pipe piece requirements for a specific pallet, i.e., the pipe pieces required to outfit on-unit, on-block or on-board during a specific stage.

Problem areas for palletizing are:

- deck,
- accommodation, and
- machinery.

Stage is simply:

- palletizing.

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