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THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

**Flexible Production
Indices**

U.S. DEPARTMENT OF TRANSPORTATION
Maritime Administration
in cooperation with
Todd Pacific Shipyards Corporation

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FOREWORD

This publication supplements others, referenced herein, which describe various aspects of the very effective *flexible production system* developed by Ishikawajima-Harima Heavy Industries Co., Ltd. (IHI) for operating shipyards. Their use is described to show how man-hour budgeting for most work is based on certainty.

The indices are used to relate man-hours required to physical characteristics of materials that are to be fabricated, assembled, or painted. With extraordinary attention to material definition, starting in basic design, the indices permit constant refinement of manpower requirements as design progress refines material requirements. The consequence is unprecedented control of production through control of material.

The indices described herein are as for construction of ships and end products other than ships. When supplemented to address rip-out (disassembly) and open-and-inspect work, they are applicable for overhaul and modernization of naval ships. The indices are corporate experience.

A product work breakdown and product oriented material management are essential.

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The material on which the contents are based was compiled by a team for which overall management was provided by H. Nakai, President of IHI Marine Technology, Inc., New York City. Y. Okayama, Deputy Senior Manager, IHI International Division, Tokyo, is the principal author. He was assisted by T. Hatsuzaki, S. Yahiro, F. Morimoto, K. Sayarna, and T. Hotehama, Senior Engineers in IHI's Kure Shipyard assigned respectively to the Hull Construction Department, Machinery Outfitting Section, Pipe Piece Manufacturing, Shop, Sub-block and Block Assembly Section, and Painting Section. Editing and some supplemental writing were performed by L.D. Chirillo.

Appreciation is particularly expressed to E.J. Petersen who, during tenure as the Chairman of the Ship Production Committee of the Society of Naval Architects and Marine Engineers and while a Vice President of Todd Pacific Shipyards Corporation, provided valuable guidance, constant encouragement, and treasured friendship.

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This publication is an end product of one of the many projects managed and cost shared by Todd for the National Shipbuilding Research Program. The Program is a "cooperative effort by the Maritime Administration's Office of Advanced Ship Development, the U.S. Navy, and the U.S. shipbuilding industry. The objective, described by Panel SP-2 of the Ship Production Committee of the Society of Naval Architects and Marine Engineers, is to improve productivity.

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EX SCIENTIA EFFCIENS

*This book is dedicated to the memory of
a shipbuilder
from Seattle, Washington*

*Donald M. Surgenor
January 14, 1929 — January 20, 1987*

1.0 INTRODUCTION

Indices are needed to acquire realistic production ability and availability. They identify limits in manpower and facilities and are also used to:

- . estimate a shipyard's workload at first in relatively large units and as each design phase develops, in smaller units,
 - . evaluate productivity for each ship type and size and for each type of work by manufacturing level, zone, and problem area,
 - forecast manpower which will be needed and monitor manpower spent with production progress,
 - . compare budgeted man-hours with man-hours spent to detect over and under deviations for control purposes, and
 - maintain schedules by tracking interim products and compensating for late or early deviations.
- .Statistical, stochastic, and continuous exploitation of indices are production control means for preventing waste such as:
- . idle time waiting for materials, manpower, information, etc.. and
 - . man-hours charged for re-work.

.The effective use of indices results in the reduction of man-hours consumed and on-schedule delivery of interim products by a process per requirements of the next process. Good indices are evidence that systems reduce production costs and assure compliance with contract delivery dates.

1.1 Objectives of Indices

In order to be effective, any industrial endeavor must predict realistic production ability and availability. This is difficult in a market which consists of different ships and end products other than ships in varying quantities. Problems are encountered in:

- .estimating material volume,
- **evaluating productivity,**
- **allocating and leveling workloads,**
- . tracking production progress, i.e., identifying unfinished and finished work volume, and
- . monitoring manpower consumed and to be consumed.

.Indices facilitate scientific solutions.

.Indices for monitoring manpower expenditures, progress, and productivity are expressed as:

. Manpower Expenditure Index = $\text{Man-hours/Unit Time}$

. Production Progress Index = $\text{Work Volume/Unit Time}$

- **Productivity Index = $\text{Man-hours/Work Volume, or Work Volume/Man-hour}$**

Work volume is expressed in terms which employ physical characteristics of the work to be done, i.e., cutting length, welding length, erected weight, etc. Specific indices for monitoring manpower, progress and productivity consistent with a product work breakdown structure are given in Figure 1-1.

					MANPOWER EXPENDITURE INDEX	PRODUCTION PROGRESS INDEX	PRODUCTIVITY INDEX
TYPE OF WORK	HULL CONSTRUCTION	FAB	PART		MHRS/UT	FABRICATED WT/UT CUTTING LENGTH/UT	MHRS/FABRICATED WT MHRS/CUTTING LENG
		ASSEMBLY	SUB BLOCK		" "	SUB-BLOCK WT/UT SUB-BLOCK WL/UT	MHRS/SUB-BLOCK WT SUB-BLOCK WL/MHR
			BLOCK		" "	BLOCK WT/UT BLOCK WL/UT	MHRS/BLOCK WT BLOCK WL/MHR
			ERECT		" "	ERECTED WT/UT ERECTED WP/UT	MHRS/ERECTED WT ERECTED WP/MHR
	OUTFITTING	FAB	PPFM		" "	MANUFACTURED WT/UT MANUFACTURED PIECES/UT	MHRS/MANUFACTURED WT MHRS/MANUFACTURED PIECES
		ASSEMBLY	DECK		"	PARAMETRIC-COMPONENT WT/UT	MHRS/PARAMETRIC-COMPONENT WT
			MACH		"	"	"
			ACCOM		"	"	"
			ELECT		" " "	LAI D CABLE LENGTH/UT CONNECTED CABLE PIECES/UT PARAMETRIC-COMPONENT WT/UT	MHRS/LAI D CABLE LENGTH MHRS/CONNECTED CABLE PIECES MHRS/PARAMETRIC-COMPONENT WT
	PAINT	ASSEM	—		"	COATED SQUARE METERS/UT	MHRS/COATED SQUARE METER

FIGURE 1-1: Indices for Monitoring Man-hours, Progress, and Productivity. MHRS — man-hours. UT — unit time. WT — weight. WL — welding length. WP — parametric welding length taking into account weld type, size, and position. Parametric Component WT — weight of only fittings for which variations in the ratios WT/UT and MHRS/WT approximate normal distributions. The indices for Pipe Piece Family Manufacturing (PPFM) are applied separately to each work flow designated for a pipe piece family.

Work volumes are contrived separately for hull construction, outfitting, and painting and each is subdivided by manufacturing levels. As shown in Figures 1-2 and 1-3, using hull construction as an example, the manufacturing levels are fabrication, assembly and erection. Further subdivision is made by zone/problem area/stage, at first in a large frame sense, and as a design develops, in a small frame sense (from large to small mesh).

After hull construction work is so organized, workers are organized in groups which match the divided work volume as follows:

- Hull Construction Department - Work Type
- Shop/Section - Manufacturing Level/Zone¹
- Foreman (F) Group - Problem Area
- Assistant Foreman (AF) Group - Stage²

When work is categorized in accordance with a product work breakdown and workers are organized in matching groups, work becomes susceptible to statistical control by "...eliminating special causes one by one on statistical signal, leaving only the random variation of a stable process." Thus, each of the indices can be realistically expressed with a mean value and standard deviations. Work which is not in control is readily detected. Variations of indices for work in control approximate a normal distribution. Otherwise, the indices are not useful.³

Obtaining indices that are useful enough for effective shipbuilding is virtually impossible with traditional system-by-system grouping of work. Variations in each index do not approximate a normal distribution because work on one system interferes with work on other systems in many different ways. In addition system-by-system work packages are relatively large in scope. As they must be scheduled for implementation over prolonged periods, it is very easy for supervisors to mischarge in order to avoid having to explain why work was not performed as scheduled. As a consequence, achieving normal distributions of index variations is impossible. Feedback contains little that qualifies as the *corporate* experience necessary to constantly develop a shipyard management system.

A product work breakdown that facilitates classification of work by problem categories regardless of design details, is essential. The work circumstances for each such category are predictable and opportunity exists to achieve statistical control. See Figures 1-4 and 1-5.

The product work breakdown used in the world's most effective shipyards consists of the:

- . Hull Block Construction Method (HBCM),
- Zone Outfitting Method (ZOFM),
- . Zone Painting Method (ZPTM), and
- Pipe Piece Family Manufacturing Method (PPFM).⁴

1.2 Relationship Between Indices and Budget Control System

Budgets are made for all projects, i.e., for each ship and end product other than a ship. Each budget is estimated in two accounts, i.e., for direct and indirect costs. Each of the accounts is categorized into three parts: manpower, material, and other expenses. Other expenses, e.g., for tug services, launching ceremony, etc., are independently estimated because they cannot be derived from productivity indices. They are not discussed herein.

All materials required for a project are first described in a Basic Material List (MLB), sometimes called a Budget Control List, prepared by estimators. Each MLB contains about 650 cost classifications and is divided to separately show materials required for hull, deck, accommodation, electrical, and painting (H/DAME/P) specialties. Material amounts for each clarification are given as quantities and weights or just weights. Exact quantities are given for items such as a main engine or an auxiliary machine. Estimated quantities are given for other items such as steel plate, valves, pipe, and paint. Actual weights, when available, or estimated weights are always included.⁵

¹ With regard to usage of "shop/section", *shops* deal with *fabrication* such as the manufacture of hull parts and pipe pieces. *Sections* are responsible for *assembly* work only. *Shop* has the connotation of a fixed work place. *Section* implies flexibility and movement to wherever work is to be performed. Otherwise shop and section are the same.

² The titles *F-group* and *AF-group* designate organizations for which foremen and assistant foremen have cognizance respectively. Thus the organization hierarchy as employed by IHI and used herein is: shipyard, department, shop/section, F-group, and AF-group. A shop/section has more than one F-group and an F-group has more than one AF-group. For typical F-group and AF-group responsibilities see Figures 4-1 (Hull Construction), 5-1 (Outfitting), 6-1 (Painting), and 7-1 (Pipe Piece Manufacturing) of the National Shipbuilding Research Program (NSRP) publication "Flexible Production Scheduling System - April 1986".

³ The quotation is from W. Edwards Deming, "Quality, Productivity, and Competitive Position", MIT Center for Advanced Engineering Study, Cambridge, MA 1982, p. 119 (ISBN 0-911379-00-2).

⁴ See the NSRP publication "Product Work Breakdown Structure - Revised November 1982". Other pertinent NSRP publications include: "Integrated Hull Construction, Outfitting, and Painting - May 1983", "Design for Zone Outfitting - September 1983", "Shipyard Organization and Management Development - October 1985", and "Flexible Production Scheduling System - April 1986".

⁵ H/DAME/P represents a basic separation by problem categories, i.e., hull (H) work problems are inherently different from outfitting (DAME) and painting (P) work problems, and deck (D), accommodation (A), machinery (M) and electrical (E) work problems are sufficiently different from each other to justify separate classifications. For warships other classifications would be added, e.g., weapons (W) and nuclear (N).

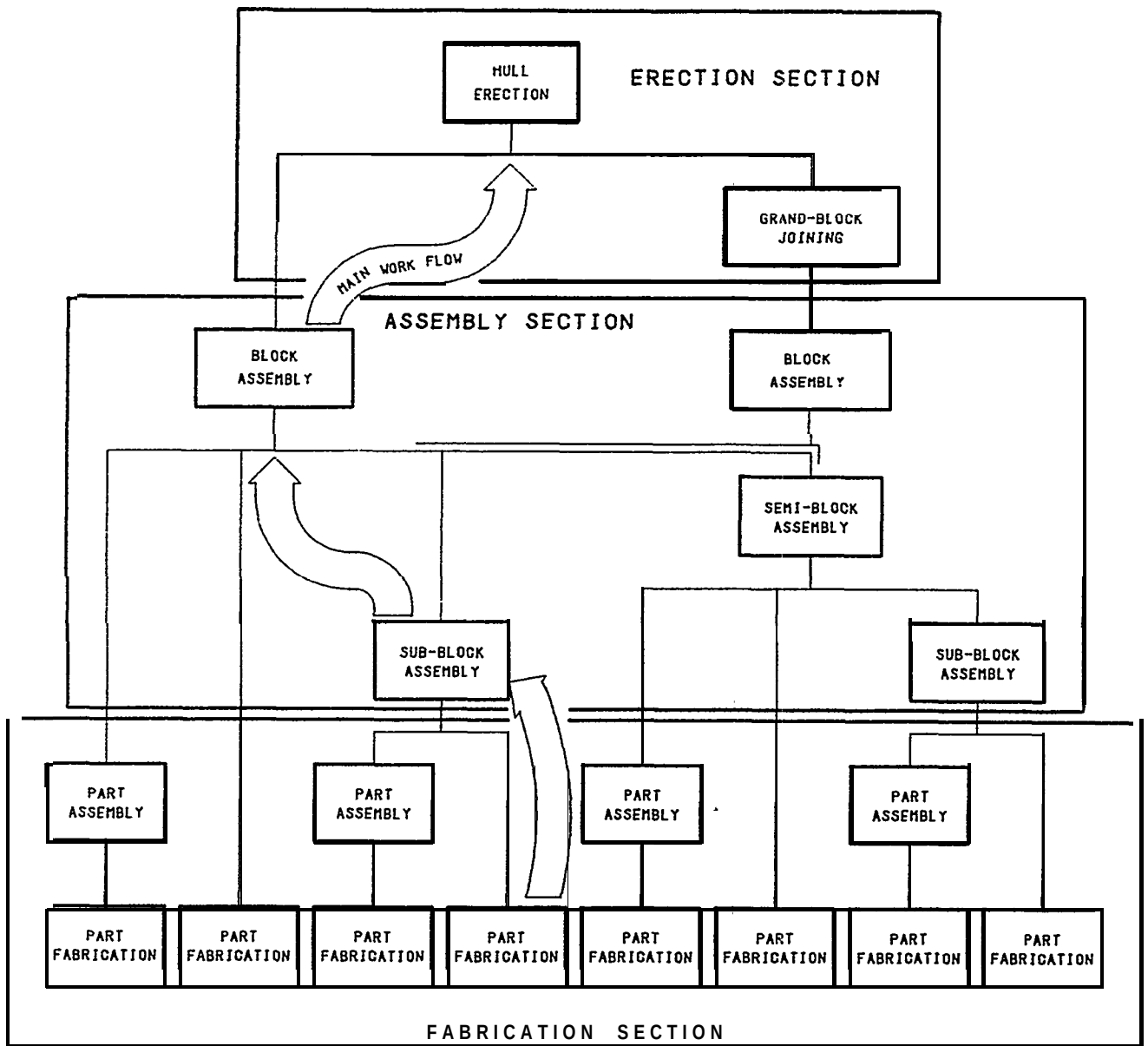
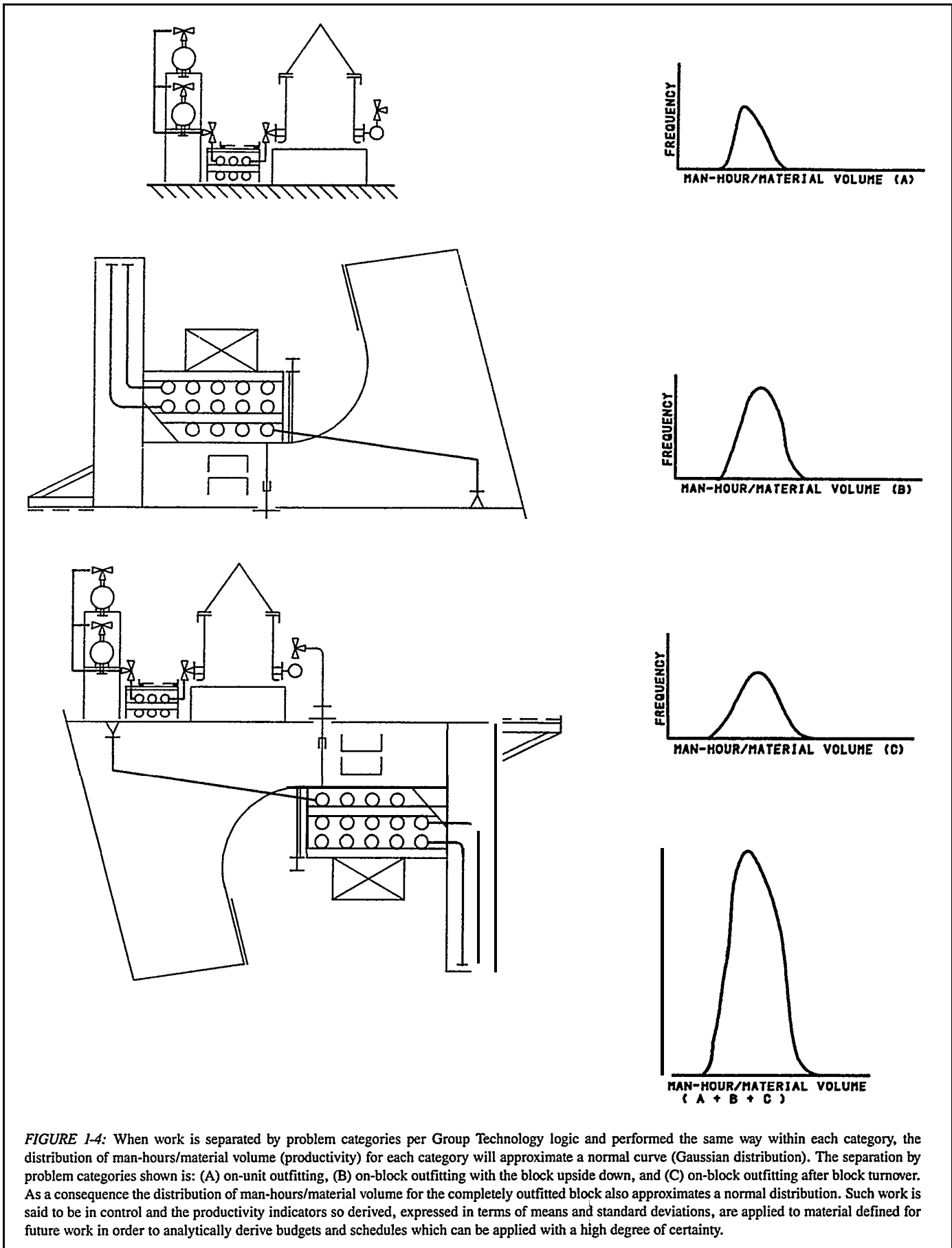
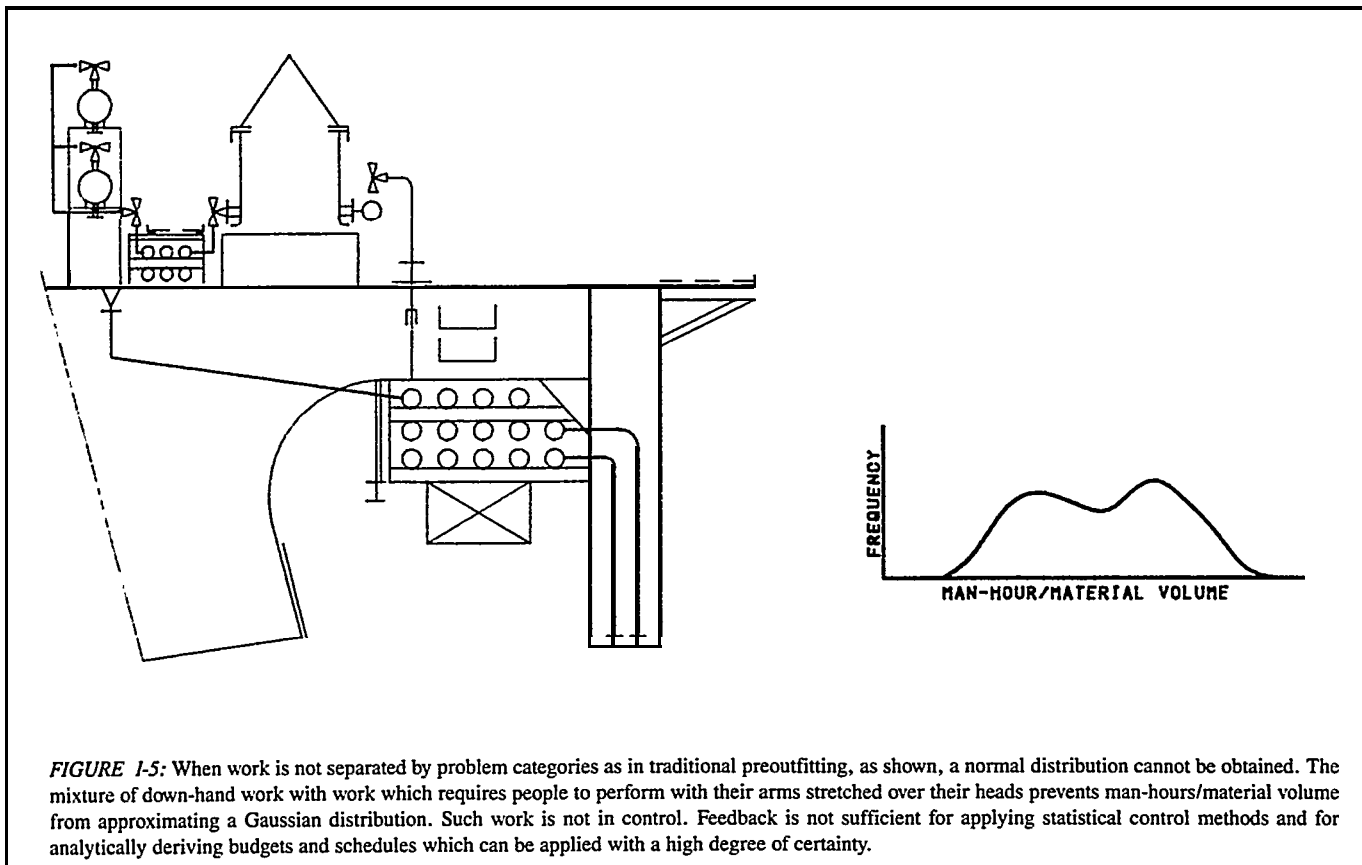


FIGURE 1-2: Typical Manufacturing Levels for the Hull Block Construction Method (HBCM).

PLAN'S LEVEL	'F' & EVEL	PRODUCT ASPECTS										CODES				
		ZONE	AREA					STAGE					ZONE	AREA	TAG	
1	7	SHIP	BLOCK	NIL	FORE HULL	CARGO HOLD	ENGINE ROOM	AFT HULL	SUPERSTRUCTURE	TEST						
					FLAT PANEL	CURVED PANEL	SUPERSTRUCTURE	ERECTION								
BACK PRE-ERECTION	NIL															
PRE-ERECTION	NIL															
2	6	BLOCK	NIL	FLAT	SPECIAL FLAT	CURVED	SPECIAL CURVED	SUPERSTRUCTURE	JOINING	NIL						
									ASSEMBLY							
3	5	BLOCK	NIL	FLAT	SPECIAL FLAT	CURVED	SPECIAL CURVED	SUPERSTRUCTURE	BACK ASSEMBLY	NIL						
									FRAMING					NIL		
4	4	SUB BLOCK	NIL	SIMILAR WORK CONTENT IN A LARGE QUANTITY				SIMILAR WORK CONTENT IN A SMALL QUANTITY				PLATE JOINING	NIL			
												ASSEMBLY				
5	3	SUB BLOCK	NIL	SUB-BLOCK PART				BUILT-UP PART				BACK ASSEMBLY	NIL			
												ASSEMBLY				
6	2	PART	PARALLEL PART FROM PLATE	NON PARALLEL PART FROM PLATE	INTERNAL PART FROM PLATE	PART FROM ROLLED SHAPE	OTHER	BENDING	NIL							
								ASSEMBLY								
7	1	PART	PARALLEL PART FROM PLATE	NON PARALLEL PART FROM PLATE	INTERNAL PART FROM PLATE	PART FROM ROLLED SHAPE	OTHER	BENDING	NIL							
								MARKING & CUTTING								
									PLATE JOINING	NIL						
SECTION F-GROUP AF-GROUP																
CODES																
ZONE AREA TAG																
SHIP NO. GRAND BLOCK CODE GRAND BLOCK CODE BLOCK CODE STAGE CODE STAGE CODE																
BLOCK CODE BLOCK CODE STAGE CODE STAGE CODE																
SEMI-BLOCK CODE SEMI-BLOCK CODE STAGE CODE STAGE CODE																
SUB-BLOCK CODE ASSEMBLED PART CODE STAGE CODE STAGE CODE																
PART CODE PART CODE STAGE CODE STAGE CODE																

FIGURE 1-3: Typical Classifications by Product Aspects for the Hull Block Construction Method (HBCM).





Weight (wgt) summarized for each of the H/DAME/P groups is the *material volume* for each group. When a productivity indicator peculiar to each group is applied, work volume in man-hours (mh) is obtained:

$$\text{work volume,} = \frac{\text{material volume, (wgt)}}{\text{productivity index, (mh/wgt)}}$$

where $i = \text{H/DAME/P}$

Because of the correlation when work is in statistical control, most work volumes are obtained from material volumes. Sometimes other factors are applied such as for taking into account the different degrees of difficulty experienced with various owners and regulators.

When a new type of ship is to be built, the foregoing analytical approach for determining H/DAME/P work volumes can only be used for work problem categories for which there is prior experience. For example, when the first exotic coatings were required for product-carrier tanks, estimators and product engineers had to collaborate on how to predict work volumes because there were no applicable productivity indices. In another case, because the H/DAME/P productivity indicators were derived from shipbuilding experiences, a project team was organized to determine how and where to apply existing H/DAME/P indicators for building an offshore platform.

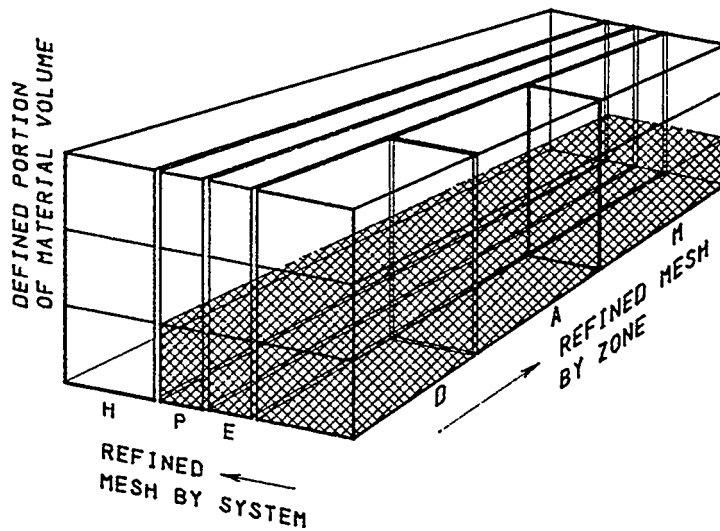
Following initial budgeting, based on a contract design and grouping of material by H/DAME/P, material volume is further

refined as system diagrammatics and their material lists (MLS) are produced. The consequence of this refinement is fed back to effect the first revision to the MLB. The latter consists of intermediate-size frames of material reflecting systems divided by H/DAME/P each of which is subdivided into 3 to 7 material ordering zones sequenced per the build strategy. Productivity indicators peculiar to this intermediate level are applied to obtain work volumes for each hull block and on-board zone per shop/section while maintaining the H/DAME/P divisions. This systematic refinement of material volume commensurate with the progress of design phases is illustrated schematically in Figure 1-6.

The next or third material budgeting effort effects Revision 2 to the MLB by grouping materials per pallet (MLF), i.e., fittings needed for a work package classified by zone/problem area/stage. Productivity indicators peculiar to this third level are applied to obtain work volume per pallet.

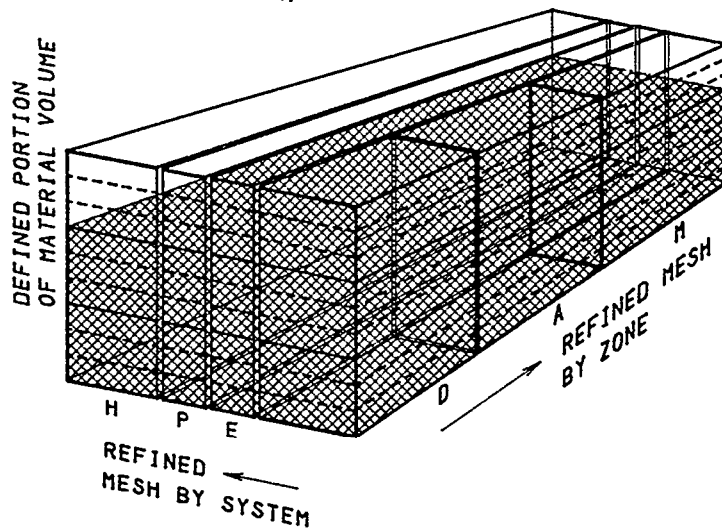
A fourth level of material definition addresses material required for manufacturing pipe pieces (MLP) and components other than pipe pieces (MLC), e.g., ladders. But, as a practical matter, this definition is performed simultaneously with that for pallets and is included in Revision 2 to the MLB.

Depending on the manufacturing level involved, problem area classifications, how shop/section supervisors are assigned, and subcontracting policies, work volumes obtained from material volumes are used to estimate work volumes for F-groups, AF-groups, and subcontractors.



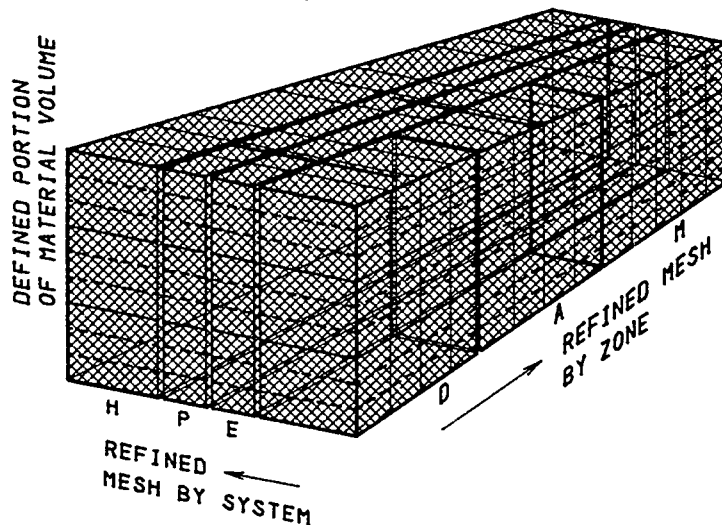
BASIC DESIGN

Material volume and Budget is definitively and preliminary defined by MLB and Budget Control List (RO) With defined Level of the contract drawings and specifications by system in rough mesh.



FUNCTIONAL DESIGN

Material volume and budget to be preliminarily and definitively refined and defined by MLS and Budget Control List (R1) with further defined level of the functional drawings and purchase order specifications by system in fine mesh.



WORK INSTRUCTION DESIGN

Material volume and budget to be definitively refined and defined by MLF/P/C and Budget Control List (R2) with finally defined level of the fitting and fabrication drawings by zone in finest mesh.

FIGURE 1-6: Material Definition Progress Commensurate with Phase-by-Phase Design Development.

ACTIVITIES LEVELS	DESIGN	MATERIAL DEFINITION		MAN-HOUR ALLOCATION	
		LIST	GROUPING BY ZONE AND SYSTEM	SCHEDULE	GROUPING BY FRAME AND GROUP
LARGE	BASIC	MLB	- DAME - DIGITS * 2, 3, OR 4	MASTER	- FKLD - HOP DEP'TS **
MEDIUM	FUNCTIONAL	MLS PRELIMINARY PALLET DEFINITION	- DAME/ PURCHASE ZONE - 4 TO 9 DIGITS	SHOP OR SECTION	- FRAMED ZONE - PROCESS YARD/ SHOP OR SECTION
SMALL	TRANSITION	FINAL PALLET DEFINITION	—	—	—
	WORK INSTRUCTION	MLF	- DAME/ PALLET - 9 DIGITS/ PIECE NO.	MONTHLY WEEKLY	- PALLET - F-GROUP - PIECE/ PALLET - AF-GROUP

FIGURE 1-7: Matrix of Outfitting Levels vs. Activities. * Nine digits provide complete definition. But, complete definition is only needed during basic design for exceptional items such as a main engine. ** Man-hour cumulative schedules which prove feasibility of a Master Schedule are prepared by staff engineers at the department level. The Master Schedule is issued by the Production Control Department which reports directly to the General Manager. F — start fabrication. K — keel laying. L — launching. D — delivery. HOP DEP'TS — hull construction, outfitting, and painting departments. SHOP is associated with *fabrication* work and SECTION is associated with *assembly* work. Otherwise, they are organizationally equivalent. F — foremen. AF — assistant foremen.

In the traditional approach, man-hour budgets are not sufficiently linked to material requirements. For example, during basic design man-hours/unit weight is not expressed accurately enough nor separately for the H/DAME/P specialties. Also, in the traditional approach, man-hours are usually budgeted once and without systematic refinement as each design phase makes more information available. As a consequence of not having total work volume divided by H/DAME/P and not refining work volume into smaller divisions commensurate with design development, traditionalists cannot impose realistic budgets and schedules based upon normal performance of work.

Evidence of the foregoing, is the frequent late deliveries, cost overruns, and shipbuilder claims which characterized building U.S. Navy ships in the mid 1970s. Due to a change in policy which suddenly allowed more time and more funds, the entire industry suddenly entered an era where all naval ships were delivered "ahead of schedule" and "under budget". In the context of the product oriented approach applied by IHI such advertisements are surrealistic because schedules and budgets are the control mechanisms needed to maintain the coordination of work flows. If a schedule or budget is not met, either by performance being over or under, something is wrong.⁶

Figure 1-7 shows the relationships between outfitting material volume (material definition) and outfitting work volume (man-hour allocations) that are maintained in the budget control system as design progress makes more definitive information available.

1.3 Concept of Indices

As a competitive measure, shipyards now have to feature flexible production methods. Upon contract awards, designs for different end products to be built are only definitized in a large-frame sense. Because of the absence of detail designs at the beginning, shipbuilding is more difficult than most other manufacturing endeavors. Upon each contract award the accuracy of estimated work volume is commensurate with the quality of information grouped by basic designers. When the grouping is performed by specialists in accordance with H/DAME/P, the quality of information grouped is far more useful than information traditionally grouped only system by system.

⁶ "In Japan the word *takuto* is used when referring to implementation of integrated schedules for different types of work inherent in shipbuilding. *Takuto* is derived from the German word *takstock* which means *baton*. In the *takuto* concept, the principle operating manager of a shipyard is envisioned as a conductor who controls many musicians to insure the same tempo. Given that schedules for different types of shipbuilding work are integrated and based upon ranges of variation for processes in statistical control, anyone being ahead of schedule when building ships becomes as detrimental as an orchestra member who exceeds the prescribed tempo." See the NSRP publication "Flexible Production Scheduling System - April 1986".

H/DAME/P separations applied during contract design represent the first subdivision by problem categories per Group Technology logic. Traditional system-by-system grouping, even for a series of ships of the same kind, does not adequately reflect problems that will be encountered. In other words, there are infinite ways that work on one system conflicts with work on other systems. While individuals become skilled in resolving such conflicts, there is no way for their experiences to become useful corporate knowledge.

Of course, subsequent refinement of work volumes with refinement of material volumes as shown in Figure 1-7, make the product-oriented H/DAME/P approach with its specialized indices far more effective than the traditional system-oriented approach. The values associated with the specialized indices are far more descriptive of each shipyard's unique capabilities.

Monitoring manpower expenditures, production progress, and productivity is performed on the basis of such indices. Planners apply the indices that are peculiar to their specialties and their positions in the decentralized planning system. Commensurate with Figure 1-7, planners for large-frame work volumes are assigned to the Production Control Department. For intermediate-frame work volumes, they are assigned to the Hull Construction, Outfitting, and Painting Departments. And for final planning, in a small-frame sense, planners are assigned to fabrication shops and assembly sections. The indices are prerequisites for planning and are defined independently at each level on the basis of production (man-hours) and design (material) statistical data which have been accumulated from past construction projects.

Note should be made that the use of standard processes and standard materials, including vendor catalog items regarded as shipyard standards, cause the indices to become more effective. Conversely, the indices focus constant attention on the cost benefits of standard design details and arrangements, materials, and work processes so that they become, literally, standards of the moment because they are always susceptible to bit-by-bit improvement.

Figure 1-8 shows relationships of planning (including design) with scheduling prerequisites. Planning per se is refined continuously as each design phase makes more information available. Basic planning progresses with basic design, intermediate planning with functional and traditional design, and final planning with work instruction design. Each design phase provides refined material volume which is the basis for refining man-hours required for scheduling.

Figure 1-9 shows the rough and, later, exact parametric weight inputs in the scheduling sequence. Basic planning uses statistically derived data from past construction projects to produce S-curves per ship per department and per shop/section which are used to make long-term forecasts of shop/section workloads. As soon as rough material volumes become available, as a consequence of functional and transition design for each ship, shop/section staff engineers apply parameters, statistically derived from past projects, to produce ship-by-ship shop/section schedules.

ORGANIZATION LEVEL DESIGN AND PLANNING PHASE	SHIPYARD	DEPARTMENT	SHOP/SECTION	F-GROUP	AF-GROUP
BASIC DESIGN & PLANNING	BAR CHART/ ALL SHIPS	S-CURVE/ALL SHIPS	S-CURVE/ SHIP		
FUNCTIONAL & TRANSITION DESIGN & INTERMEDIATE PLANNING			ROUGH MATERIAL VOLUME/ WORK PACKAGE		
WORK INSTRUCTION DESIGN & FINAL PLANNING				FINE MATERIAL VOLUME/ WORK PACKAGE	NUMBERS OF WORKERS/ CRAFT

FIGURE I-8: Relationships of design and planning with scheduling prerequisites by organization level as facilitated by a product work breakdown structure.

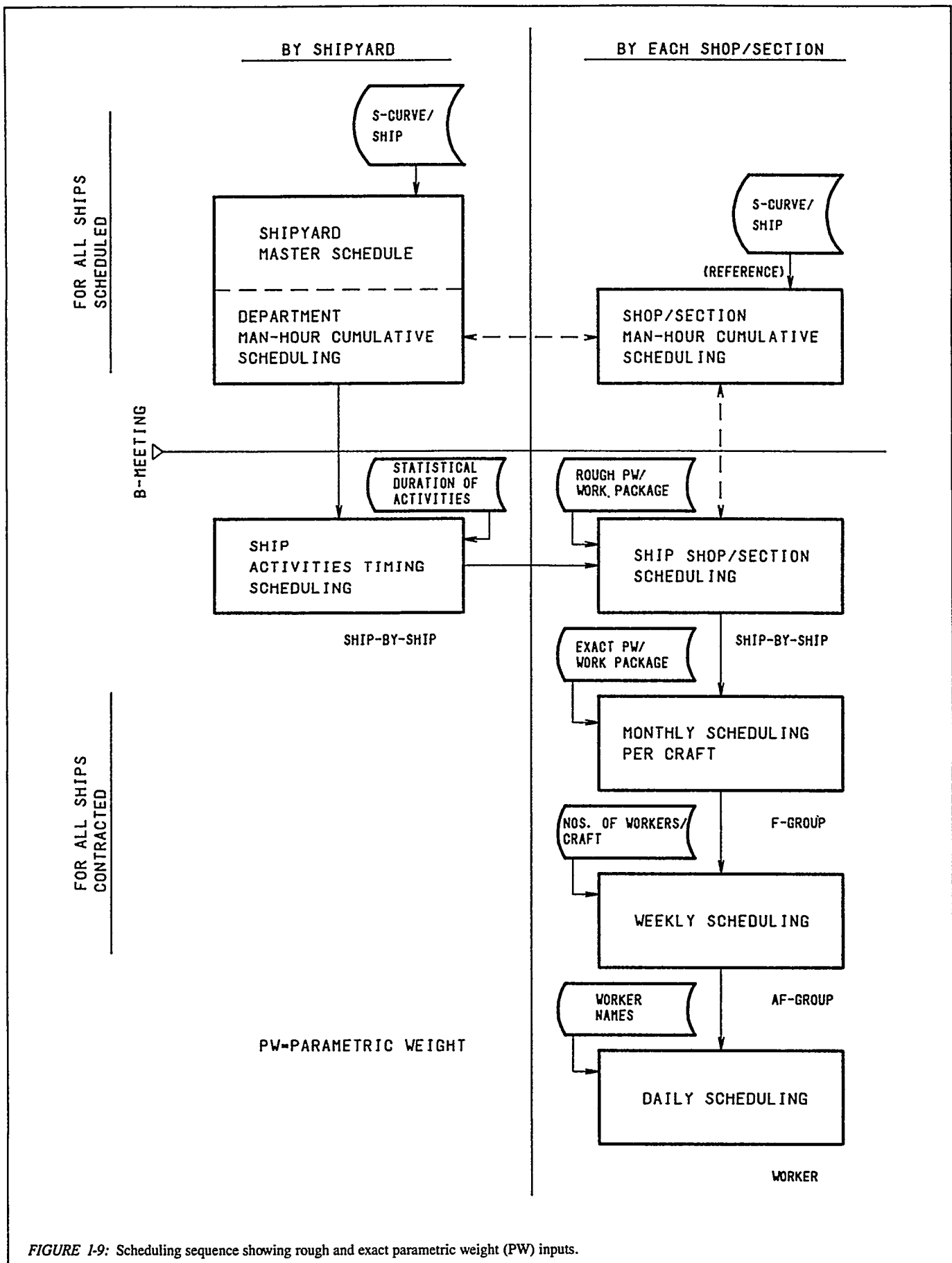


FIGURE 1-9: Scheduling sequence showing rough and exact parametric weight (PW) inputs.

When exact material volumes become known (MLF, MLP and MLC), foremen apply parameters, statistically derived from past projects, to produce monthly schedules per craft. Thus, scheduling activities are decentralized with linkage between levels.

1.4 Relationship Between Indices and the Flexible Production Scheduling System (FPSS)⁷

The relationship between a FPSS and its supporting elements as illustrated in Figure 1-10, is necessary to maintain high productivity when building a wide variety of different end products in varying quantities including one of a kind.

With reference to the management cycle shown in Figure 1-11:

- the estimating function produces rough budgets for material volume and work volume grouped by H/DAME/P,
- the planning function, which includes design, regroups and refines information so as to eventually allocate material volume by product-oriented work packages (work per zone/area/stage) and calculate their manpower requirements by using productivity indicators,
- the scheduling function fixes a duration and assigns calendar dates for each work package, i.e., start and finish dates,
- the execution function implements work and monitors progress of manpower consumption and materials processed, and
- the evaluation function computes productivity, e.g., products processed per manpower consumption.

As further shown in Figure 1-11, all functions feed back to preceding functions for updating or accuracy enhancement of indices.

1.5 Consistent Concept for Product Work Breakdown Structure (PWBS), Manpower Organization Structure (MOS), and Index Systems

Planning (includes design) phases correspond to organization levels. Production work is estimated, planned, scheduled, executed, and evaluated against measuring units which employ physical characteristics of the interim products being produced. Weight is universally used during the basic planning phase even for painting. A parameter based on past experience is applied to convert hull weight into square meters. Square meters are then used to make the first prediction of total painting man-hours required.

For hull construction during the intermediate planning phase, shop/section man-hour requirements are predicted based upon estimated cutting and welding lengths. This is the most difficult and critical planning phase because design and

material definition are not yet complete while the man-hours predicted will be the basis for preparing shop/section schedules which are to provide primary control for integrated hull construction, outfitting, and painting (IHOP).

For outfitting, attempts in IHI shipyards to associate man-hour requirements by type and size of outfitting components proved to be impractical. Data collected indicated that variation in man-hours consumed per components of the same classification, didn't approximate a normal distribution. For example, sometimes because of its location and orientation, a large and heavy pipe piece required less fitting man-hours than a small pipe piece.

A practical approach was found by regarding all outfit components in a pallet, except machinery items, to have the same man-hour/weight ratio. 'At the intermediate planning level, rough pallet weights are employed and at the final planning level actual pallet weights are substituted. Auxiliary machinery is simply ignored because actual bolting of an auxiliary machine to its foundation is nominal. Complex installations such as a main engine and its driveline, are treated as special cases for which traditional methods relate man-hours to engine type and size, shaft length, etc. Thus, for all types of fitting components mixed together in a pallet, IHI found that weight was a practical measuring unit that facilitated control.

Man-hour consumption may exceed the budget while progress is behind schedule. Obviously, this indicates trouble. Conversely, man-hour consumption may be less than the budget while progress is ahead of schedule. This seems to be a good condition, but there is reason for concern. Performance is not in accordance with the budget and schedule which are control mechanisms for integration and the basis for bidding future work. If an improved method caused the decrease in man-hours and caused progress to be ahead of schedule, upon confirmation, all budgets and schedules should be revised as necessary to: reflect the new capability, insure integration of remaining work, and become the basis for bidding future work.

Performances relative to a budget and to a schedule cannot be evaluated separately. The common reference which links them is material volume. Whether material volume is expressed as weight, welding length, or painting area, etc., is determined for different types of work based on experience. Thus, material volume is the only tangible that affords managers and planners effective means for assessing production performance.

In order to be useful, each index must represent a population of work packages (pallets) that have the same problem classification. If performance data from work packages of different problem classifications are mixed, e.g., mixing flat-panel block assembly with curved-panel block assembly or mixing on-block outfitting with on-board outfitting, normal variation of man-hours per material volume is unobtainable. A mean value for a distribution that is not normal would be useless for stochastic forecasting of man-hour requirements.

⁷FPSS is described in the National Shipbuilding Research program publication "Flexible Production Scheduling System - April 1986".

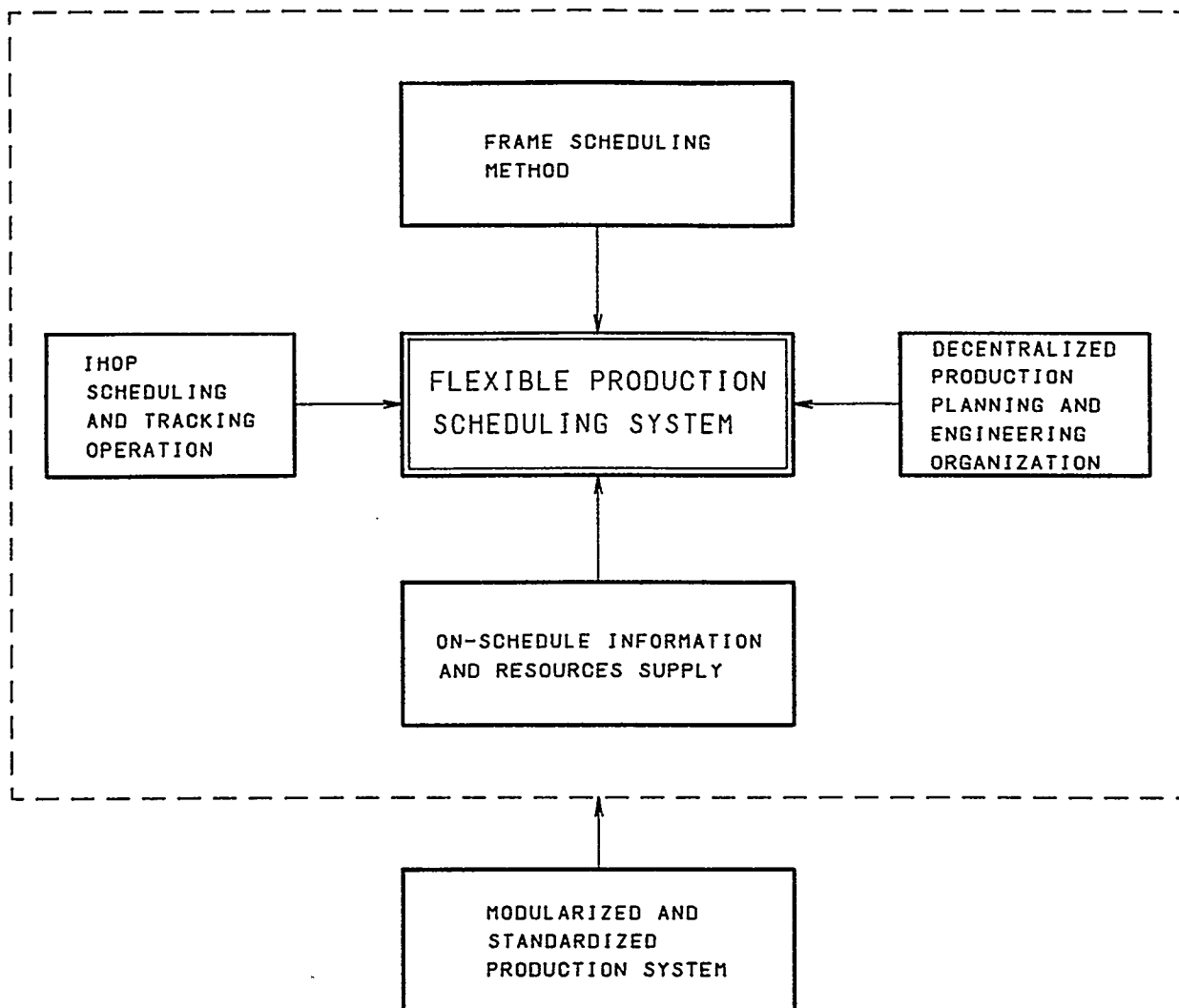


FIGURE 1-10: Relationship between Flexible Production Scheduling System and its supporting elements. IHOP — integrated hull construction, outfitting, and painting.

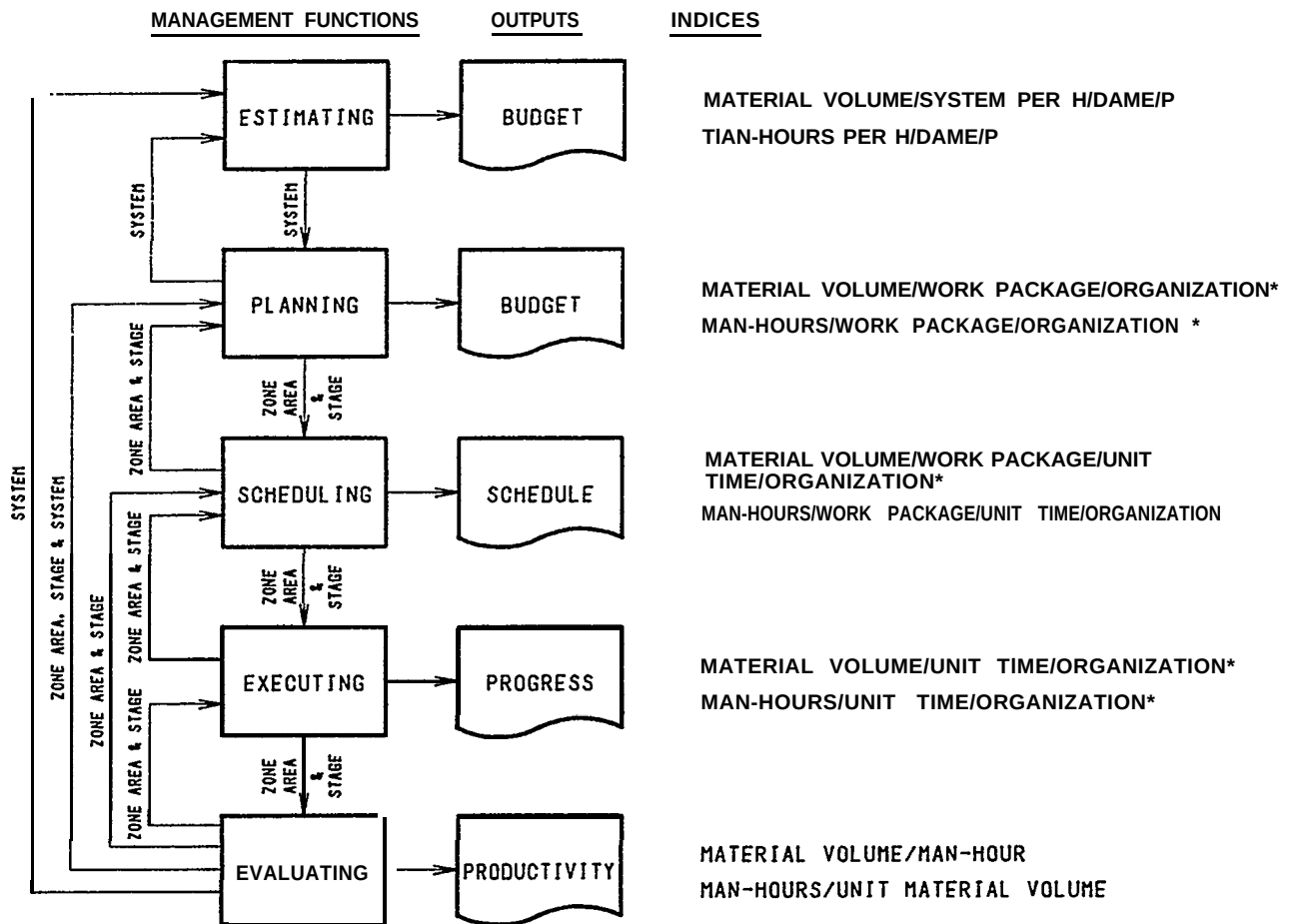


figure 1-11: Indices for Monitoring Manpower, Progress, and Productivity relative to the Management Cycle. * Organization = shop/section, F-group, or AF-group. H/DAME/P represents the following specialties respectively: hull construction, deck outfitting, accommodation outfitting, machinery outfitting, electrical outfitting, and painting.

Also, the spread of a normal distribution is indication of the degree of decentralized authority that must exist. For example, the normal distribution of man-hours/unit volume for outfitting on-unit would be very narrow compared to that for outfitting on-board. The latter requires more experienced supervisors to transfer people from work flows that are ahead to those that are behind and to have more authority to use overtime when necessary.

Index systems for monitoring manpower, progress, and productivity have to be organized the same way as people, information, and work so that all reflect the same PWBS.

Figures 1-2 and 1-3 and Figures 1-12 through 1-17 show a proven PWBS for the HBCM, ZOFM, ZPTM, and PPFM. The figures show how the products are broken down hierarchically and how they are assigned to shop/sections and F- and AF-groups. The basis for the breakdown and grouping is the product aspects zone/large/stage.

Indices applied at each manufacturing level correspond to the level of design and planning achieved, as previously shown in Figure 1-8, and also correspond to how people are organized.

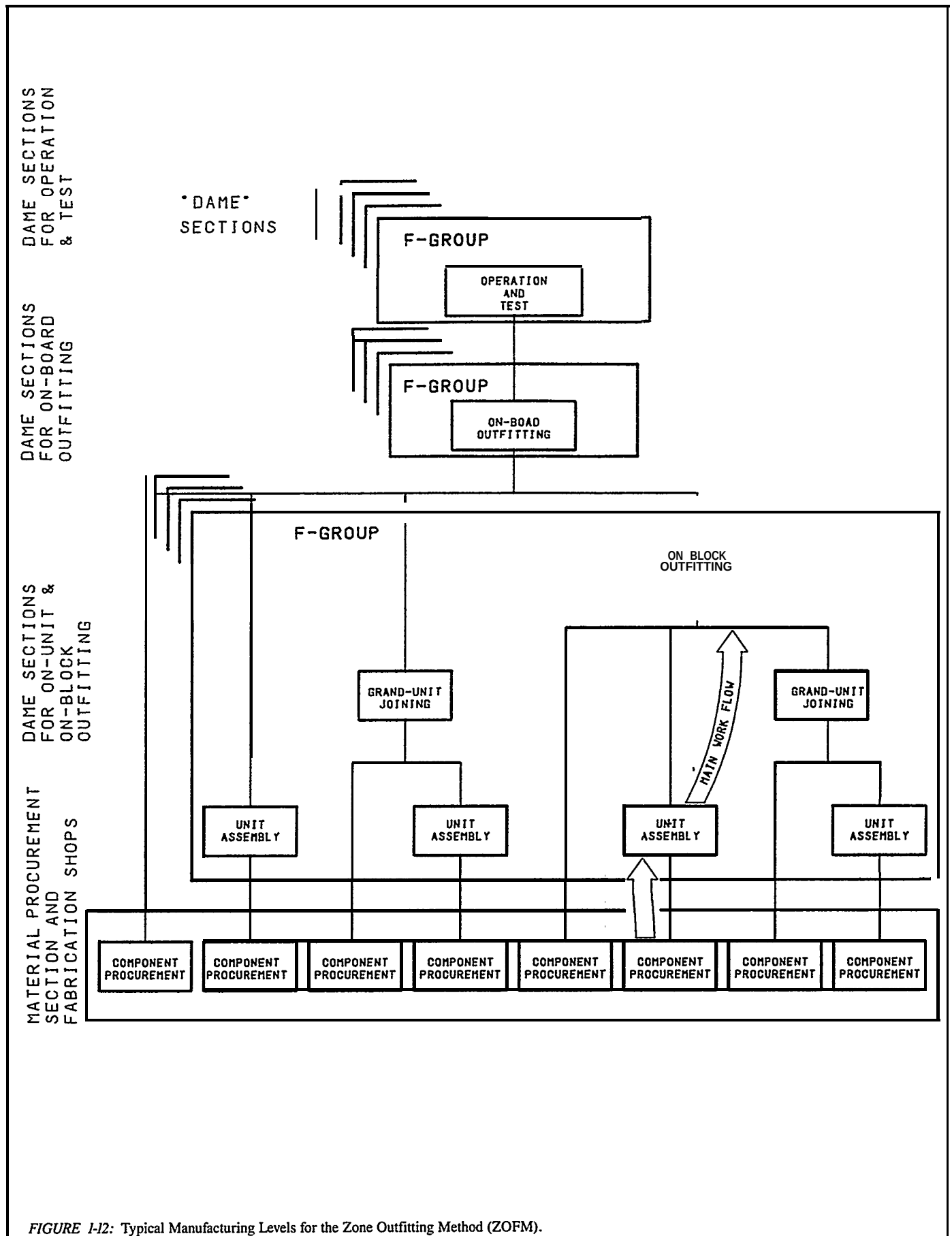


FIGURE 1-12: Typical Manufacturing Levels for the Zone Outfitting Method (ZOFM).

PLAN LEVEL		F'G LEVEL	
1	6	2	5
3		4	3
5	2		
6			

PRODUCT ASPECTS											
ZONE		AREA				STAGE					
SHIP	DECK (D)	ACCOMMODATION (A)	MACHINERY (M)	ELECTRICAL (E)	OPERATION AND TEST						
					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	
										WELDING	NIL
										ON-OPEN SPACE FITTING (BLUE SKY)	
LOCK	NIL	SPECIALTY/COMPONENTS IN A LARGE QUANTITY	SPECIALTY/COMPONENTS IN A SMALL QUANTITY		WELDING	NIL					
					ON-FLOOR FITTING						
					WELDING	NIL					
					ON-CEILING FITTING						
UNIT	NIL	LARGE SIZE UNIT	NIL		WELDING	NIL					
					JOINING						
					WELDING	NIL					
					ASSEMBLY						
COMPONENT		IN-HOUSE MANUFACTURING	OUTSIDE MANUFACTURING	PURCHASING	PALLETIZING						
					MANUFACTURING	NIL					
					DESIGN AND MATERIAL PREPARATION	NIL					

CODES									
ONE	REA	AGE							
SHIP NO	SHIP NO	OPERATION CODE							
ON-BOARD DIVISION	BLOCK CODE	HULL ERECTION STAGE CODE							
OUTFITTING SIGN/ BLOCK CODE	WORK TYPE CODE	BLOCK ASSEMBLY STAGE CODE							
UNIT ASSEMBLY SIGN/BLOCK OR ON-BOARD DIVISION OR MACHINERY UNIT CODE	BLOCK OR ON BOARD DIVISION OR MACHINERY UNIT CODE	GRAND UNIT SIGN							
EQUIPMENT PROCUREMENT CODE	UNIT SIGN								
NO SIGN									

F-GROUP

AF-GROUP

FIGURE 1-13: Typical Product Aspect Classifications for the Zone Outfitting Method (ZOFM).

PAINTING, SECTION

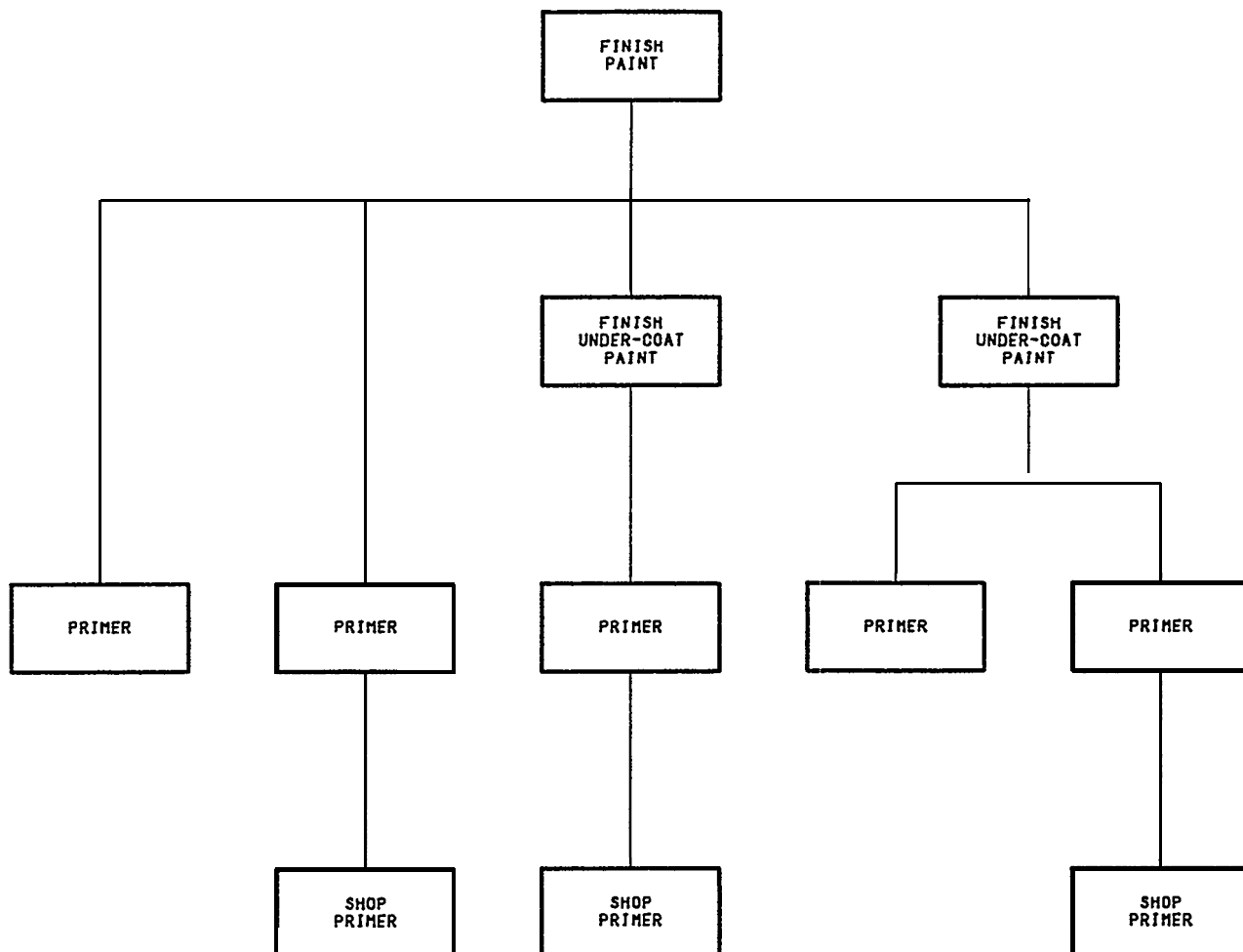


FIGURE 1-14: Typical Manufacturing Levels for the Zone Painting Method (ZOPM).

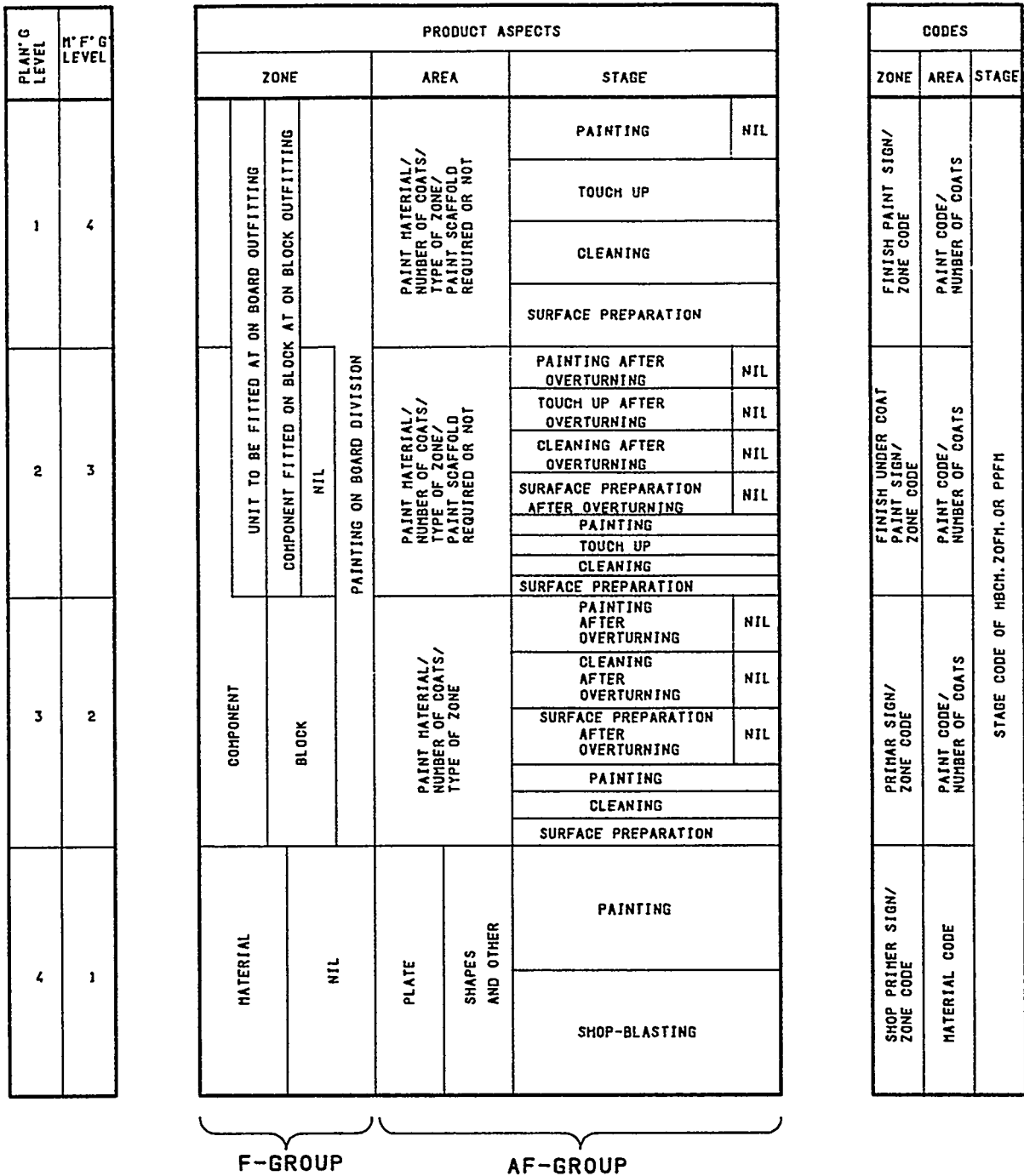


FIGURE 1-15: Typical Classifications of Product Aspects for the Zone Painting Method (ZOPM).

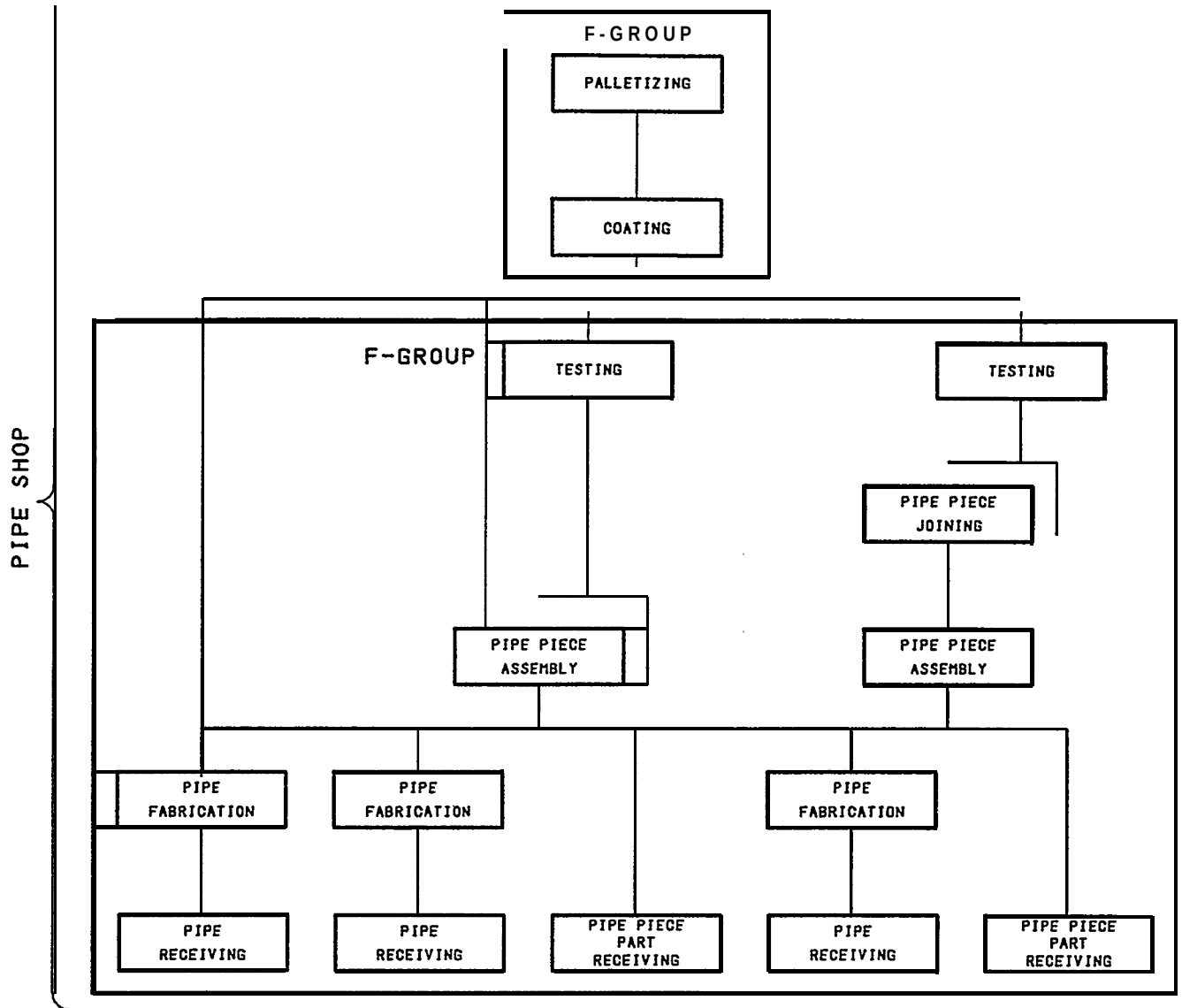


FIGURE I-16: Typical Manufacturing Levels for Pipe Piece Family Manufacturing (PPFM).

PLAN 'G LEVEL	M' F' G LEVEL
1	7
2	6
3	5
4	4
5	3
6	2
7	1

PRODUCT ASPECTS							
ZONE		AREA			STAGE		
PALLET		DECK INCLUDING ELECTRICAL	ACCOMMODATION INCLUDING ELECTRICAL	MACHINERY INCLUDING ELECTRICAL	PALLETIZING		
PIPE PIECE	NIL	COATING PROCESS			COATING	NIL	
					PICKLING	NIL	
		TEST PROCESS			TESTING	NIL	
					PIPE MATERIAL/ X-RAY OR NIL/ BORE/STRAIGHT OR BENT/ LENGTH		
		PIPE MATERIAL/ X-RAY OR NIL/ MAIN OR BRANCH/ BORE/STRAIGHT OR BENT/LENGTH			WELDING		
					JOINING		
	MARKING & CUTTING				NIL		
	BENDING ON PIPE PIECE				NIL		
	FINISHING				NIL		
	WELDING				NIL		
	CUT PIPE	NIL	PIPE MATERIAL/PIPE MAIN OR BRANCH/ BORE			ASSEMBLY	
						CUT PIPE JOINING	NIL
MACHINING						NIL	
				BENDING ON CUT PIPE		NIL	
				MARKING & CUTTING			
MATERIAL		PIPE	PIPE PIECE PART	RECEIVING			

F-GROUP

AF-GROUP

CODES		
ZONE	AREA	STAGE
PALLET CODE	SHOP NO.	SHOP NO.
PIPE PIECE NO.	COATING CODE	COATING CODE
	PIPE PIECE MANUFACTURING LANE CODE	PIPE PIECE MANUFACTURING LANE CODE
PIPE PIECE NO. / MAIN OR BRANCH SIGN	PIPE PIECE MANUFACTURING LANE CODE	PIPE PIECE MANUFACTURING LANE CODE
MATERIAL CODE	MATERIAL CODE	NIL

FIGURE 1-17: Typical Product Aspect Classifications for Pipe Piece Family Manufacturing (PPFM).

2.0 CONCEPT OF INDEX SYSTEM

The index system should provide basis for allocating man-hours and means for comparing actual performances with budgets and schedules. Data should be constantly collected and processed to make comparisons with graphic presentations of the parameters previously used, and to update parameters as necessary. Updated parameters must be completely processed throughout the management cycle.

Simultaneously and literally, systems for monitoring man-power consumption, production progress, and productivity should be correlative and based in common upon material. Otherwise, analysis and employment by different functionaries will achieve different results and forecasts. For instance, mid-way through a production effort, one analyzer watching only material consumption judges progress to be on schedule while at the same time others may insist that it is not because man-hours consumed are over or under the budget. The consumption of both materials and man-hours must be watched in order to judge if operations are being performed per schedule.

2.1 Indices System Planning

2.1.1 Determining Indices

Indices system planning should start with data collection during execution of actual work. For this purpose, a coding system is needed to designate zone/area/stage by manufacturing level. That is, the coding should be in accordance with the product work breakdown structure employed and data collected should be classified accordingly. The indices system should show realistically for each index, its past record and its current status sufficiently to forecast future trends.

System planners should select a physical characteristic of the work to be done on material which has a high correlation with progress, e.g., cutting length, welding length, and erected weight. They also have to consider indices separated by problem categories, i.e., by welding position, outfitting level, etc. In other words, indices should match work classified by type and size of ship and zone/area/stage. This is graphically shown for hull construction for a specific ship size and type in Figure 2-1.

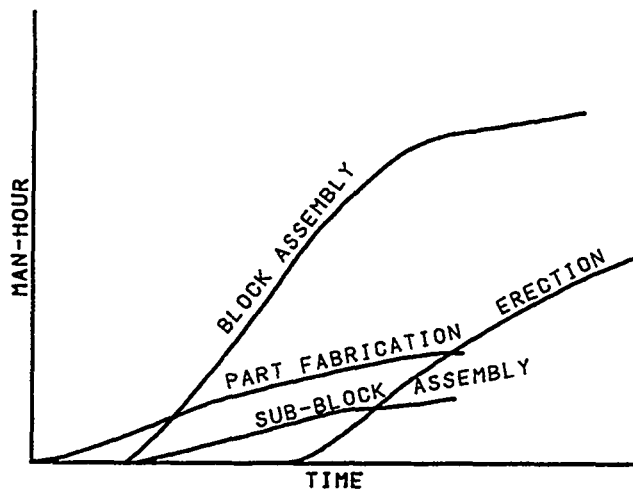
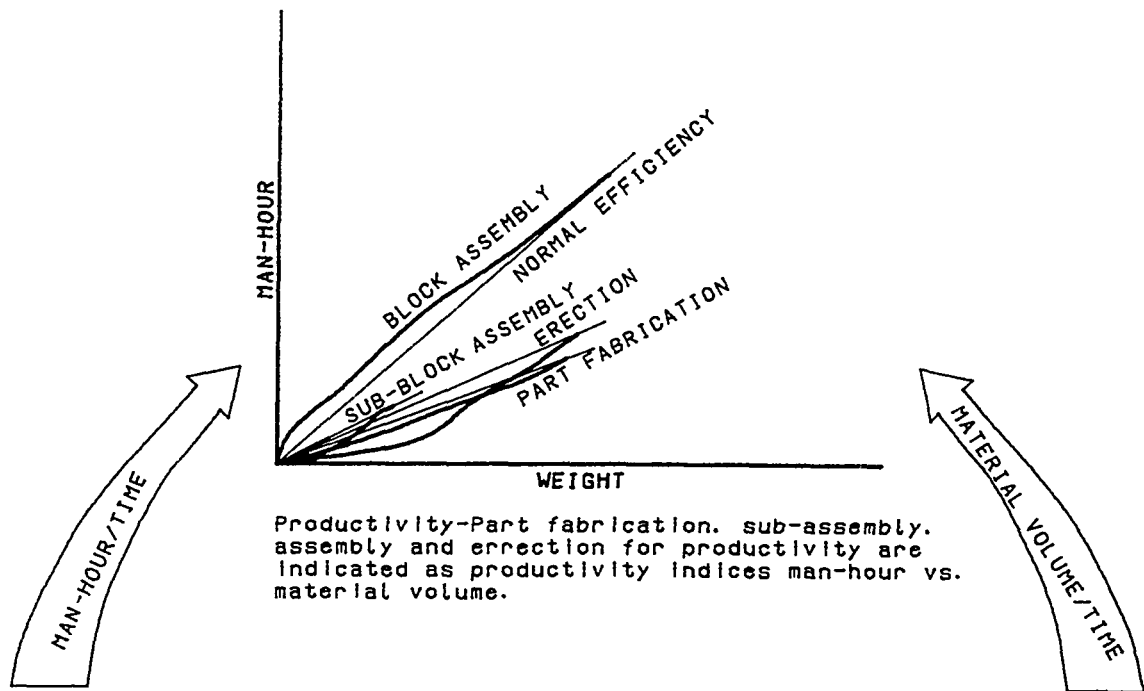
2.1.2 Quantification of Indices

As repeatedly described, an index presents an analyzer with means to forecast trends quantitatively when it is displayed graphically together with performance data. Digital data serves as backup.

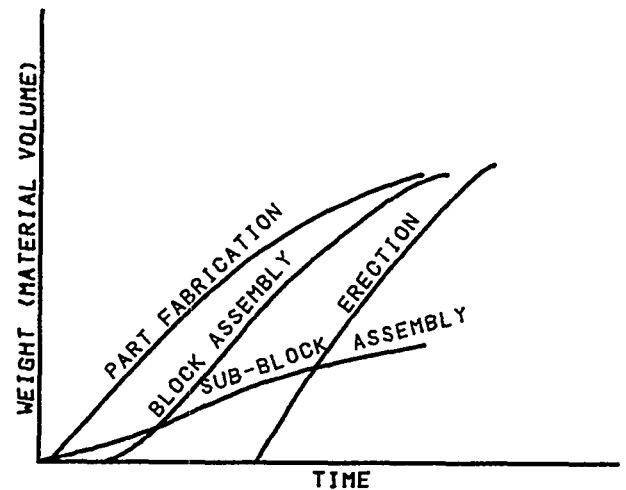
Two sets of data are associated with each index when production work is in progress. One set consists of historical data which are processed statistically to predict how cumulative man-hours should conform to an S-curve distribution and to maintain the limits of variation from the S-curve which establish boundaries for normal operation, i.e., within upper and lower control limits as defined by statisticians. The significance of deviations from mean values are readily apparent and even trends toward undesirable performance can be detected before the control limits are exceeded. Thus, much of the judgmental opinions employed by traditionalists, which are highly susceptible to optimism and pessimism, are replaced by analytical methods.

2.1.3 Feedback System

Man-hours consumed and notice of pallets started are fed back every day from an assistant foreman to a foreman who reports the data to the production control department. Only notice of start of a work package is sufficient for reporting material consumption as completion of the previous package in the work flow is assumed unless an assistant foreman reports otherwise. Subsequent data processing relates man-hours consumed per unit time and material volume consumed per unit time in order to calculate productivity. The data so simply collected are used for presentation, adjustment and forecasting of work progress and for estimating new projects.



Man-hour Consumption—Hull Construction



Material Volume Processed in Weight-Hull Construction

FIGURE 2-1: Typical set of curves for hull construction for a specific ship size and type. These curves show how man-hours/unit-time and material volume processed/unit time are combined by factoring out time to achieve plots of man-hours/material volume processed, i.e., productivity or efficiency.

2.1.4 Basic Formulation of Productivity Indices

Each productivity index (P) for a cost center is:

$$P = \frac{H}{V}$$

where: H = total man-hour consumption

V = total material volume processed

Total man-hour consumption is:

$$H = \sum h_i, \quad \sum h_i = f(t)$$

Total material volume processed is:

$$V = \sum v_i, \quad \sum v_i = f(t)$$

where: h = man-hour consumption/work package

v = material processed/work package

t = unit time

i = total number of work packages of the same problem classification

Figure 2-1 portrays typical plots of productivity index(P), man-hour consumption (H), material volume (V).

2.2 Material Volume Definition

As already discussed, manpower requirements are determined from material volume. Therefore accurate definition of material volume is very important because it ultimately becomes the basis for scheduling and progressing. Material definition is performed commensurate with the progress of design phases, i.e., basic, functional, and work instruction. Thus, scheduling and progressing is critically dependent upon the quality of the MLB hull weight, rough-cutting plans, and hull-block parts list for hull construction, and on the MLB, MLS, and MLF with MLP and MLC, for outfitting. These documents provide planners with sufficient enough material volume for accurately computing manpower commensurate with the requirements of each planning level.

2.3 Definition of Manpower Consumption

Manpower consumption is primarily represented by man-hours (sometimes man-days, or man-months). Man-hours are calculated from material volume as previously stated. Man-hour budgets are therefore based on the net material volume indicated in a design, i.e., scrap is not included.

The budgeting approach for hull construction is typically shown in Figure 2-2. Actually there are two approaches that proceed independently of each other as means for cross checking.

The purpose of one approach, by department staff engineers, is to obtain a target for total man-hours using basic ship partic-

ulars, i.e., in a large-frame sense. This approach takes two paths.

One path, called strategic, utilizes historical data for just ship type and deadweight for the purpose of obtaining total estimated man-hours using current productivity. The other path simply employs statistical data based on ship type, deadweight, and regulatory classification to also achieve a total estimate that is used for comparison.

If the manufacturing system has improved, the strategic estimate should be less than the statistical estimate and should be used as the total estimate. If this condition is not met, an investigation should be conducted to determine the cause and verify the amount of productivity decrease.

The second approach, by shop/section staff engineers, is to obtain total man-hours by each fabrication shop and assembly section from current control parameters applied to the basic particulars for the ship, i.e., in a smaller-frame sense. The effort by each shop/section, produces what each shop/section is proposing as its manpower budget.

Totals from the two approaches are compared, at first by the department manager who may wish to modify a current control parameter by a factor for future improvement based on evidence of a rate of constant improvement resulting from quality circle activity, statistical control, etc. The totals from the two approaches would then be compared by the General Manager who may take into account market and political circumstances. The final total budgeted man-hours are then apportioned after discussions with shop/section managers concerning differences and, when appropriate, concerning the different production methods that will necessarily be used.

The budgeting approaches for outfitting and painting are the same as in Figure 2-2, but of course, with peculiar control parameters.

The dual approach for cross check purposes is also used within shop/sections for budgeting man-hours by F-groups, and within F-groups for budgeting man-hours by AF-groups.

The decentralized budgeting approach requires participation by all managerial and supervisory levels and a total budget that agrees with the accumulated work package budgets. The approach identifies inconsistencies and as all levels of managers and supervisors participated in formulating budgets they are more apt to recognize their responsibilities. As a consequence, they have more incentive to fulfill the budgets.

2.4 Index System

The quality of indices is dependent on collecting, analyzing, and correcting real production data. Enhancement of productivity depends on and is not better than the accuracy of index system performance for analyzing data, examining facts, and improving current and future production.

Figure 2-3 shows the circulation of information between three major functions. In addition the figure shows the circulation of information around each one of the major functions as discussed in the following paragraphs.

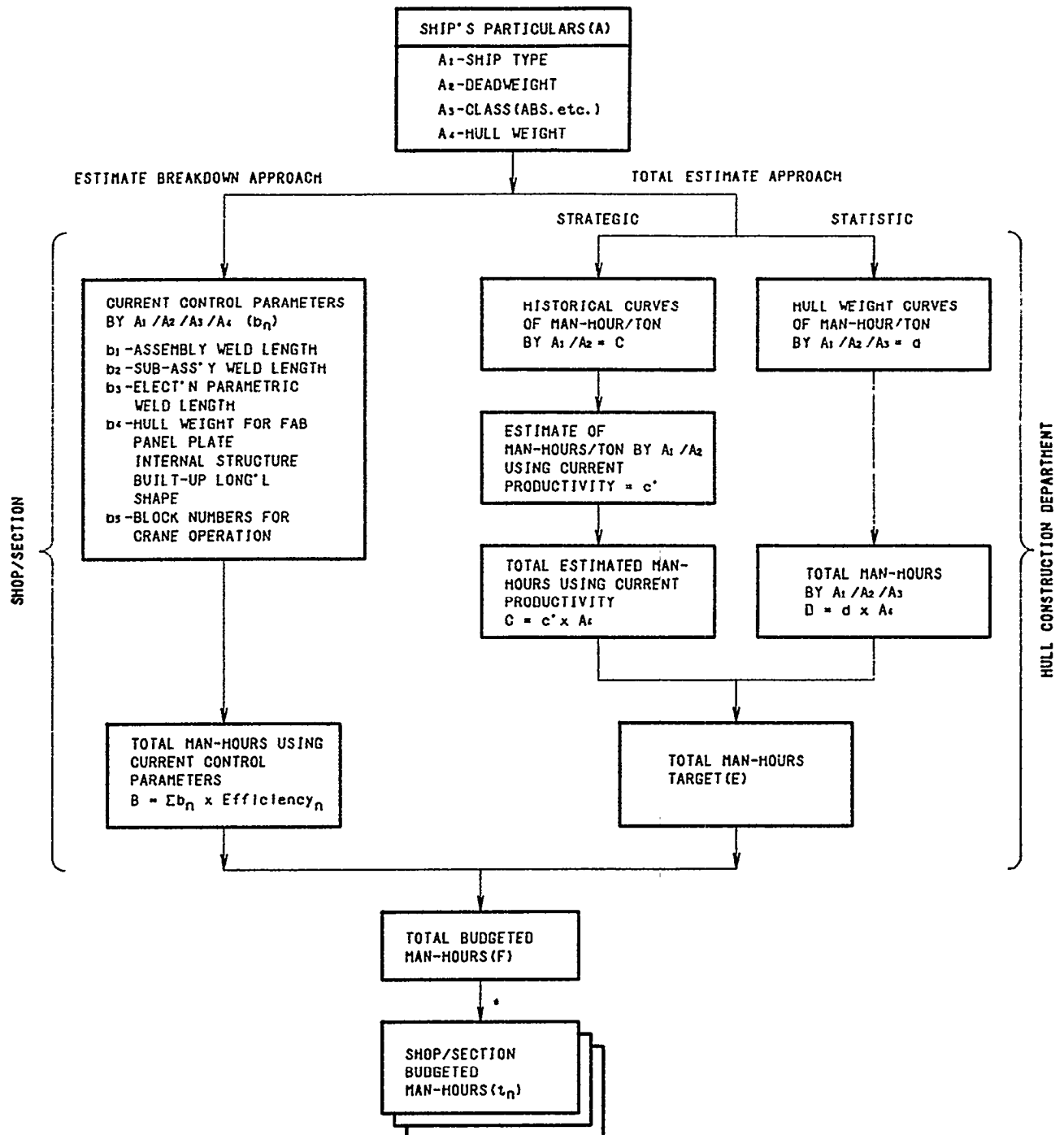


FIGURE 2-2: System for Determining Man-hour Budgets. Total budgeted man-hours are cross-checked by results from the two approaches before finalizing budgeted man-hours for each shop/section, F-group, and AF-group successively.

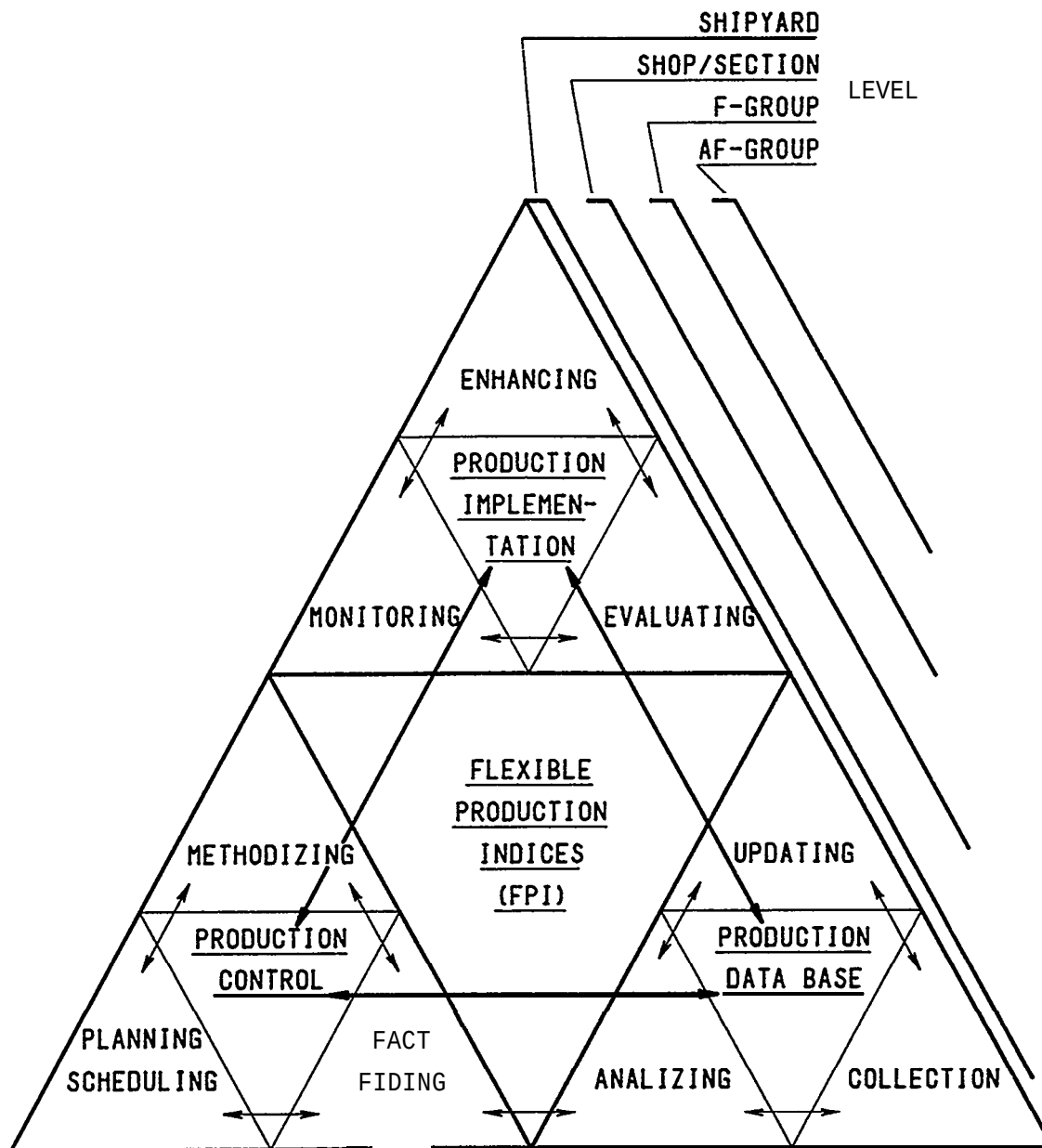


FIGURE 2-3: Activities circulating around Flexible Production Indices (FPI). As shown, major activities are Production Data Base, Production Control, and Production Implementation each of which are dependent upon three unique activities. Although the arrows show information circulation, all activities are accessible to each other. Note that the same information circulation occurs at each level consistent with decentraliition of responsbllics.

2.4.1 Production Data Base

Collection of data is the start of the production data base function. The effectiveness of analysis is dependent upon classifying data for each purpose, e.g., work type and zone/area/stage level-by-level per year. This is absolutely important. In addition, data should be sorted to show the effects of new facilities, quality circles, etc. The objective of this function is to constantly update the presentation of indices in preferably graphical form for man-hours, progress, and productivity.

2.4.2 Production Control

Production control constantly analyzes updated data for facts and must react to the facts as they are disclosed. Obviously, this means that production controllers must not only focus on facts that are simply collected, but also on facts having significance that are statistically sorted from promiscuous facts. Incorrect data collecting or analyzing has a deleterious effect on planning, scheduling, and executing production methods. Methodizing for production includes budgeting material volume and man-hours, preparing a manning plan, scheduling time between activities, and assigning activity durations as well as defining methods, sequences, process lanes, etc.

Planning is executed in a decentralized fashion level-by-level. Similarly, all other production control functions, e.g., methodizing and scheduling, are performed by a tree-structured decentralized organization as typically shown in Figures 2-4 and 2-5.¹

2.4.3 Production Implementation

At each level, production is implemented in response to the terms and conditions imposed by the next highest management level, namely:

- . production period (how long),
- \production time (when),
- . production plan (how to make),
- production site (where),
- . production material volume (what with),
- production group and people (who), and
- production man-hours (budget).

The terms and conditions are first given by the Production Control Department in large frames. They are then broken down by subordinate groups in the succession that they appear in the organization. As addressed in Part 2.3 the breakdown of terms and conditions by one level are not finalized until they are coordinated with an independently prepared breakdown by its succeeding level. In other words to insure compatibility, there is coordination between a department with each of its shop/sections, by a shop/section with each of its F-groups, and by an F-group with each of its AF-groups. Simultaneously, coordination takes place “horizontally” at each level. That is before the terms and conditions are finalized, departments coordinate with each other, shop/sections (even of the different departments) coordinate with each other, etc. This is Integrated Hull Construction, Outfitting, and Painting (IHOP) using a tree-structured network with standard-size “frames” assigned each level as shown in Figure 2-6 for work grouped by type and zonelareaistage

The purpose of FPI is production enhancement. For this purpose, monitoring man-hours consumed and tracking material volumes processed must be continuous and the results must be continuously compared with the terms and conditions of budgets and schedules. That is, constant knowledge of the differences between given and actual must be maintained.

During execution, production engineers in the Production Control Department assigned as staff at the department and shop/section levels, and foremen and assistant foremen, evaluate the differences. Commensurate with their levels of responsibility, they make manning adjustments and schedule changes and plan for improving future work by applying the more up-to-date indices.

1 See Part 2.3.3 of the NSRP publication “Flexible Production Scheduling System - April 1986”.

2 The word frame” as used herein is defined in Part 2.1 of the NSRP publication “Flexible Production Scheduling System - April 1986”.

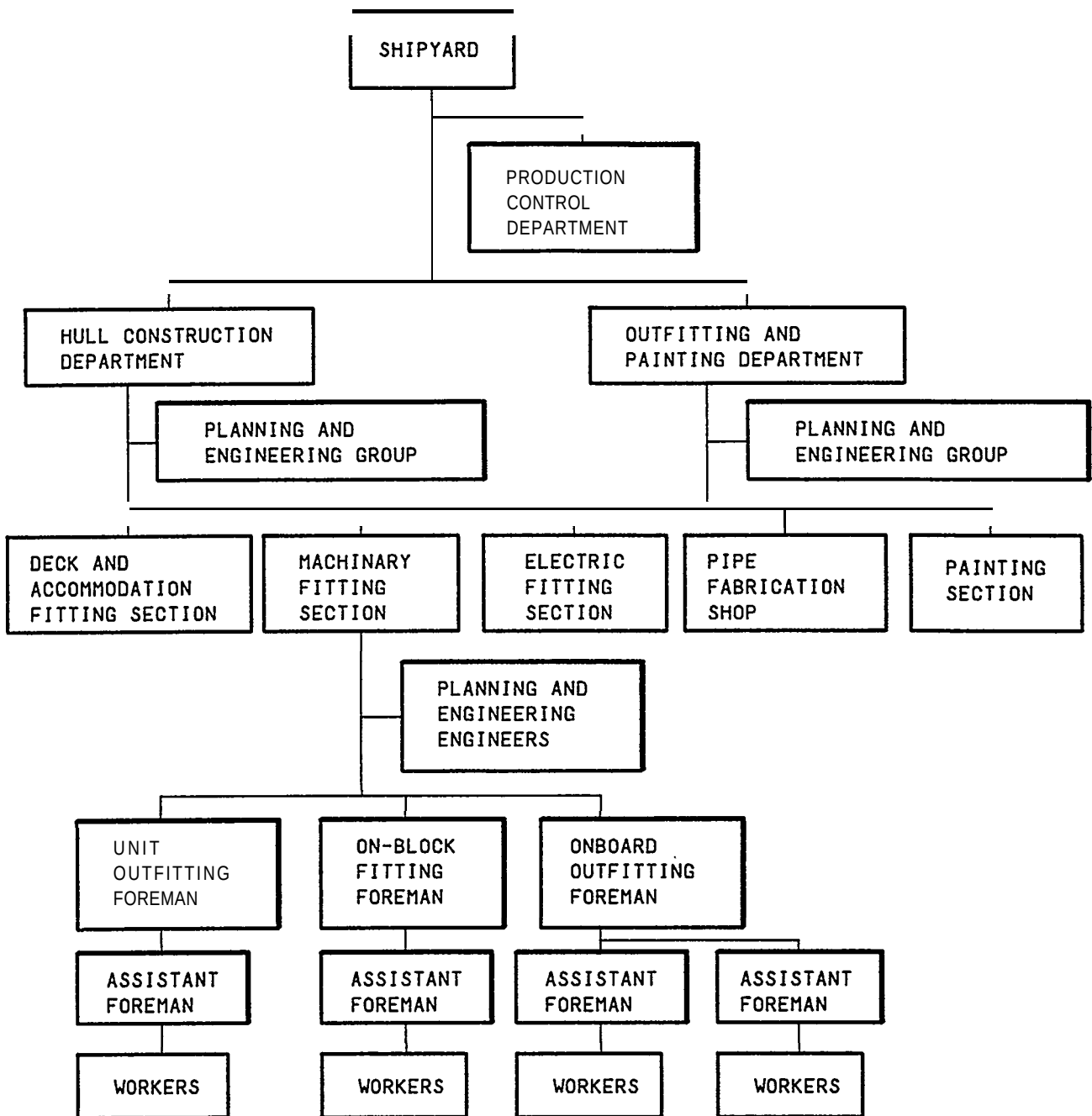


FIGURE 2-4: Decentralized Organization for Production Engineering, Planning, and Scheduling. Bold lines show where responsibilities are assigned for decentralized production engineering, planning, and scheduling.

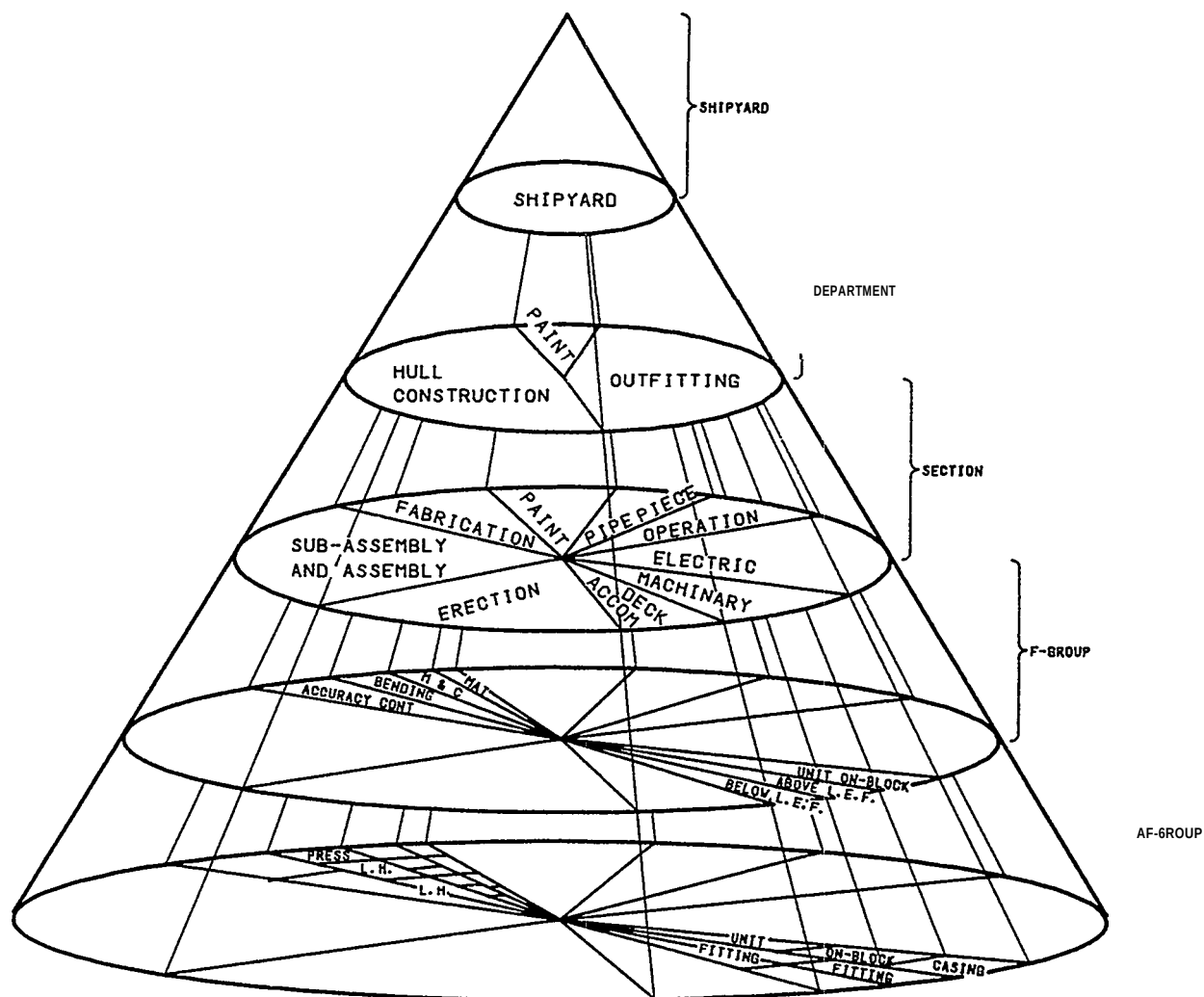


FIGURE 2-5: Tree-Structured Network. background on even level is connected by lines upwards, downwards, and horizontally. M & C-marking and cutting. L.E.F. — lower engine room flat. L.H. — line heating.

SCHEDULES	TIME		WORK VOLUME INDICATION			RESPONSIBILITY
	PERIOD	UPDATION	SUMMARY UNIT	SUMMARY PERIOD	PARAMETER	
DEPARTMENT OR SHOP MAN-HOUR CUMULATIVE SCHEDULE	3 YEARS (DEPT) 1.5 YEARS (SECT)	EVERY 3 MOS EVERY 6 MOS (SECT)	FKLD/SHIP/ DEPARTMENT OR SHOP/SECTION	MONTH	S-CURVE	DEPARTMENT OR SHOP/SECTION MANAGER
HULL CONST. ACTIVITIES TIMING SCHEDULE	A SHIPBUILDING PERIOD	NOT RELEVANT	GROUP OF BLOCKS/SHIP	NOT RELEVANT	STATISTIC DURATION	DEPARTMENT MANAGER
SHOP/SECTION SCHEDULE	6 MONTHS	EVERY 2 MONTHS	INTERIM PRODUCT/ SHIP/ PROCESS YARD	10 WORKING DAYS (2 WEEKS)	-WELDING LENGTH (ROUGH)	SHOP/SECTION MANAGER
MONTHLY SCHEDULE	1.5 MONTHS	EVERY 2 WEEKS	INTERIM PRODUCT/SHIP/ PROCESS YARD/ STATION	5 WORKING DAYS (1 WEEK)	-WELDING LENGTH (ACCURATE) -NUMBERS PER CRAFT	FOREMAN
WEEKLY SCHEDULE	2 WEEKS	EVERY WEEK	INTERIM PRODUCT/ SHIP/PROCESS YARD/STATION	1 DAY	-NUMBERS PER CRAFT -WORKER NAME	ASSISTANT FOREMAN
DAILY SCHEDULE	1 DAY	EVERY DAY	INTERIM PRODUCT/ SHIP/PROCESS YARD/STATION	HOURS	-WORKER NAME	WORKER

F-START FABRICATION K-KEEL LAYING L-LAUNCHING D-DELIVERY

FIGURE 2-6: Schedule Frames for Hull Construction.

3.0 CODE SYSTEMS PERTINENT FOR FPI

Code systems are necessary tools for accurate performance during operation and maintenance of FPI activities. The codes for material volume and manpower consumption must be grouped in a product- (zone-) oriented manner which coincides with how people, information, and work are organized. This is essential for effective FPI.

3.1 Coding for Material Volume

In some shipyards, materials are coded commodity-by-commodity and system-by-system which is sufficient only for estimating material costs by system as during contract negotiations. But, the system-by-system approach is not pertinent for grouping material volumes for production to be performed in accordance with a PWBS. Estimating and defining material volumes for FPI requires product- (zone-) oriented code systems for interim products at all manufacturing levels, e.g., components, subassemblies, and assemblies.

Material volume associated with HBCM assembly work is grouped level by level and zone by zone for coding. The zone code is a key code and the *block* code is a master code. For instance, block assembly work is designated by material volume expressed as block weight or welding length *per block*. The same is true for outfitting and painting. Such work is designated by material volume respectively expressed as outfit weight and paint required per square meter *per block* or *per on-board zone*.

For fabrication of parts in the HBCM, cutting one, a few, or many parts from a single plate or structural shape are regarded as separate problem categories for which separate codes are required in order to obtain separate indices. Therefore, fabrication work is designated by material volume expressed as block weight or cutting length per plate (or structural shape) *per block*.

3.2 Coding for Manpower Consumption

In traditional shipyards, manpower is charged to system-by-system codes. These are not compatible for work in accordance with a PWBS controlled by FPI. Now, shipyards which employ product work breakdowns have organized people in the same manner. Thus, their manpower codes also correspond to a product-oriented organization, e.g., by department, shop/section, F-group and AF-group reflecting separation by problem categories as shown in Figures 1-2 and 1-3 and Figures 1-12 through 1-17. Each code belongs to a respective organizational group which is responsible for comparing budgeted with actual manpower consumption and budgeted with actual material consumption in order to realistically track production progress.

4.0 FPI PROCEDURE

Applying FPI to the HBCM is simpler than applying them for the ZOFG, ZPTM and PPFM because the relationship between material volume processed and manpower consumed for hull construction has less variation than is experienced for the other types of work. Regardless, FPI is applied for the four methods in the same way. In this chapter, a general procedure is described for all methods. In the following chapters, references and input data for each specific method is described.

4.1 Production Data Base

A good database is prerequisite for good estimating, budgeting and scheduling. These functions provide yardsticks for monitoring manpower consumption, tracking production progress, and evaluating productivity. They are also the bases for setting targets for step-by-step production enhancement.'

4.1.1 Data Collection

The data to be collected for FPI pertains to parts fabrication, block assembly and erection work for the HBCM, on-unit, on-block and on-board work for the ZOFG, and on-component (painting components before they are fitted on-unit or on-block), on-block, and on-board work for the ZPTM, and PPFM work for the purposes of:

- **monitoring current production, and**
- . projecting future production.

Material and manpower consumptions must be sorted and collected by the code systems as shown in Figure 4-1 and Figure 4-2 respectively.

Before the design is defined for a specific ship, statistical data collected from past production are used to estimate material volume. Material volume is always estimated for each group as shown in Figure 4-1.

4.1.2 Data Analyzing

The collected data for material volume and manpower level-by-level and group-by-group should be analyzed:

- Is productivity high or low?
- Why is it high or low?
- Are there any irregularities such as inclement weather, poor work sites or an owner's unusually severe requirements?
- Is there any learning-curve efficiency such as from previous construction of ships of the same design?
- . Are there any system, technique, or facility innovations?

The data should be normalized by discarding data from extraordinary experiences as identified through analysis.

Figure 4-3 shows year by year, actually consumed manhours for similar size and type ships built in the last decade and the rates at which consumed man-hours decreased. Figure 4-4 similarly shows the improvement rate for productivity expressed as decreasing man-hours/material volume. The graph in Figure 4-5 shows how productivity relates to ship sizes as expressed by material volume. Data which deviates from mean values should be annotated with the reasons determined during analysis.

' See the NSRP publication "Analytical Quality Circles - September 1986."

	GROUPING OF MATERIAL VOLUME
HBCM	WEIGHT OR WELDING LENGTH/BLOCK
ZOFM	PARAMETRIC COMPONENT WEIGHT/PALLET
ZPTM	PAINT KIND/PAINTING ZONE
PPFM	NUMBERS OF PIPE PIECE/FAMILY

FIGURE 4-1: Material Volume Grouping Principles.

	GROUPING OF MANPOWER
HBCM	MAN-HOUR/LEVEL/PROCESS LINE/TRADE
ZOFM	MAN-HOUR/DRAFT/LEVEL/TRADE
ZPTM	MAN-HOUR/LEVEL/TRADE
PPFM	MAN-HOUR/LEVEL/PRODUCTION LINE

FIGURE 4-2: Manpower Grouping Principles.

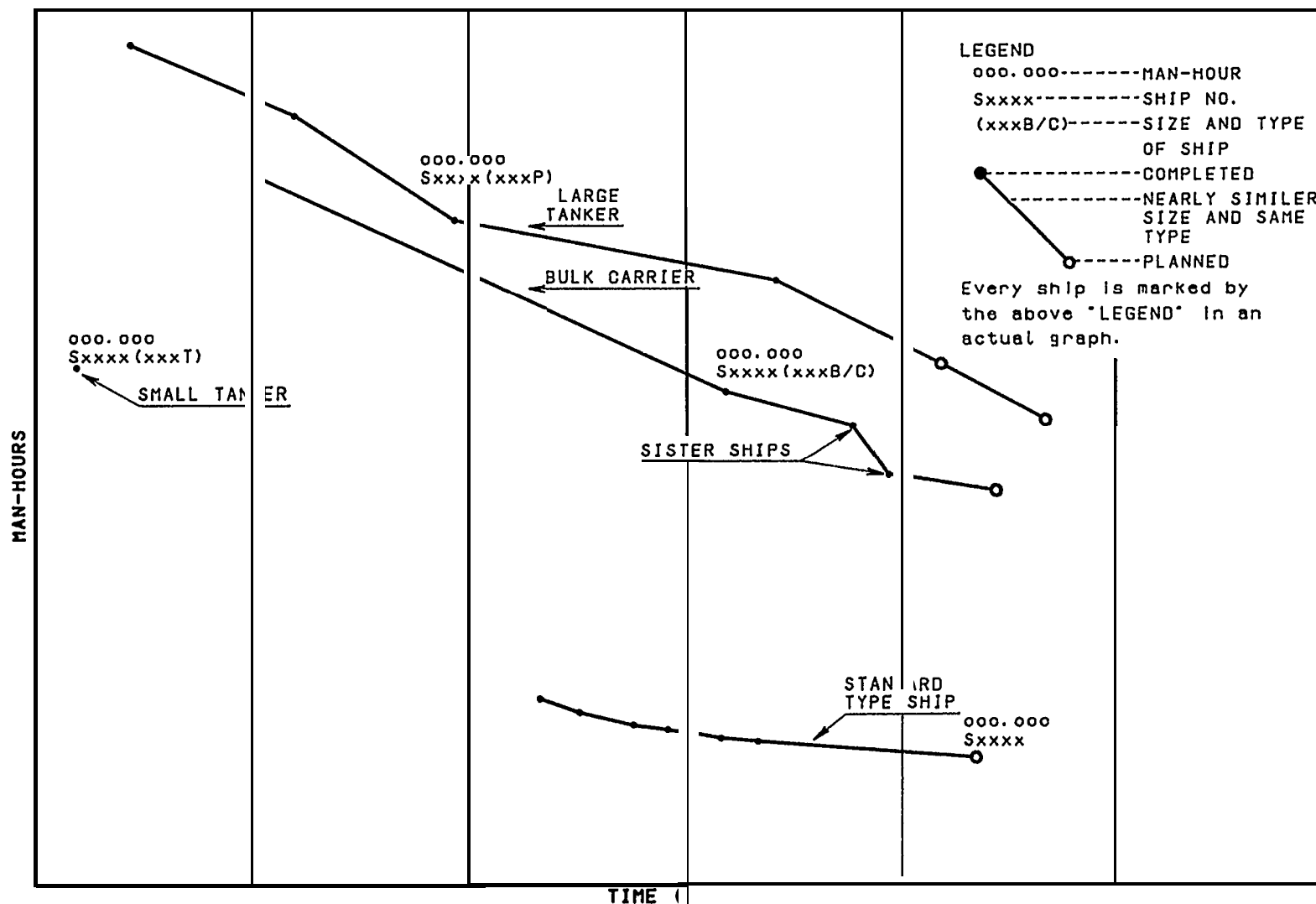


FIGURE 4-3: Typical Department or Shop/Section Plots of Man-Hour Consumption by Basic Types of Ships.

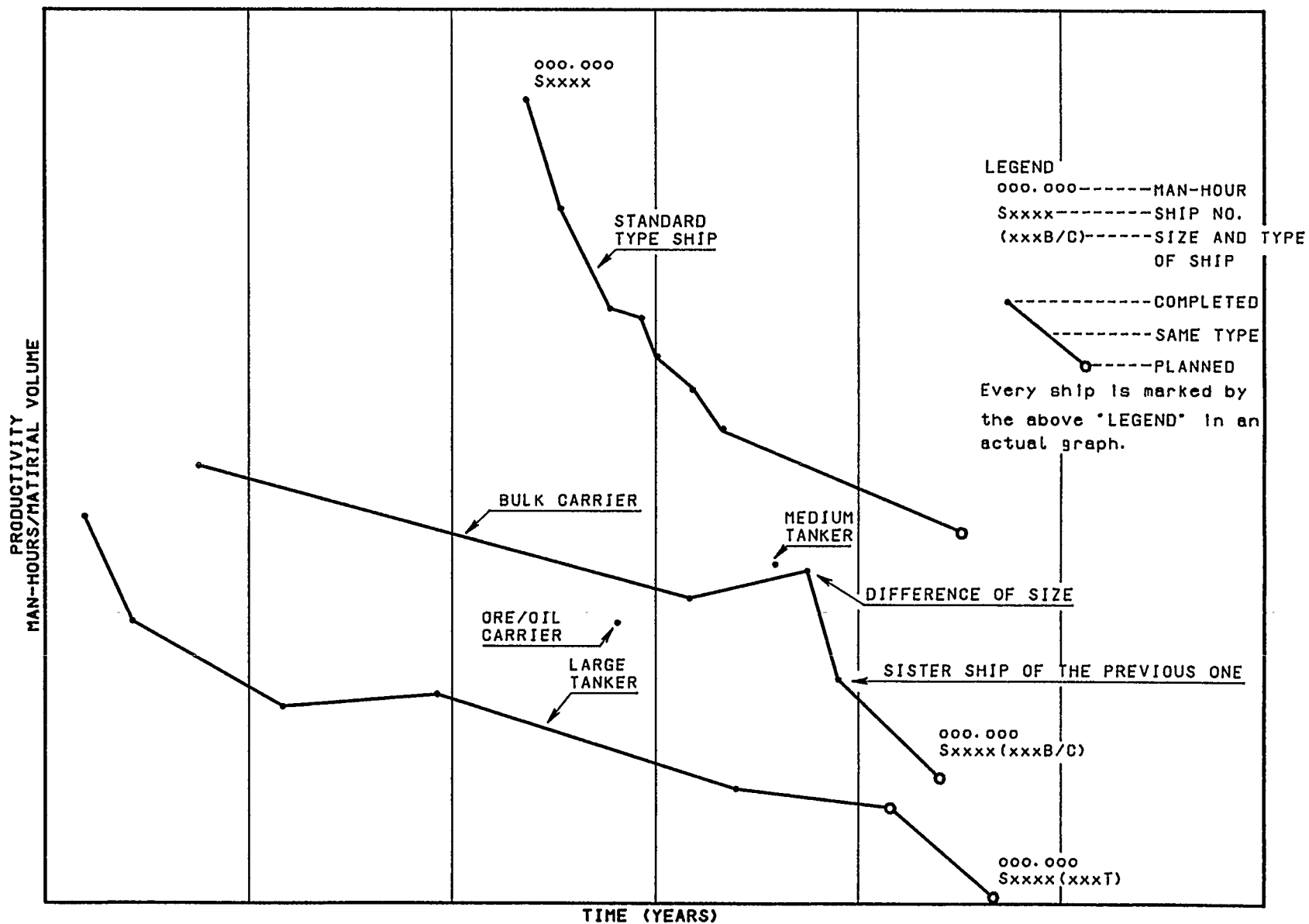


FIGURE 4-4: Typical Department or Shop/Section Plots of Productivity by the same Basic Types of Ships shown in Figure 4-3.

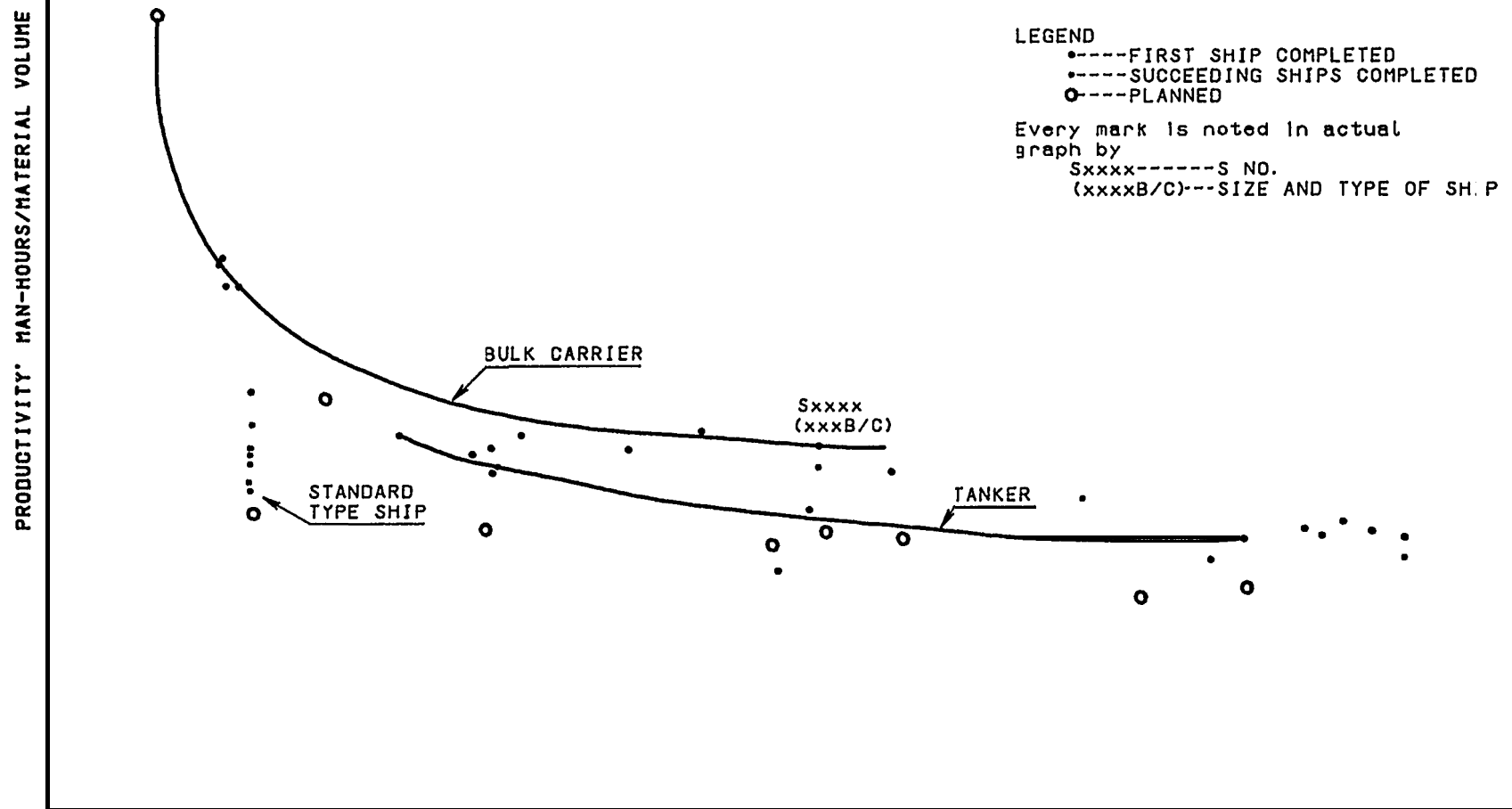


FIGURE 4-5: Typical Shop/Section, F-Group, or AF-Group Plots of Productivity vs. Material Volume by Basic Types of Ships.

4.1.3 Updating

After and during production for a specific ship, planners must statistically update the current FPI data base with the newly produced data. Even where product-oriented methods are well developed, material volume processed and manpower consumption deviate from what is budgeted. They could deviate in a way that compensates for each other so that for some time period, productivity is as projected. However, a trend may be indicated which could be warning of a potential productivity decline. Thus, it is extremely important that data be updated and monitored frequently and simultaneously for all parameters, i.e., material volume processed, man-hour consumption, and productivity.

4.2 Production Control

Activities for production control are:

- fact finding,
- planning, engineering and scheduling, and
- methodizing.

4.2.1 Fact Finding

Many traditional shipyard managers do not maintain sufficient knowledge of their shipyards' capabilities. With a product-oriented data base, capabilities are easily determined and all planners have access to the same data. Very little is left to individual judgement. Regardless of different people engaged from time to time, the outcome of planning and scheduling is essentially the same. Of course, someone with relatively little experience will require more time and is apt to make some errors in allocating man-hours. When a specific contract is awarded, planners retrieve index data from the data base which is usually in the form of a graphic display. If the index data is not exactly applicable, planners interpolate, extrapolate, or estimate and make inputs level by level, e.g.:

- material volume using data from past similar ships,
- man-hours based on material volume as shown in Figures 4-3 to 4-5,
- S-curves chosen from past similar ships for monitoring man-hour consumption and tracking production progress by material processed, e.g., biweekly (IHI accounts every ten calendar days),
- man-hours available (MHa) which can be derived from the formula:

$$MHa = W \times X \times WD \times WA \times AR$$

where: WH = work hours/day

WD = work days/summary unit, e.g., per month or per week

WA = number of workers available

AR = attendance rate

4.2.2 Planning and Scheduling

Staff engineers assigned to departments and shop/sections and foremen and assistant foremen perform planning and scheduling for their *respective* manufacturing levels. They independently use indices to assess total man-hours that they each require and compare them to what each of their higher managers propose to allocate. If a proposed manpower budget is less than what a manager, foreman or assistant foremen estimates, negotiations are started as mentioned in Part 2.3. Both parties to each negotiation prepare graphs for budgeting material and man-hours as shown in Figures 4-6 through 4-8.

The graphs, for example by a department, are made with the department's own data obtained from previous shipbuilding experiences. Similarly, each shop/section, F-group, and AF-group maintains a data base of past experiences for the same purpose. As shown in Figure 4-8, the efficiency from a past similar ship is used as guidance to establish the efficiency line for a contemplated ship.

4.2.3 Methodizing

Planners for the various levels methodize virtually every activity of all production functions including standardizing ways to collect and present data. This insures that the indices for each level become more and more reliable and facilitates systemization which is essential for effective operation of FPI. Figures 4-9 through 4-12 supplement Figures 4-1 through 4-8 as examples of, graphic displays of how indices are employed. Graphic displays are superior to digital tabulations because they permit managers and planners to easily grasp tendencies which enables them to effectively:

- monitor actual manpower consumption vs. budgeted manpower,
- track production progress or interim products processed vs. schedules, and
- monitor actual vs. planned productivity.

4.3 Production Implementation

Production implementation must follow methods upon which plans and schedules are based. Activities for monitoring and tracking, evaluating and enhancing production, produce data which must be fed back from each level to the next higher level and filed in a data base for updating indices and for application to future projects.

4.3.1 Monitoring

Monitoring is most effectively done with graphic displays which compare material volume processed with budgeted material volume and manpower expended with budgeted man-hours as shown in Figures 4-9 and 4-10 respectively.

If the processed material is lower than what is budgeted, production progress is behind schedule, or budgeted material volume may have been misestimated.

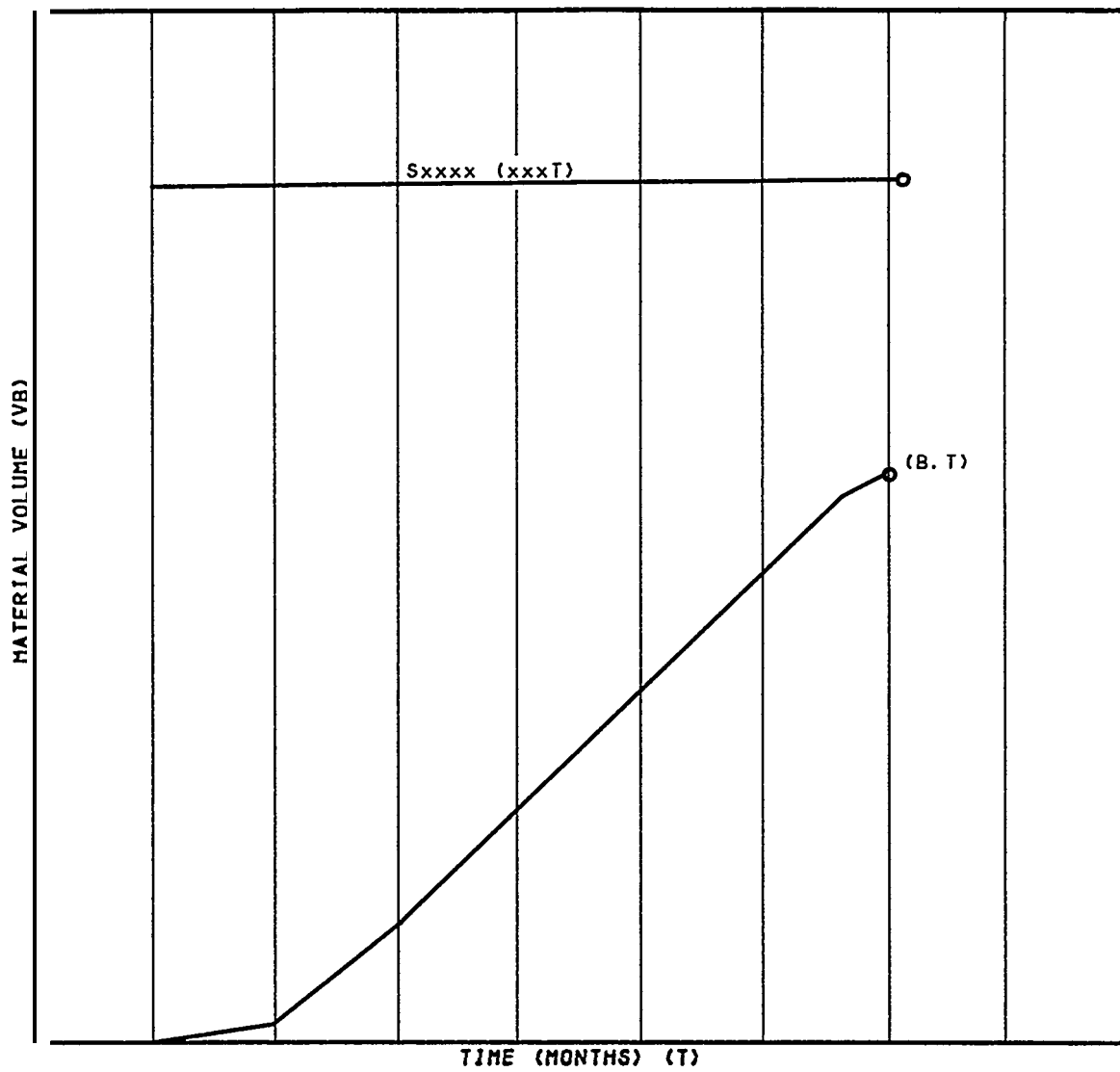
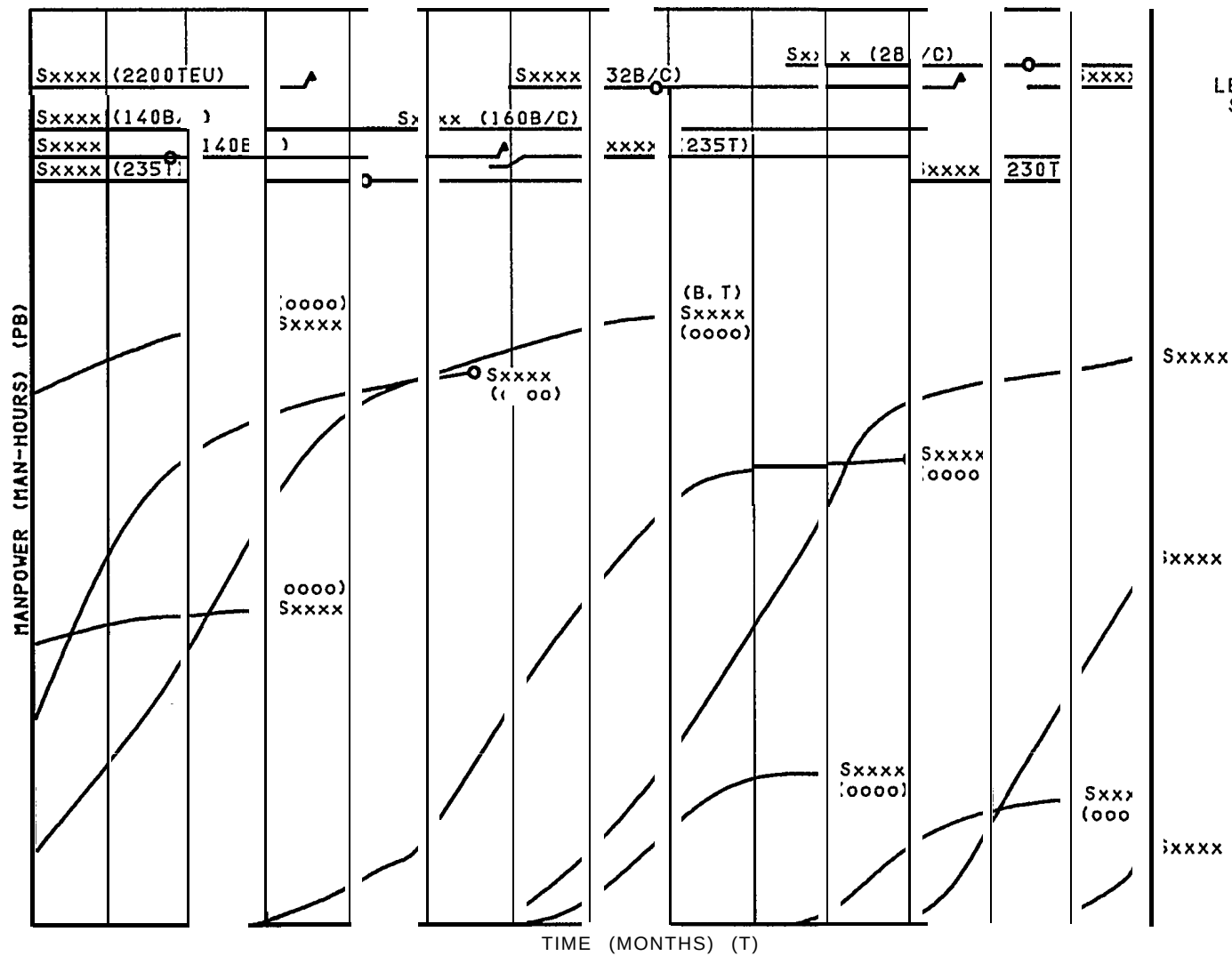


FIGURE 4-6: Typical Department or Shop/Section Budget for Material Volume Consumption (Production Progress).



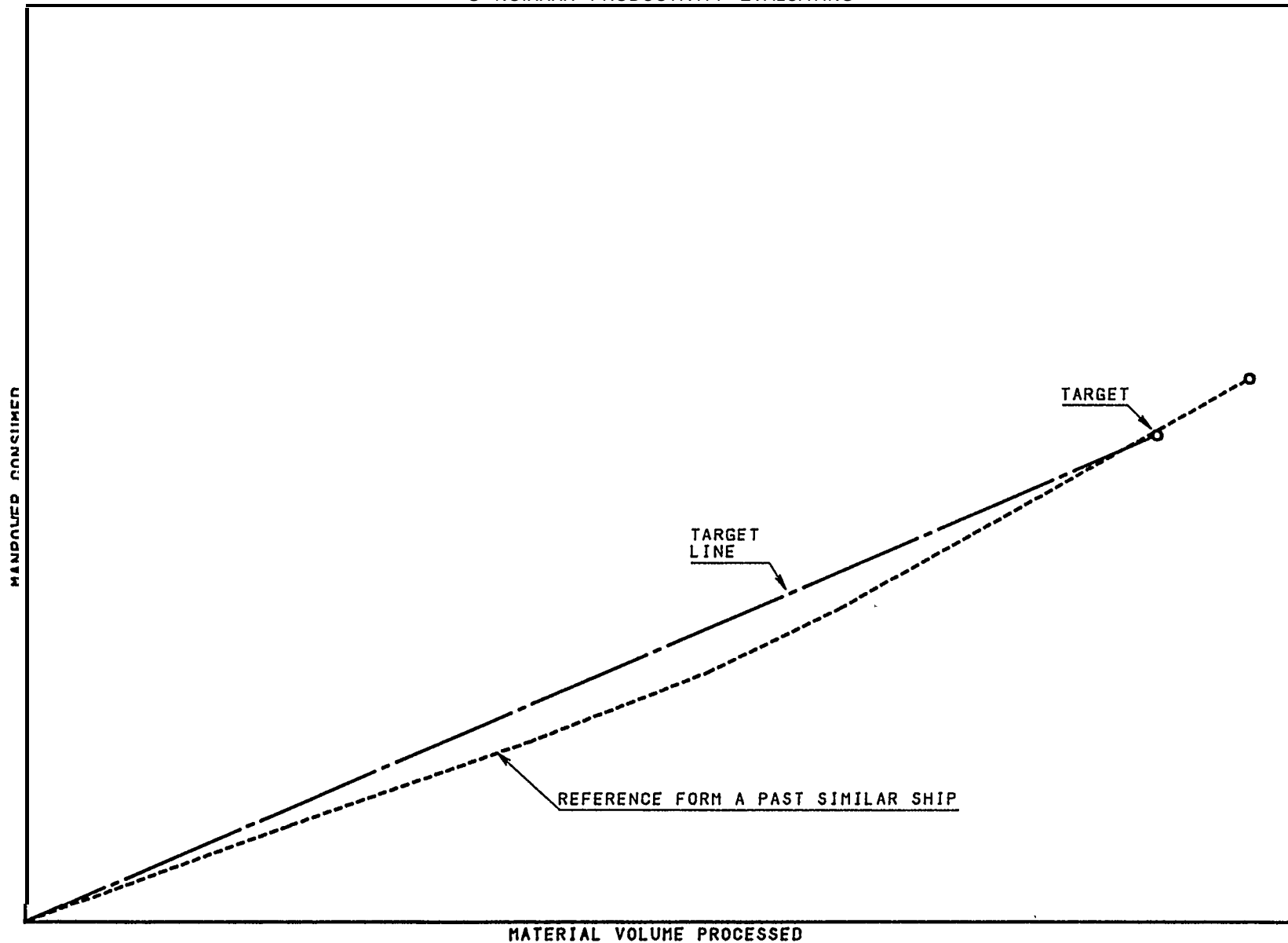


FIGURE 4-8: Plot of Manpower vs. Material Volume used for evaluating productivity by a Shop/Section, F-Group, or AF-Group. The efficiency obtained during construction of a similar ship in the past serves as a reference.

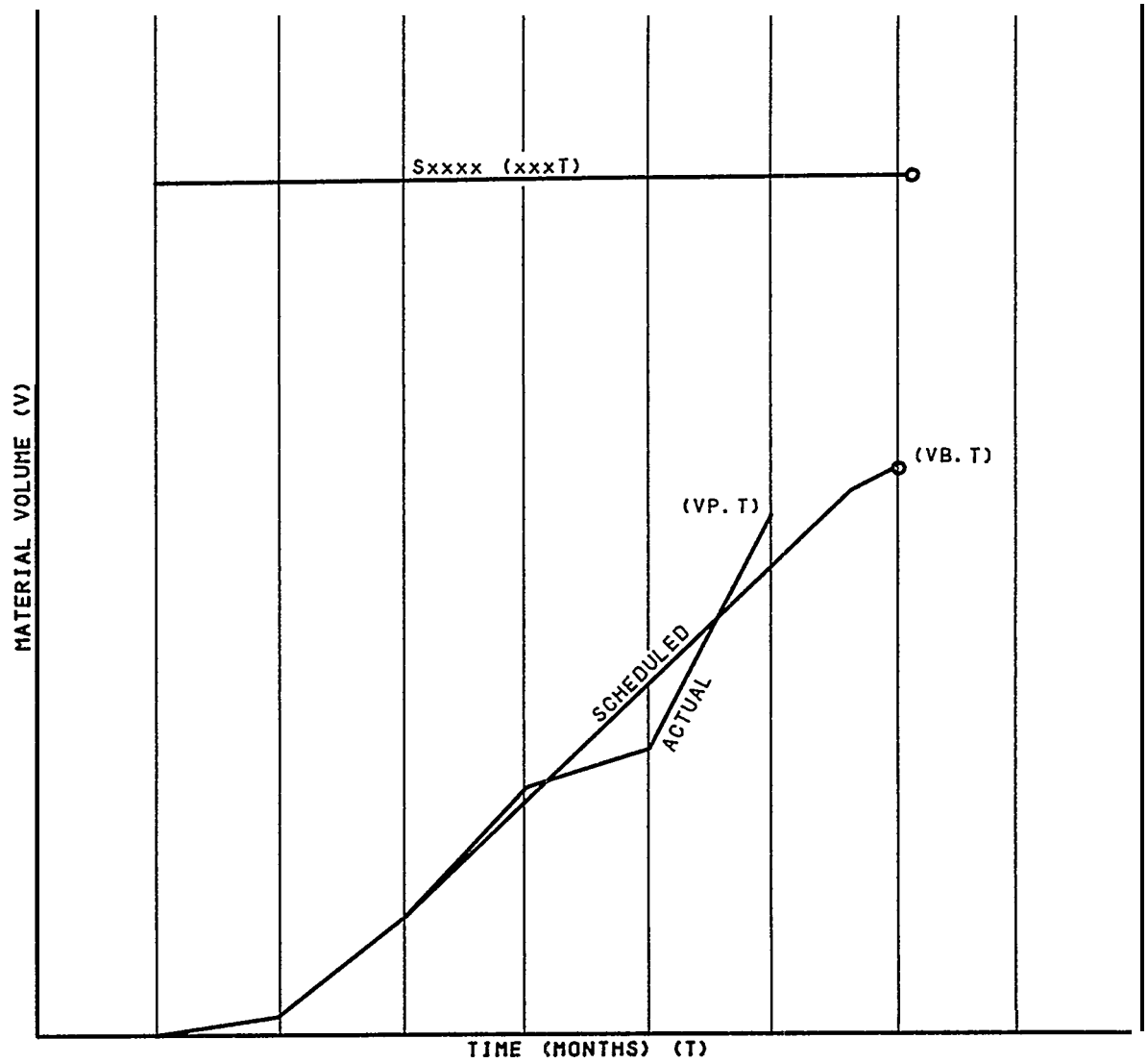


FIGURE 4-9: Plot of Material Volume vs. Time used for tracking production progress by a Department or Shop/Section.

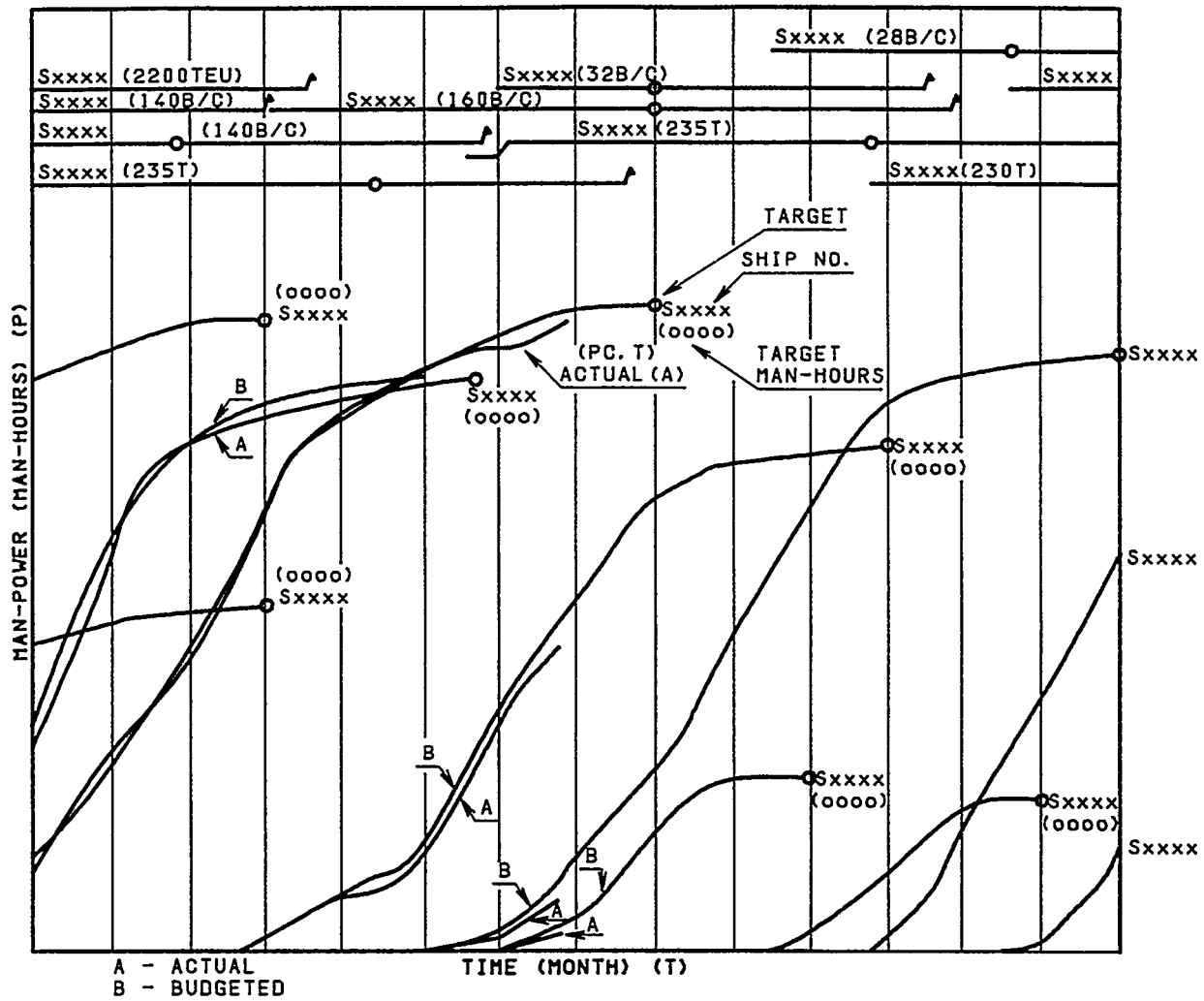


FIGURE 4-10: Plots of Manpower vs. Time used for monitoring manpower consumption by a Department or Shop/Section.

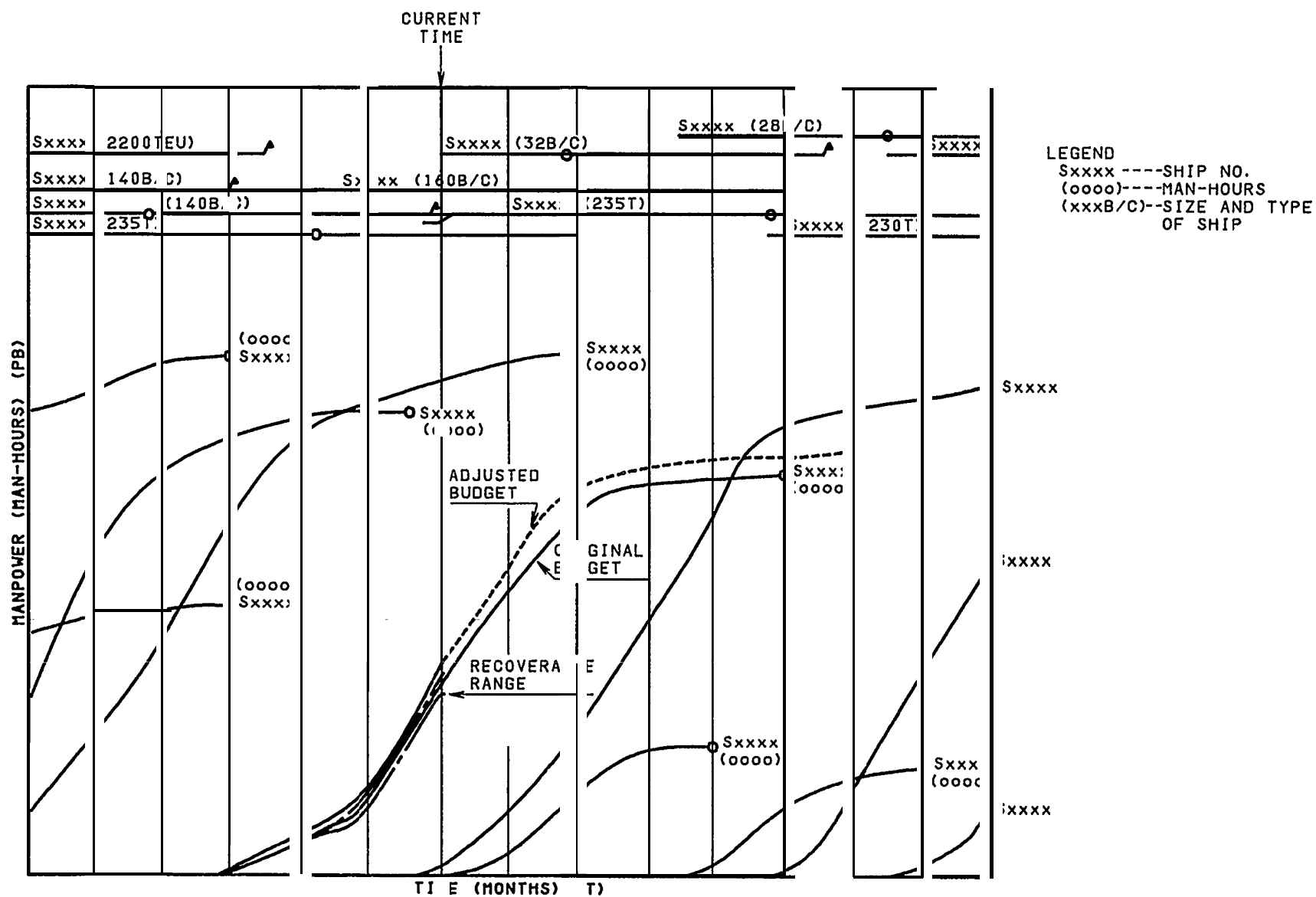


FIGURE 4-11: Plots of Manpower Budgeted vs. Time as used by a Department or Shop/Section showing an adjusted budget due to over consumption of man-hours.

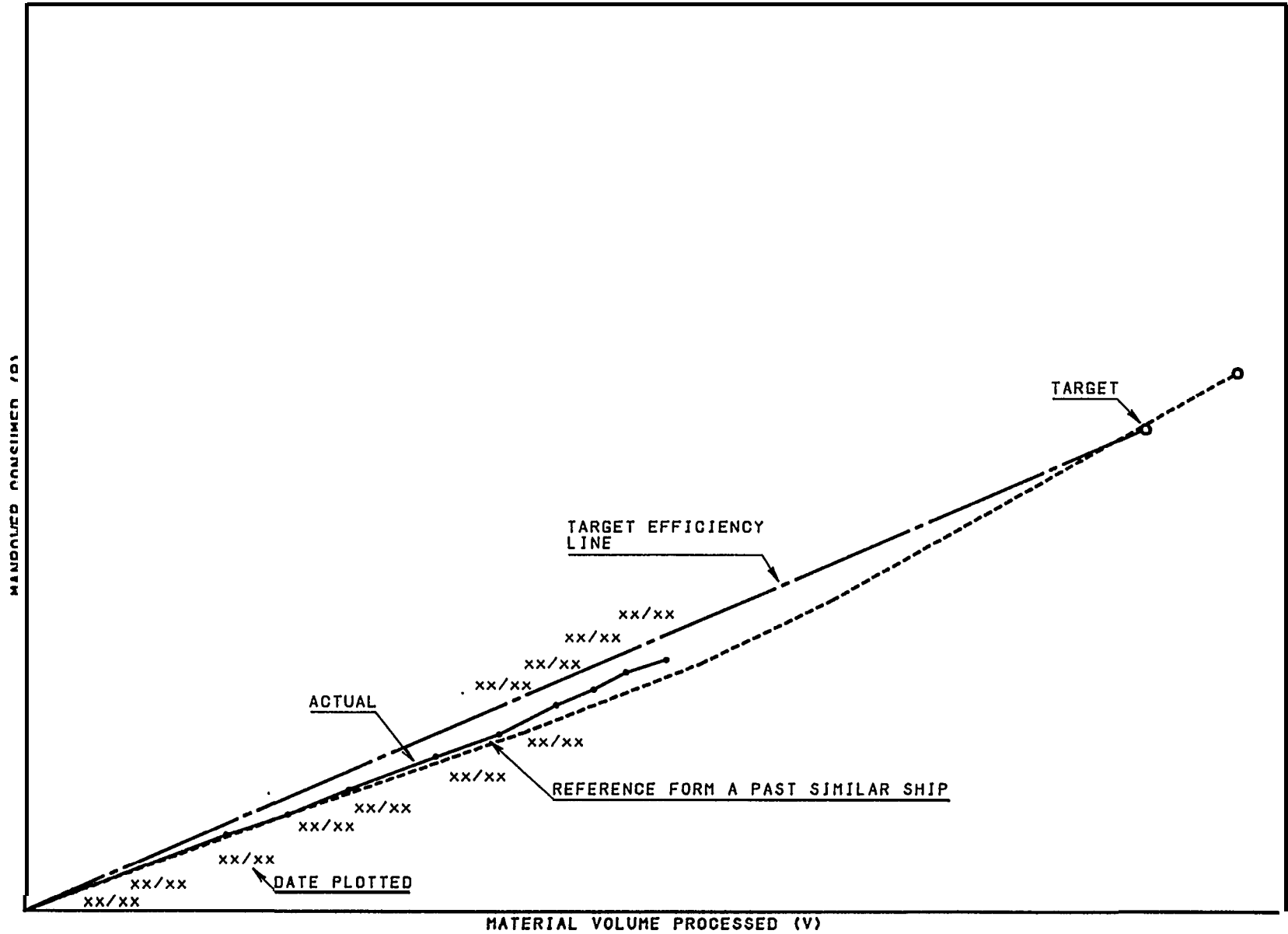


FIGURE 4-12: Plot of Manpower vs. Material Volume; actual productivity achieved annotated as by a Shop/Section, F-Group, or AF-Group

In the same time intervals as for tracking production progress, planners plot consumed manpower relative to budgeted manpower as shown on Figure 4-10. The interpretation of this graph is more complex. If consumed manpower is lower than budgeted manpower, either production progress is behind schedule because some jobs did not start as scheduled or material consumption to date (progress) is better than what was forecast. If consumed manpower is ahead of schedule, production progress could be ahead of schedule, but this is not likely. Probably, productivity is worse than forecast. Productivity could be less than forecast regardless of production progress being ahead or behind schedule.

If productivity is more than that predicted and production is ahead of schedule, the indices which were used to budget material and manpower were either incorrect or outdated. More likely when consumed manpower is ahead of schedule, material consumption is either on or behind schedule indicating less productivity than what was planned. Depending on magnitude, this could be a serious condition. Therefore, monitoring manpower consumption is always done in conjunction with monitoring material consumption.

4.3.2 Evaluating

Evaluating productivity and deviations from manpower and material consumption schedules must be quantitatively performed based on accumulated data prepared by the activities responsible for monitoring manpower consumption and tracking production progress, i.e., AF-groups, F-groups, shop/sections, and departments as follows:

• Production Progress

Deviations of production progress are readily apparent when accumulated material consumed is superimposed over that scheduled as shown in Figure 4-9. One glance is sufficient for determining if production progress is as scheduled. If at a particular level the deviation is excessive, someone at that level must check and analyze material consumption at the immediate lower level, e.g., a shop/section manager checks F-group data.

• Manpower Consumption

Deviations from predicted manpower consumption are readily apparent when cumulative man-hours expended are superimposed over scheduled man-hours as shown in Figure 4-10. Manpower consumption does not indicate production progress directly. It only shows cumulative consumption relative to the budget distribution and a final target. If accumulated man-hours goes outside the range of recovery, either over or under, planners must determine if the applied index was incorrect or the S-curve for budgeted man-hours was incorrectly derived from the material S-curve, or if the overall production period scheduled is too short or too long.

If accumulated man-hours are over budgeted man-hours, managers must check material consumption (progress) as shown in Figure 4-9. If material consumption is below or equal to the scheduled amount, productivity is obviously less than what was planned. Even if material consumption is ahead of schedule, productivity could be less than what was expected. Managers should determine the reasons for the material consumption deviations and act quickly to adjust the manpower budget to establish a revised target that can be met within the time imposed by the next higher managerial level.

If made early, a nominal man-hour increase spread over a long period has little effect on productivity. Whereas, if a revision is made late so as to require a greater increase in man-hours applied over a short period, there will be an adverse effect on productivity coupled with less chance of meeting completion dates. A relatively early adjustment is shown in Figure 4-11.

Obviously, the progress of material consumption is the key. It is for this reason that IHI managers say, "We must control material because we cannot control people." Also for this reason that IHI managers have expended significant resources to develop a highly effective material management system.²

The watchfulness and reactions are actually performed by staff engineers assigned to the Production Control Department, production departments, and shop/sections, a foreman and assistant foreman. That is the planning, scheduling, and tracking are integrated at each level and same time are decentralized.

• Productivity

Productivity is evaluated by plotting actual manpower consumed over a target line as shown in Figure 4-12. At the end of each time unit, a staff engineer, foreman, or assistant foreman, dependent on the material consumption level, plots a point representing actual cumulative man-hours and material volume consumed thus far. Productivity thus far, and compares the result to the line established at the time of initial planning and scheduling. If the value of a plotted point is over the target line, productivity was overestimated or material volume underestimated. In either case, more than originally estimated manpower is required or delay will be experienced. The staff engineer, foreman, or assistant foreman, as appropriate, must investigate and find the real reasons on a case basis and report them to an appropriate manager. The manager may wish to recover schedule performance by arranging for more manpower, e.g., through transferring workers from elsewhere, overtime, subcontracting, or recruitment of new workers, or may, if the contract date permits, revise the schedule to allow more time commensurate with productivity.

²See the NSRP publication "Product Oriented Material Management - June 1985".

4.3.3 *Enhancing*

Enhancing is the last activity for past production, and the first activity for future production in the production implementation cycle shown in Figure 2-3.

During and at the end of production for each specific ship, productivity enhancement must be attempted through fact finding, planning (including designing and methodizing), scheduling, and especially for monitoring and evaluating.

For the purpose of continuously evaluating productivity through continuous monitoring of manpower consumed and material volume processed, planners must review indices used to produce graphs as shown in Figures 4-10 and 4-11. They should constantly strive to make the indices and the index system more effective as well as looking for ways to improve production, production control methods, etc. After completion of production, they must feed back the results of such efforts and particularly insure that the results are reflected in the production data base. Then the indices tell managers, staff engineers, foremen, and assistant foremen about true manpower consumption, production progress and productivity.³

5.0 FPI FOR HULL BLOCK CONSTRUCTION METHOD (HBCM)

Indices are easier to apply in the HBCM than in the ZOFM, ZPTM and PPFM because the correlation between material volume processed and manpower consumed is better and because work packages at each level are more consistent.

5.1.4 Hull Construction Department

Staff engineers at the department level prepare a man-hour cumulative schedule (S-curve) for forecasting and leveling the department's long-term workload. They use the S-curve to compare man-hours required with man-hours available and to monitor man-hours consumed per unit time as shown in Figure 4-10.

5.1.1 Reference Data

For effective operation of FPI, the department must constantly update its data base which consists of:

- Records for Hull Construction Activities Timing Schedule

Records from construction of similar type ships grouped by hull-steel weight are employed for preparation of a Hull Construction Activities Timing Schedule (see Figure A-3 of the NSRP publication "Flexible Production Scheduling System - April 1986"). The schedule controls issues of material requisitions and work instruction drawings and gives the starts and completions of groups of blocks of the same problem category.

- Man-hours Required

Required man-hours are derived from curves that are best fitted to plots of actual hull-steel weight vs. actual man-hours consumed from records of ships built in the past. The curves are drawn separately for tankers, bulk carriers, etc. to minimize scattering and achieve correlation as shown in Figure 4-3. The curves thus derived are more reliable as plots are increased in number. Also improvements in productivity should be reflected on the curves by discarding obsolete data as the newest plots are made. The curves should always be again best fitted after data deletions and/or additions.

- Statistical S-curve

The statistical S-curve relates total cumulative hull construction man-hours to time so as to identify percentages of total man-hours between such milestones as contract award, fabrication start, keel-laying, launching, and delivery (also subdivisions between such milestones when necessary to achieve a smooth S-curve).

Based on analysis of records of similar ships built in the past, a family of S-curves are drawn representing *rapid*, *normal*, and *late rise*. The actual S-curve adopted for constructing a particular ship is determined by considering expected timing of drawing issues, estimated delivery dates for materials, and requirements for ships adjacent in the schedule as shown in Figure 4-7. In any event, the S-curve finally adopted must fall within the range of the rapid and late rise S-curves. A useful technique employs the percentages of cumulated manhours between milestones and their subdivisions from actual S-curves of similar ships as guidance for constructing a statistical S-curve to be used in the future.

During and upon completion of a hull, the statistical S-curve used should always be checked against the actual S-curve recorded. Any conspicuous deviation between the two curves should be investigated to pinpoint the causes. The findings should be taken into consideration during planning for subsequent jobs.

The statistical S-curve is used to predict manpower consumption relative to time, particularly to key events. Simultaneously with preparing S-curves for *adjacent* ships, each curve is adjusted in order to level total man-hours required as much as possible. The result is compared to man-hours available for the purpose of predicting the amounts of overtime and/or subcontractor assistance that will be required. Each final statistical S-curve is used to monitor actual man-hour consumption by the Hull Construction Department for a specific ship.

.1.2 Input Data and liming - Original

Input timing at the Hull Construction Department level should be as frequent as every three months if as many as five or six ships/year are built per dock or if the workload is of a fluctuating nature. It should be less often, perhaps every six months, commensurate with lesser or more stable workloads. Data required consists of:

. Budget Material List (MLB)

The substance conveyed by a MLB (also called a Budget Control List) is type of ship and hull steel weight. It is used to estimate the manpower required for constructing a hull.

. Shipyard Master Schedule

The substance conveyed by a Shipyard Master Schedule consists of dates of contract award, fabrication start, keel-laying, launching, and delivery, i.e., scheduling in the largest frame sense.

. Man-hours Available

Man-hours available per month are determined by applying a factor for absenteeism to the total manning assigned to the Hull Construction Department. This information is needed when leveling the workload to determine the sufficiency of manpower available.

5.1.3 Input Data and liming - Monitoring

Input data, in this instance for monitoring, is the same at all levels of supervision, i.e., department, shop/section, F-group, and AF-group. In IHI shipyards actual man-hours consumed are entered every ten calendar days. Elsewhere it may be more convenient to make such entries weekly or biweekly dependent upon the rate of hull construction activities.

The purpose of this input is to monitor man-hours consumed compared to man-hours budgeted.

5.2 Shop/Sections

The Fabrication Shop, Assembly Section, and Erection Section of the Hull Construction Department each prepares:

- a man-hour cumulative schedule for forecasting and leveling its *intermediate frame* workload and comparing it to man-hours available as previously described for the Hull Construction Department in a large frame sense,
- . a statistical S-curve showing the distribution of budgeted man-hours for monitoring actual man-hours consumed for each specific ship as previously described for the Hull Construction Department and as shown in Figure 4-10,
- . an S-curve distribution of budgeted material volume to be used as a basis for comparison with actual material volume consumed as shown in Figure 4-9,

. an S-curve for predicting productivity expressed as material volume processed vs. manpower consumed to be used as the basis for comparison with actual productivity achieved as shown in Figure 4-12, and

- assembly and erection section schedules for coordinating preceding and succeeding shop/section schedules and other pertinent section schedules and for tracking production progress by color shading as interim products are completed (See Figures A-5, A-6, and A-7 of the NSRP publication "Flexible Production Scheduling System - April 1986").

5.2.1 Reference Data

For effective operation of FPI each shop/section has to independently keep and update its own production data base consisting of:

. Statistical Man-hours

Actual man-hour consumption data from past projects must be filed and maintained by each shop/section in the same manner as at the department level.

• Statistical S-curves

Statistical S-curves actually achieved in the past must be filed and maintained by each shop/section in the same manner as at the department level.

. Block Erection Sequence and Timing Records

Actual performances of erection progress for ships built in the past should be maintained in files by ship type and hull steel weight. The formats should be as used for scheduling but updated to show actual progress of erection work. See the formats of Figures A-3 and A-4 of the NSRP publication "Flexible Production Scheduling System - April 1986" which provide such data in two levels of detail as needed for future reference. Experienced people are not likely to use the less detailed schedules as references for future work, but they should be filed as they are very useful to people who do not have great planning and scheduling experience.

The Erection Section data base is needed to prepare a Tentative Erection Schedule which includes ships which are the goals of marketing efforts and to refine that schedule into a Preliminary Erection Schedule (see Figure A-4 of the NSRP publication "Flexible Production Scheduling System - April 1986").

• Block Erection, Block Assembly, Sub-block Assembly, Parts Fabrication Duration and Sequence Records

Duration and sequence records for actual erection, assembly, subassembly, and fabrication of ships built in the past that are organized block by block should be maintained in files by ship type and hull-steel weight per similar ships. They are used as guidance for preparing and refining schedules for erection, assembly, subassembly, and fabrication work and for preliminary sequencing of such work for a definitive IHOP schedule.

- Statistical Productivity Curves

Statistical productivity (or efficiency) is defined as man-hours related to material volume for each type of work. They are derived from actual man-hours expended per material volume consumed during past projects. Actual efficiencies are recorded for each shop/section by *process yard* for various types of work using data describing actual performances on past ships; see Figure 4-12. (*Process yard* is defined as a group of work stages, usually in the same work flow such as for assembling flat-panel blocks.) The statistical productivity curves are used to prepare shop/section schedules for future work and to evaluate productivity of current work.

5.2.2 Input Data and Timing - Original

Data is inputted at the time of preparation of man-hour cumulative schedules and consists of:

- . Budget Material List (MLB)

The substance conveyed by a MLB (also called a Budget Control List) for each shop/section is type of ship and hull steel weight. It is used to estimate the manpower consumption required by each shop/section.

- . Shipyard Master Schedule

The substance conveyed by a Shipyard Master Schedule consists of dates of contract award, fabrication start, keel-laying, launching, and delivery, i.e., scheduling in the largest frame sense.

- Man-hours Available

Man-hours available per month are determined by applying a factor for each shop/section for absenteeism, to the total manning assigned each shop/section. This information is required to level each shop/section workload in order to determine the sufficiency of manpower available..

5.2.3 Input Data and Timing - Monitoring

Input data, in this instance for monitoring, is the same at all levels of supervision, i.e., department, shop/section, F-group, and AF-group. In IHI shipyards actual man-hours consumed are entered every ten calendar days. Elsewhere it may be more convenient to make such entries weekly or biweekly dependent upon the rate of hull construction activities. The purpose of this input is to monitor man-hours consumed compared to man-hours budgeted.

5.2.4 Material Volume Input - Original and Monitoring

Physical characteristics of the interim products to be built are the basis for determining material volume as follows:

- . Welding Length

Welding lengths for erection, assembly and sub-assembly are estimated per block from key plans, i.e., as produced during functional design to show structural functions. The welding lengths so obtained are used to estimate man-hours required for each section by process yard.

- Cutting Length

Cutting lengths per plate and per structural shape, as estimated from key plans, are used for calculating rough cutting length per block. This information is used for estimating the man-hours required for each of the cutting process yards in the Fabrication Shop.

- Bending

The number of parts to be bent per each block are estimated from key plans. This information is used for estimating man-hours required for the bending process yard in the Fabrication Shop.

5.3 F-Groups

Each F-group within each shop/section prepares:

- productivity graphs, ship by ship, which show actual manpower consumption vs. material volume in comparison with what was budgeted; see Figure 4-12, and
- a monthly schedule for coordinating its process yard with the monthly schedules for preceding and succeeding yards and to govern AF-group weekly schedules. Tracking actual production progress is performed on the monthly schedule by color shading.

5.3.1 Reference Data

For effective operation of FPI, the F-groups have to keep and update the following references as a data base:

- Block Erection, Assembly, Sub-block Assembly and Parts Fabrication Duration and Sequence Records.

These are records of actual progress for each process yard/process station per block by ship type and hull steel weight. They are used to prepare monthly schedules for each process yard and are updated every month based on tracking actual production progress on the monthly schedule.

- Productivity Graphs

These graphs are per process yard and relate actual man-hours to material volume consumed. A productivity graph, as typically shown in Figure 4-12, is used for preparing monthly schedules for monitoring productivity.

5.3.2 Input Data and Timing

Input timing for the following data is the 20th of every month:

- . Accurate Welding Length

This is the welding length for erection, assembly and sub-assembly for each block as measured from stage plans, i.e., final work instructions. These measured lengths are used to calculate man-hours required for scheduling at the F-group level, i.e., an implementation level just above that for which AF-groups have cognizance.

- Cutting Length

Cutting lengths per plate and per structural shape are as calculated from stage plans, i.e., final work instructions both for manual and numerical-control cutting. This information is used for calculating the man-hours required for each process yard and for F-group level scheduling.

- Bending

The number of parts per block that are to be bent are calculated from stage plans. This information is used for calculating man-hours required and scheduling work in the bending process yard, i.e., F-group level scheduling.

- . Man-hours Available

Man-hours available per day are determined by applying a factor for each F-group for absenteeism to the total manning assigned each process yard. This information is required to level each process yard's workload in order to determine the sufficiency of manpower available.

- Reports of Actual Production Processed

Reports of how production is currently processing are needed to prepare the coming month's schedule, considering advanced or delayed work.

5.4 AF-groups

Each AF-group prepares:

- . Productivity curves, i.e., material volume vs. manpower consumption for each problem area (trade) per process station. An assistant foreman having cognizance of two process stations performing the same work would combine data from both stations to produce one productivity curve. The curve is used for evaluating current productivity and for forecasting future productivity.
- . Weekly schedules for each station per problem area (trade) for their coordination with weekly schedules for preceding and succeeding stations or yards. The weekly schedules are used for tracking actual production progress by color shading.

5.4.1 Reference Data

For effective operation of FPI, AF-groups have to keep and update the following references as a data base:

- . Block erection, block assembly, sub-block assembly, and parts fabrication duration and sequence records.

These are records of actual progress for each process station/trade/block by ship type and hull steel weight. They are used to prepare the weekly schedules for each process station and are updated every week based on tracking production progress on biweekly schedules.

- Statistical Productivity Graphs

These graphs are per process station/trade and relate actual man-hours to material volume consumed. A productivity graph as typically shown in Figure 4-12 is used for preparing weekly schedules for monitoring productivity.

5.4.2 Input Data and timing

Input data is the same as for the F-groups as described in Part 5.3.2 and input timing is every Thursday.

6.0 FPI FOR ZONE OUTFITTING METHOD (ZOFM)

FPI are applied to the ZOFM in accordance with the same concept used for the HBCM as described in Chapter 5.0. But, correlating material volume processed with manpower consumed in the ZOFM is not as easy as it is for the HBCM. Man-hours consumed per hull steel weight, cutting length, and welding length do not vary much for hull construction work as compared, for example, to variations in man-hours consumed per fitting weight. But, properly classified data from past experiences are sufficient to devise useful indices for the ZOFM.

Required assembly man-hours for certain fittings are related enough to their weights or lengths for employing man-hours/component weight or length as a manpower index. These so-called *parametric components* for which *weight* is useful to devise an index, are pipe pieces, pipe supports, valves, ladders, vent ducts, machinery foundations, electric-cable hangers and many other miscellaneous fabricated steel components. Electric cables are also regarded as parametric components, but *length* is used to devise an index. Non-parametric components include main engines, boilers, diesel generators, pumps, separately fitted tanks, hatch covers, and other such large items.

Fitting man-hours are separately calculated per summary unit. For example, a summary unit for F- and AF-groups is a pallet. Pallet manpower requirements are summarized to obtain total manpower required per group. For DAME Sections, the summary unit is a block or on-board zone. Block and on-board zone manpower requirements are summarized to obtain total manpower required per section.¹

Fitting man-hours for parametric components are calculated by the formula:

$$MH = PI \times MV$$

where:

MH = man-hours for a summary unit of work volume

PI = a productivity index pertinent for the summary unit

MV = material volume pertinent for the summary unit, e.g., parametric component weight, electric-cable length, etc.

Man-hours for fitting non-parametric components and system testing and operation are calculated individually. Experiential data must be tiled and maintained for each non-parametric component and for each system as shown for complete ships in Figure 4-5. For example, man-hour data is separately plotted for fitting each particular main-engine type, for each type of auxiliary machine, and for operation including testing of separate distributive systems. Although data is so plotted, the nature of fitting, operation, and testing non-parametric components requires dependence on estimating man-hours by conventional methods.

6.1 Outfitting Department

The Outfitting Department prepares a man-hour cumulative schedule for forecasting and leveling the long-term workload, compares it to man-hours available, and monitors man-hours consumed with progress of production against an S-curve distribution of man-hours budgeted as shown in 4-10.

6.1.1 Reference Data

For effective operation of FPI, the department must file and constantly update the following reference data:

- Outfitting Activities Timing Records and Operation and Test Activities Timing Schedule

Actual records of outfitting activities timing including outfit component requisitions, hull block erection, and work instruction drawing issue dates for each "group" of blocks and on-board zones per ship of a similar type and size. This represents establishing required dates in a relatively large frame sense. (See Figures A-10 and A-12 of the NSRP publication "Flexible Production Scheduling System - April 1986")

- Man-hours Required

Man-hours required are determined from curves that are best fitted to plots of actual parametric component weight (material volume) vs. actual man-hours consumed from records of ships built in the past. The curves should be drawn separately for tankers, bulk carriers, etc. to minimize scattering and achieve correlation as shown in Figure 4-3.

¹Ability to control is inversely proportional to pallet size. Thus, the most effective shipyards use a "number" of pallets to produce a single outfit unit, to outfit on a single block, or to outfit in a single on-board zone where an on-board zone is whatever is convenient to define a region on or in an erected ship. In IHI shipyards, such pallets have been gradually reduced in size and are now nearly down to five man-days each.

- Statistical S-curve

The statistical S-curve relates total cumulative outfitting man-hours to time so as to identify percentages of total man-hours between such milestones as contract award, fabrication start, keel laying, launching, delivery, and subdivisions between such key events when necessary to achieve a smooth S-curve.

Based on analysis of records of similar ships built in the past, a family of S-curves are drawn representing “rapid”, “normal”, and “late” rise. The actual S-curve adopted for constructing a particular ship is determined by considering expected timing of drawing issues, estimated delivery dates for materials, and requirements for ships adjacent in the schedule as shown in Figure 4-7. In any event, the S-curve finally adopted must fall within the range of the rapid- and late-rise S-curves. A useful technique employs the percentages of cumulated man-hours between milestones and their subdivisions from actual S-curves of similar ships as guidance for constructing a statistical S-curve to be used in the future.

During and upon completion of outfitting a ship, the statistical S-curve used should always be checked against the actual S-curve recorded. Any conspicuous deviation between the two curves should be investigated to pinpoint the causes. Findings should be taken into consideration during planning for future jobs.

The statistical S-curve is used to predict manpower consumption relative to time, particularly to key events. Simultaneously with S-curves for adjacent ships, each curve is adjusted in order to level total man-hours required as much as possible. The result is compared to man-hours available for the purpose of predicting the amounts of overtime and/or subcontractor assistance that will be required. Each final statistical S-curve is used to monitor actual man-hour consumption by the Outfitting Department for a specific ship.

6.1.2 Input Data and Timing - Original

Input timing at the Outfitting Department level should be as frequent as every three months if as many as five or six ships/year are built per dock or if the workload is of a fluctuating nature. It should be less often, perhaps every six months, commensurate with lesser or more stable workloads. Data required consists of:

. Budget Material List (MLB)

The substance conveyed by an MLB (also called a Budget Control List) for outfitting is type of ship, parametric component weight, length, etc. An MLB is used to estimate manpower required for outfitting.²

- Shipyard Master Schedule

The substance conveyed by a Shipyard Master Schedule consists of dates of contract award, fabrication start, keel laying, launching, and delivery, i.e., scheduling in the largest frame sense.

- Man-hours Available

Man-hours available per month are determined by applying a factor for absenteeism to the total manning assigned to the Outfitting Department. This information is needed when leveling the workload to determine the sufficiency of manpower available.

6.1.3 Input Data and Timing - Monitoring

Input data, in this instance for monitoring, is the same at all levels of supervision, i.e., department, shop/section, F-group, and AF-group. In IHI shipyards actual man-hours consumed are entered every ten calendar days. Elsewhere it may be more convenient to make such entries weekly or biweekly dependent upon the rate of outfitting activities.

The purpose of this input is to monitor man-hours consumed compared to man-hours budgeted.

6.2 DAME Sections

Each DAME section of the Outfitting Department, including a separate Machinery Operation Section, prepares schedules and S-curve graphs in the same way and for the same purposes as described in Part 5.2 for the shop/sections of the Hull Construction Department.

6.2.1 Reference Data

For effective operation of FPI, each section has to independently keep and update its own production data base consisting of:

- Statistical Man-hours

Actual man-hour consumption data from past projects must be filed and maintained by each section in the same manner as at the department level.

- Statistical S-curves

Statistical S-curves actually achieved in the past must be filed and maintained by each section in the same manner as at the department level.

- Major Machinery Erection (Blue Sky Outfitting) Sequence and Timing Records

² Only parametric component weight, length, etc. are utilized for estimating total man-hours required. Even though the total weight for non-parametric components can be relatively great, the total of fitting man-hours for non-parametric components relative to the total for parametric components is small enough to be ignored. Man-hours for a main-engine foundation are included in hull construction. Auxiliary machinery foundations, including foundations for deck machinery, are parametric components.

Actual performance of erection progress for blue-sky outfitting of each major machine in the past should be maintained in file by ship type and size. Such major outfit components appear on the Outfitting and Hull Construction Activities Timing Schedules to insure their integration with hull-block erection activities (see Figures A-10, A-11 and A-3 of the NSRP publication “Flexible Production Scheduling System - April 1986”). Typical such major components are: main engines, boilers, diesel generators, propellers, rudders, hatch covers, cargo gear, radar masts, etc.

The blue-sky outfitting records are used to prepare and refine section schedules for DAME outfitting, for machinery testing and operation, and for preliminary sequencing of such work as needed for preparing a definitive IHOP schedule.

. Statistical Productivity Curves

Statistical productivity (or efficiency) is defined as man-hours related to material volume for each type of work. They are derived from actual man-hours expended per material volume consumed during past projects. But, the material volume for fitting parametric components is divided by DAME and by on-unit, on-block, and on-board. That is the separation by DAME are summary units and the separation by the manufacturing levels, on-unit, on-block, and on-board are summary units. The combination represents a matrix that is summed both ways.

For installation of non parametric components and testing and operating systems, the actual records of past experiences are utilized for guidance in predicting productivity. More reliance is placed on traditional methods as compared to the analytical methods used for parametric components.

6.2.2 Input Data and liming - Original

Data is inputted at the time of preparation of man-hour cumulative schedules and consists of:

- Budget Material List (MLB)

The substance conveyed by a MLB (also called a Budget Control List) for each DAME section is type of ship and parametric component weight, length, etc. It is used to estimate the manpower required by each DAME section.

- Shipyard master Schedule

The substance conveyed by a Shipyard Master Schedule consists of dates of contract award, fabrication start, keel laying, launching, and delivery, i.e., scheduling in the largest frame sense.

6.2.3 Input Data and Timing - Monitoring

Input data, in this instance for monitoring, is the same at all levels of supervision, i.e., department, section, F-group, and AF-group. In IHI shipyards actual man-hours consumed are entered every ten calendar days. Elsewhere it may be more

convenient to make such entries weekly or biweekly dependent upon the rate of outfitting activities.

The purpose of this input is to monitor man-hours consumed compared to man-hours budgeted.

6.2.4 Material Volume Input - Original and Monitoring

Characteristics of parametric components that will be in the interim products to be assembled, are the basis for determining material volume as follows:

- Parametric Component Weight

Parametric component weight for on-unit and on-block outfitting by each block and for on-board outfitting by each on-board zone, are estimated from the Budget Material List (BML). The weights obtained are used to estimate man-hours required for each DAME section by manufacturing level, i.e., on-unit, on-block, and on-board.

- Non-Parametric Component Weight

Non-parametric component weight for on-unit and on-block outfitting for each block and for outfitting in each on-board zone, are obtained from a machinery list of standard man-hours required.

- Laid Cable Length

Laid cable length for on-unit and on-block outfitting for each block and for on-board outfitting for each on-board zone, is estimated from the Budget Material List (MLB). The lengths obtained are used to estimate man-hours required for the electrical section by manufacturing level, i.e., on-unit, on-block, and on-board.

- Operation and Testing

There is no parametric material associated with testing and operation. Thus, material volume is not applicable. The MLB is used only to identify test and operation work that must be anticipated. Man-hours for such work are predicted with traditional methods using past data as guidance.

6.3 F-Groups

Each F-group within DAME sections prepares an S-curve and monthly schedule in the same way and for the same purposes as described in Part 5.3 for hull construction.

6.3.1 Reference Data

For effective operation of FPI, the F-groups have to keep and update the following as a data base:

- . Outfitting Work Duration and Sequence Records per Pallet

Actual records are maintained of on-unit, on-block, and on-board outfitting, and operation and testing of systems for each process yard/process station per block, or for systems, by ship type. This information is used to prepare and update monthly schedules, which comply with a section schedule, for each process yard. Using each assistant foreman's report of actual progress, shading on a monthly schedule constitutes a tracking report of actual production progress.³

. Statistical Productivity Graphs

These graphs are per process yard and relate actual man-hours to material volume consumed. A productivity graph as typically shown in Figure 4-12 would be based on parametric component weight. A similar productivity graph would apply for parametric component (cable) length. Separate such graphs would apply for each major non-parametric component classified by main engine size and type, boiler size and type, etc. All such graphs are used for preparing monthly schedules when needed for monitoring productivity.

. Integrated Graph for Simultaneously Monitoring Man-hour Consumption and Productivity

As shown in Figure 6-1, a 45-degree-line graph is effective for simultaneously:

- monitoring man-hours consumed relative to budgeted man-hours, and
- tracking production progress relative to scheduled work.

In other words, the graph is contrived to have a 45-degree line represent planned productivity. The way each plotted point departs from the 45-degree line indicates whether man-hours are over or under budget and at the same time, whether work performance **is ahead or behind** schedule.

A 45-degree-line graph is optimum for use by F-groups because it shows performance status as work is immediately completed pallet by pallet. In addition to keeping F-groups immediately advised of how they are performing, 45-degree-line graphs are used to check the separate graphs for monitoring man-hour consumption, progress, and productivity, prepared at the section and department levels as previously described.

6.3.2 Input Data and timing

Input timing is the 20th of every month for monthly scheduling. But, as previously noted, in IHI shipyards outfitting monthly schedules **were** discontinued when design phases started to progress very rapidly. The higher-tier larger-frame section schedules **are** used to check off progress by shading. This again illustrates the benefit of FPI. Mesh sizes can be readily changed dependent upon the rate that activities are accomplished.

Data required consists of:

. Parametric Component Weight

Parametric component weights as needed for on-unit, on-block, and, on-board outfitting are obtained from material lists for fitting (MLF). Accumulations of parametric weights/pallet are used to calculate man-hours for F-group scheduling.

. Non-parametric Component Weight

Non-parametric component weight of each pallet for on-unit, on-block, and on-board outfitting is estimated from information included in the machinery list. Such non-parametric weights are used to adjust man-hours for F-group scheduling by traditional methods.

. Laid Cable Length

The total electric-cable length for each pallet is summed from lengths/cable recorded in MLF. These are used to calculate the man-hours for F-group scheduling of cable pulling work.

•Manpower Consumption for Operation and Test

Man-hours required for operation and testing of machinery and systems are estimated using previous experiences and pertinent operating manuals and shipyard test procedures. The man-hours derived are used for calculating the man-hours needed for F-group scheduling.

. Man-hours Available

Man-hours available per day are determined by the number of people assigned to an F-group multiplied by a factor for absenteeism. Man-hours available are needed for comparison to required man-hours when leveling workloads.

•Reports of Production Progress

Current production progress status is required for preparing the coming monthly schedule with due consideration for work progress ahead or behind schedule.

6.4 AF-Groups

Each assistant foreman prepares a weekly schedule for each station or for each worker for their coordination with weekly schedules for preceding and succeeding stations or workers. The weekly schedules are used for tracking actual production progress by color shading.

³If design phases are implemented rapidly enough, the outfitting monthly schedules can be omitted as in IHI shipyards. Progress is adequately monitored by shading on a section schedule using assistant foremen reports of actual progress.

6.4.1 Reference Data

Generally, AF-groups do not file and maintain reference data. But, they must report their actual progress and conditions such as difficulties experienced or improvements made for enhancing productivity.

6.4.2 Input Data and liming

Input timing for data needed to prepare weekly schedules is every Thursday. The data is that required by F-groups to check the status of material per MLF before including a pallet on a weekly schedule. This check includes both materials supplied by vendors and interim products from preceding production processes. In addition, F-groups insure that required work instruction drawings from the design department are in hand before a pallet is entered on a weekly schedule.

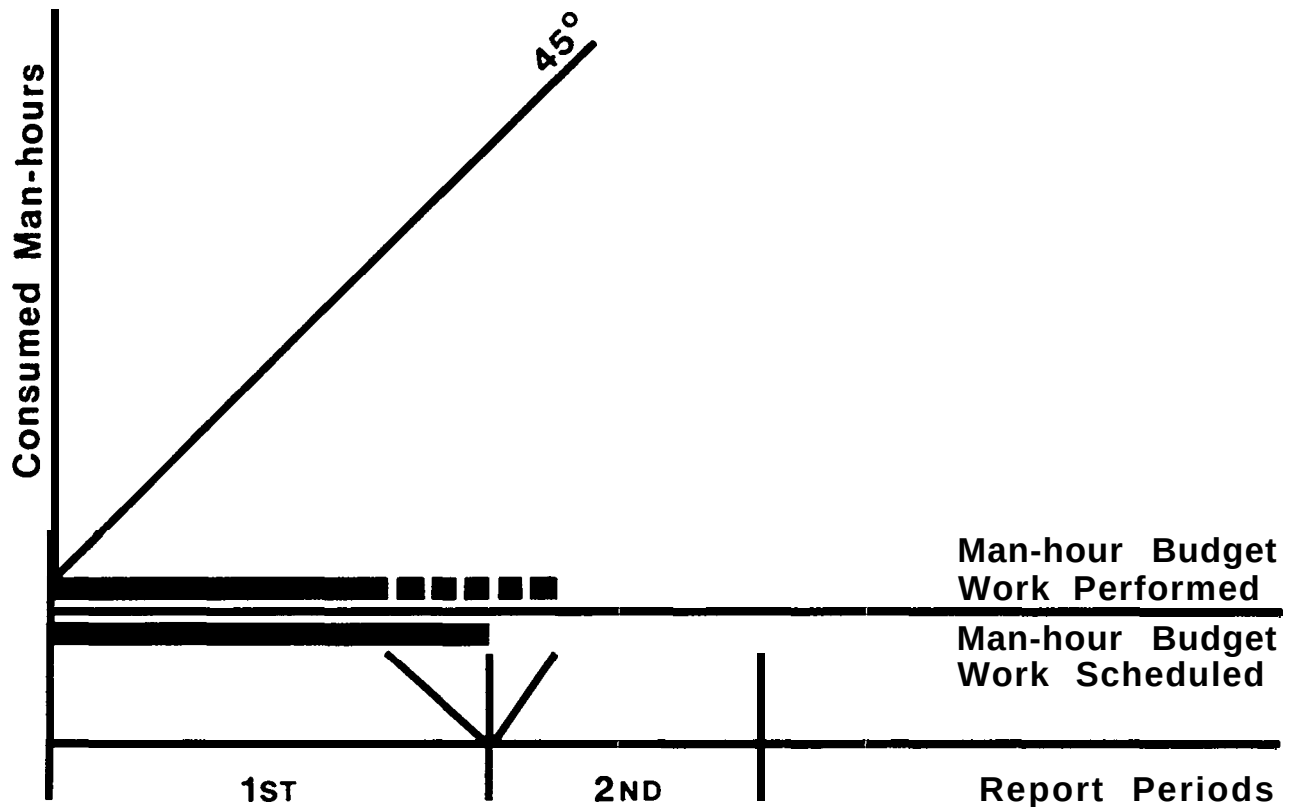


FIGURE 6-1(a): In order to assess performance when implementing a series of work packages of the same problem classification, both budget and schedule adherence must be monitored. An ideal visual aid is a 45-degree line graph, as shown, where both the horizontal and vertical scales are in man-hours. The man-hours for work scheduled in each report period determines the width shown for that report period. Man-hour entries for both abscissors and ordinates are cumulative. If accumulated consumed man-hours at the end of each report period were exactly as budgeted for work scheduled, all plotted points would appear on the 45-degree line. Work performance is then in accordance with the budget and schedule. But, as parametric material and man-hours are related through productivity indices, in a sense material and man-hours are synonymous, material processed represents work performed. Thus, at the end of each report period, material processed is converted to the man-hour budget for work performed. As shown above, the amount of work (work volume) that is **behind schedule is represented by the difference** in lengths of the two horizontal solid lines. In order to enhance the visual effect and to maintain a visual record, an indicator is drawn at the end of each report period which points to the cumulative total of **man-hours budgeted for work performed**. The indicator, operating like a windshield wiper, points to the left when the amount of work performed (material processed) is less than what was scheduled to date, and to the right when the amount of work performed is more than scheduled (as represented by the dotted line extension shown). Also, the angle at which the pointer deviates from vertical is proportional to the work volume differential. See Figure 6-1(b).

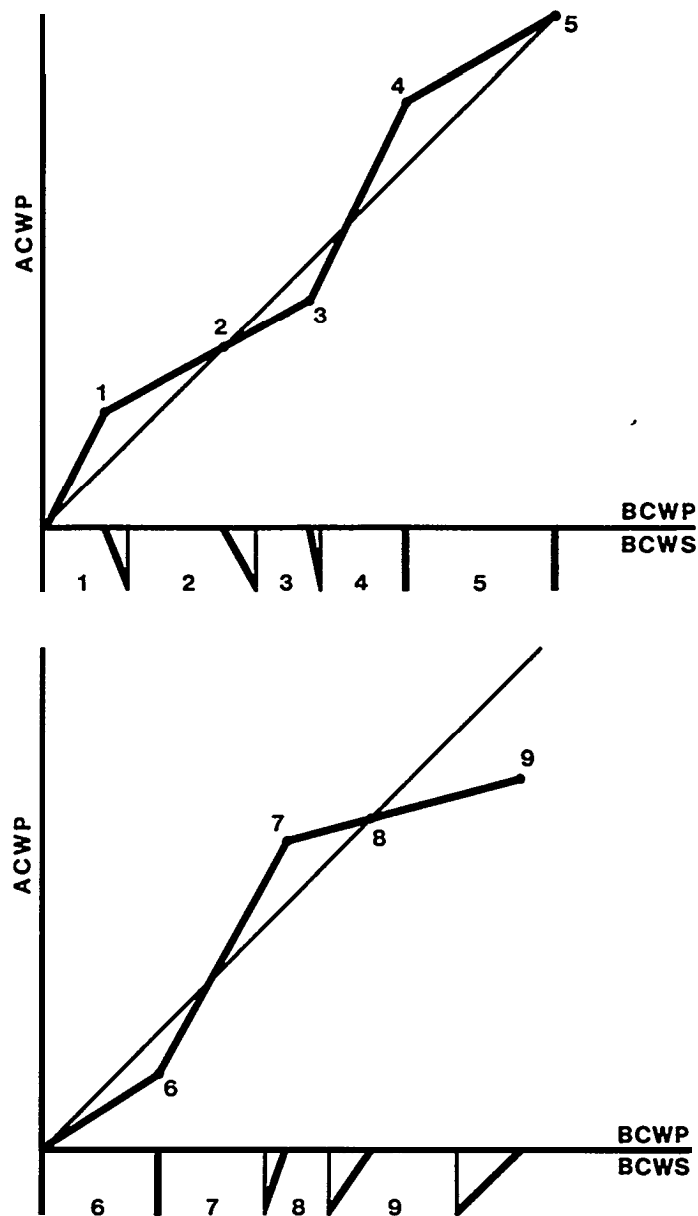


FIGURE 6-1(b): For the purpose of showing that a Product Work Breakdown Structure (PWBS) and the concept of relating man-hours to *parametric* materials is ideal for implementation of Cost/Schedule Control Systems Criteria as published for guidance by the U.S. Department of Defense, the following terms taken from the latter are substituted in the 45-degree line graphs shown: Budgeted *Cost* of Work Scheduled (BCWS), Budgeted *Cost* of Work Performed (BCWP), and Actual *Cost* of Work Performed (ACWP). While the 45-degree line graphs shown are in *man-hours* for production control purposes, the productivity index relates budgeted man-hours to the materials both budgeted and consumed as exactly identified in material lists (MLF, MLP, and MLC). Thus, 45-degree line graphs can be readily employed to incorporate the cost of materials. Since work performed can be behind schedule, per schedule, or ahead of schedule, while consumed man-hours could be more than budgeted, as budgeted, or less than budgeted, there are nine possible combinations as shown in the above plots. Since the plots are for one work flow (of the same problem area with work in statistical control), the pertinent budget and schedule were based on *normalcy*, i.e., an index expressed as a *mean* with *standard deviations*. Thus, constant bracketing of the 45-degree line is normal as it represents an immediate supervisor making adjustments (e.g., transferring workers from a work flow that is ahead to one that is behind, substituting a more for a less experienced worker, and/or authorizing overtime), to insure performance per schedule and budget. Significant departures associated with any of the nine cases shown are cause for concern and investigation. Case 1 would be most serious as both schedule and budget lapses are indicated. Case 9 represents the best situation to have to react to. Work is being performed significantly ahead of schedule and man-hours consumed are significantly less than budgeted for the work performed. The cause must be identified. The trend must be confirmed, perhaps through continued progress through one or two more report periods. Then, the impact on other work flows must be examined and adjustments made, if possible, to improved the overall manufacturing system while maintaining integration of the various work flows for different types of work. Finally, if the foregoing conditions are met, the pertinent indices must be revised as well as the budgets and schedules for remaining work. Estimators and marketing people must be advised of the revisions, however small and frequent, to insure that they will be reflected in bids for future work and that the improved capabilities are incorporated in marketing promotions.

7.0 FPI FOR ZONE PAINTING METHOD (ZPTM)

The ZOPM employs FPI in a similar way to application for the HBCM as described in Chapter 5.0. Correlation between material volume processed and manpower consumed in the ZPTM is also very good, and in addition, is expressed only in one unit, i.e., square meters. Man-hours required are obtained by the formula:

$$MH = PI \times MV \times NC$$

where: MH = man-hours for a summary unit of work volume¹

PI = a productivity index by pertinent summary unit

MV = area to be painted in square meters

NC = number of coats

7.1 Painting Department

The department or, where painting workloads are relatively small, section, prepares a man-hour cumulative schedule for forecasting and leveling the long-term workload by making comparisons with man-hours available. An S-curve distribution of man-hours budgeted is used as the basis for comparing man-hours consumed as shown in Figure 4-10.

7.1.1 Reference Data

For operation of FPI, the department (or section) must maintain an updated data base as follows:

•Painting Activities Timing Records

Actual records are kept of painting activities timing, including records of painting materials used, hull construction and outfitting activities on-block and on-board, and painting specifications per groups of blocks of the same problem category and on-board zones by ship type and size. This information is used to prepare a Painting Activities Timing Schedule for a specific ship which is usually included in the Outfitting Activities Timing Schedule (See Figures A-10, A-10, and A-12 of the NSRP publication "Flexible Production Scheduling System - April 1986").

•Statistical Man-hours

Man-hours required are obtained from average man-hours consumed for painting ships previously built. They are derived from curves drawn through plotted points which represent area times the number of coats (material volume) vs. actual man-hours consumed and which represent man-hours/material volume (manpower efficiency) vs. time from records of ships built in the past. The curves should be drawn separately for different painting specifications in order to minimize scattering of plots. This information is needed to estimate the total man-hour budget for the painting department (or section).

•Statistical S-curve

Defining, preparing, maintaining, and using a statistical S-curve for painting is as described in Part 5.1.1 for hull construction.

7.1.2 Input Data and Timing - Original

The timing for the following data is every three months:

. Budget Material List (MLB)

The BML identifies certain basic ship characteristics such as ship type, and painting specifications, including kinds of paint and numbers of coats required. This information is required for estimating manpower requirements for painting.

. Shipyard Master Schedule

The substance conveyed by a shipyard master schedule consists of dates of contract award, fabrication start, keel laying, launching, and delivery, i.e., scheduling in a large frame sense.

•Man-hours Available

Man-hours available per month are determined by applying a factor for absenteeism to the total manning assigned to the Painting Department (or Section). This information is needed for comparison to level the workload in order to determine the sufficiency of manpower available.

¹A summary unit is different at each level of the organization. A summary unit for F- and AF-groups is a block for on-block painting or a compartment for on-board painting, and for sections a block or on-board zone. At the section and department levels, a summary unit is a block or an on-board zone. For interior painting, the latter may consist of a number of compartments having the same problem category for painting.

7.1.3 Input Data and Timing - Monitoring

Input data, in this instance for monitoring, is the same at all levels, i.e., department and/or section, F-group, and AF-group. In IHI shipyards actual man-hours consumed are entered every ten calendar-days. Elsewhere it may be more convenient to make such entries weekly or biweekly dependent upon the rate of painting activities.

The purpose of this input is to monitor the man-hours consumed compared to man-hours budgeted.

7.2 Sections

The painting section prepares schedules and S-curve graphs in the same way and for the same purposes as described in Part 5.2 for hull construction. If a separate painting department is not justified, the Painting Section prepares and monitors progress on the department-level S-curve as previously mentioned.

7.2.1 Reference Data

For effective operation of FPI the section has to keep and update its own production data base as necessary.

•Painting Time Requirements

Actual records of durations experienced should be filed by specifications and by paint brands with special attention given to the time intervals needed between paint coats. This information is needed to prepare and refine the Section schedule for painting and for integrating painting work when preparing preliminary and definitive IHOP schedules.

. Statistical Productivity Curves

Statistical productivity (or efficiency) is defined as man-hours related to material volume for each type of work. It is derived from actual man-hours expended per material volume consumed during past projects. But for painting, material volume is expressed in terms of square meters times the number of coats. Painting efficiency varies with different work circumstances, e.g., on-block vs. on-board, exterior vs. interior, and small vs. large compartments.

7.2.2 Input Data and Timing - Original

Input of the following data is in time for preparing the Section man-hour cumulative schedule:

•Hull Construction Key Plans and Yard Plans (block plans)

These plans indicate the type of ship, painting specifications, and area to be painted per block and per on-board zone. The plans are issued for the purpose of estimating each block and each on-board zone.

•Shipyard Master Schedule

The substance conveyed by a shipyard master schedule consists of dates of contract award, fabrication start, keel laying, launching, and delivery, i.e., scheduling in a large frame sense.

. Man-hours Available

Man-hours per available month are determined by applying a factor for each section which is applied to the total manpower assigned to each section. This information is required to level the section workload in order to determine the sufficiency of manpower available.

7.2.3 Input Data and Timing - Monitoring

Input data, in this instance for monitoring, is the same at all levels, i.e., department and/or section, and F- and AF-group. In IHI shipyards actual man-hours are entered every ten calendar-days. Elsewhere it may be more convenient to make such entries weekly or biweekly dependent upon the rate of painting activities.

7.2.4 Material Volume Input - Original and Monitoring

Physical characteristics of the interim products to be produced are the basis for determining material volume as follows:

•Painting Area

Painting areas for blocks and on-board zones are as estimated from key and yard plans. This data is needed to estimate man-hours for the painting section schedule.

7.3 F-Groups

Each F-group of the painting section can prepare S-curve graphs and monthly schedules in the same way and for the same purposes as described in Part 5.3. But, in effective shipyards, painting efficiency does not vary much as compared to efficiencies for other types of work. That is, the normal distribution of painting efficiency variations is relatively narrow. Therefore, a simple standard efficiency table can be established by kind of paint, manufacturing level (on-block or on-board), and by problem category (e.g., degree of access).

7.3.1 Reference Data

For effective operation of FPI, F-groups have to keep and update the following references as a data base:

Painting Work Durations and Sequence Records per Block or On-board Zone

Actual records of on-block and on-board painting for each process yard/station per block and per on-board painting zone should be maintained by ship type, kinds of paint, and painting specifications. The records are used to prepare and update monthly schedules for on-block and on-board painting. The latter are used for tracking actual production progress. (Note: As previously mentioned for outfitting, IHI shipyards omit monthly schedules and employ section schedules for tracking.)

- Statistical Productivity Curves

These graphs are per process yard and relate actual man-hours to material volume consumed. A productivity graph as shown in Figure 4-12 is used for preparing monthly schedules and for monitoring productivity.

7.3.2 Input Data and Timing

Input timing for the following data is the 20th of every month except for reports of production progress which are made every ten calendar-days.

- . Painting Area

Painting area for on-block and on-board painting is summed per work package, i.e., pallet, as measured from key and yard plans for hull construction. Square meters/work package are used to calculate man-hours for F-group schedules.

- Man-hours Available

Man-hours available per day are determined by applying an absentee factor to the total manpower assigned and are used for comparison when leveling a workload.

- Reports of Production Progress

Reports of production progressed are made every ten calendar-days. They are used to take into consideration advanced or delayed work when preparing the coming monthly schedule.

7.4 AF-Groups

Each AF-group prepares weekly schedules as described in Part 5.4 for hull construction.

7.4.1 Reference Data

Generally, AF-groups do not formally file and maintain reference data. They do so individually as necessary. But, they must report their actual conditions such as difficulties experience or improvements for enhancing productivity that were accomplished.

7.4.2 Input Data and Timing

Input timing is every Thursday. In addition to providing data to its respective F-group, each AF-group must check the status of materials and of interim products from preceding production processes and work-instruction drawings before they include a work package in a weekly schedule.

8.0 FPI FOR PIPE PIECE FAMILY MANUFACTURING (PPFM)

PPFM applies FPI in a way that is similar to application for the HBCM as described in Chapter 5.0. Process similarities include marking, cutting, assembling (fitting and welding), and bending. Coating and palletizing are additional processes. Correlation between material volume processed and man-hours consumed depends on finished pipe-piece shapes (straight or bent), pipe diameters, basic materials, etc. That is, pipe pieces are classified by *families*. Each family employs physical characteristics that relate to problems inherent in manufacturing that distinguishes it from other families. Man-hours are budgeted per pipe-piece family.

Man-hours (MH) requirements for a summary unit of work volume are given by the formula:

$$MH = PI \times MV \times R$$

where:

PI = a productivity index pertinent for a summary unit

MV = material volume pertinent for the shop, an F-group, or an AF-group

R = hourly rate statistically derived from experience

8.1 Pipe Piece Manufacturing Shop

The shop is organized under the outfitting department and prepares a man-hour cumulative schedule for forecasting and leveling the workload in an intermediate frame-size sense for comparison to man-hours available. Monitoring man-hours consumed against man-hours budgeted is through S-curve comparisons as shown in Figure 4-10. Forecast of the shop's long-term workload is based on an outfitting cumulative schedule (similar to a hull construction cumulative schedule shown in Figure A-1 of the NSRP publication "Flexible Production Scheduling System - April 1986").

8.1.1 Reference Data

For effective operation of FPI the shop has to file and update the following references as a data base:

- Statistical Man-hours

Statistical data of actual man-hour consumption must be filed and maintain by the shop in the same manner as by the assembly sections.

- Pipe and Fittings for Pipe Pieces

Records are kept by weight of the materials used in the past by ship type and size. These include all components needed to manufacture pipe pieces, such as, pipe, flanges, elbows, sleeves, tees, and reducers, separately classed by types of material, i.e., steel, cast, non-ferrous, PVC, etc. These weight records are used to prepare a shop man-hour cumulation schedule.

- Statistical Productivity Graph

Statistical productivity (or efficiency) is defined as man-hours related to material volume for each type of work. They are derived from actual man-hours expended per material volume consumed during past projects. Actual efficiencies are recorded by process yard for various types of work using data which describes actual performances for past ships. (A pipe shop *process yard* is defined as facilities needed to manufacture all pipe-piece families of one of the following size categories: small diameter, medium, diameter, and large diameter. As an exception, a separate process yard addresses pipe pieces to be made from non-ferrous materials. Within each process yard work flows are organized as needed to produce specific pipe piece families.)

8.1.2 Input Data and Timing - Original

Input timing for the following is in time for preparation of the man-hour cumulative schedule:

. Budget Material List (MLB)

The MLB identifies the ship type and provides the weight of pipe and pipe piece fittings that are required. It is used by the shop to estimate man-hours required.

. Shipyard Master Schedule

The substance conveyed by a shipyard master schedule consists of dates of contract award, fabrication start, keel laying, launching, and delivery, i.e., scheduling in the largest frame sense.

• Man-hours Available

Man-hours available per month are determined by applying a factor for shop absenteeism to the total manning assigned to the shop. This information is required to level the shop workload in order to determine the sufficiency of manpower available.

8.1.3 Input Data and Timing - Monitoring

Input timing for the following information is every 10 days:

. Man-hours Consumed

The purpose of this input is to monitor man-hours consumed compared to man-hours budgeted. Significantly, budgets exist as man-hours per ship and man-hours per weekly pipe-piece lot which represent pipe piece requirements for more than one ship to be constructed as well as for ships being overhauled.

8.2 F-Groups

Each F-group prepares a two- and one-week advanced schedule which shows weekly workloads (see Figures A-27 through A-30 of the NSRP publication "Flexible Production Scheduling System - April 1986"). The workload is computed by using a rate that specifically applies for each pipe-piece family. But, improvement or innovation of technology, methods, systems, and facilities are expected to constantly enhance productivity. Thus, productivity indices should be constantly adjusted commensurate with the changes in man-hour rates.

8.2.1 Reference Data

For effective operation of FPI, each F-group has to keep and update the following references as a data base:

. Statistical Productivity Graphs

The productivity index (PI) is computed as man-hours consumed vs. material volume completed (weight). But variation per pipe-piece family is very small. Thus, as for painting, a table of productivity indices is employed for predicting weekly work lots per process yard. If the workload exceeds the man-hours available, some of work will be shifted to an earlier or later week on the two-week advanced schedule, or to other production lines on the one-week advanced schedule. The *production line* is similar in grouping concept to an F-group. Each subcontractor is regarded as an alternate line.

. Statistical Productivity Graphs for Sorting and Palletizing

Efficiency for sorting and palletizing pipe pieces is defined as man-hours consumed vs. number of pipe pieces palletized.

8.2.2 Input Data and Timing

Input timing for the following data is every Friday:

• Rates

Required man-hours per kind of work, e.g., welding, which is computed for each family and line by summing from pipe-piece drawings. This information is used to compute man-hours required for each F-group (each line) when scheduling.

• Pipe-Piece Drawings

. Man-hours Available per Day

8.3 AF-Groups

Each AF-group prepares weekly schedules as described for hull construction in Part 5.4.

8.3.1 Reference Data

AF-groups maintain records of performances by each process station, such as for, marking/cutting, joining, welding, bending, assembling, and finishing. As pallet start dates determine timing for producing specific pipe pieces, leveling made by the two and one week advanced schedules is usually not ideal. Thus, an assistant foreman shifts the workers from station to station for final workload leveling.

8.3.2 Input Data and Timing

Each assistant foreman checks the status of materials and pipe-piece drawings before every Friday report. And every ten days, each assistant foreman reports piece by piece completion of the finishing and palletizing processes and also reports progress per ship as shown in Figure 8-1.

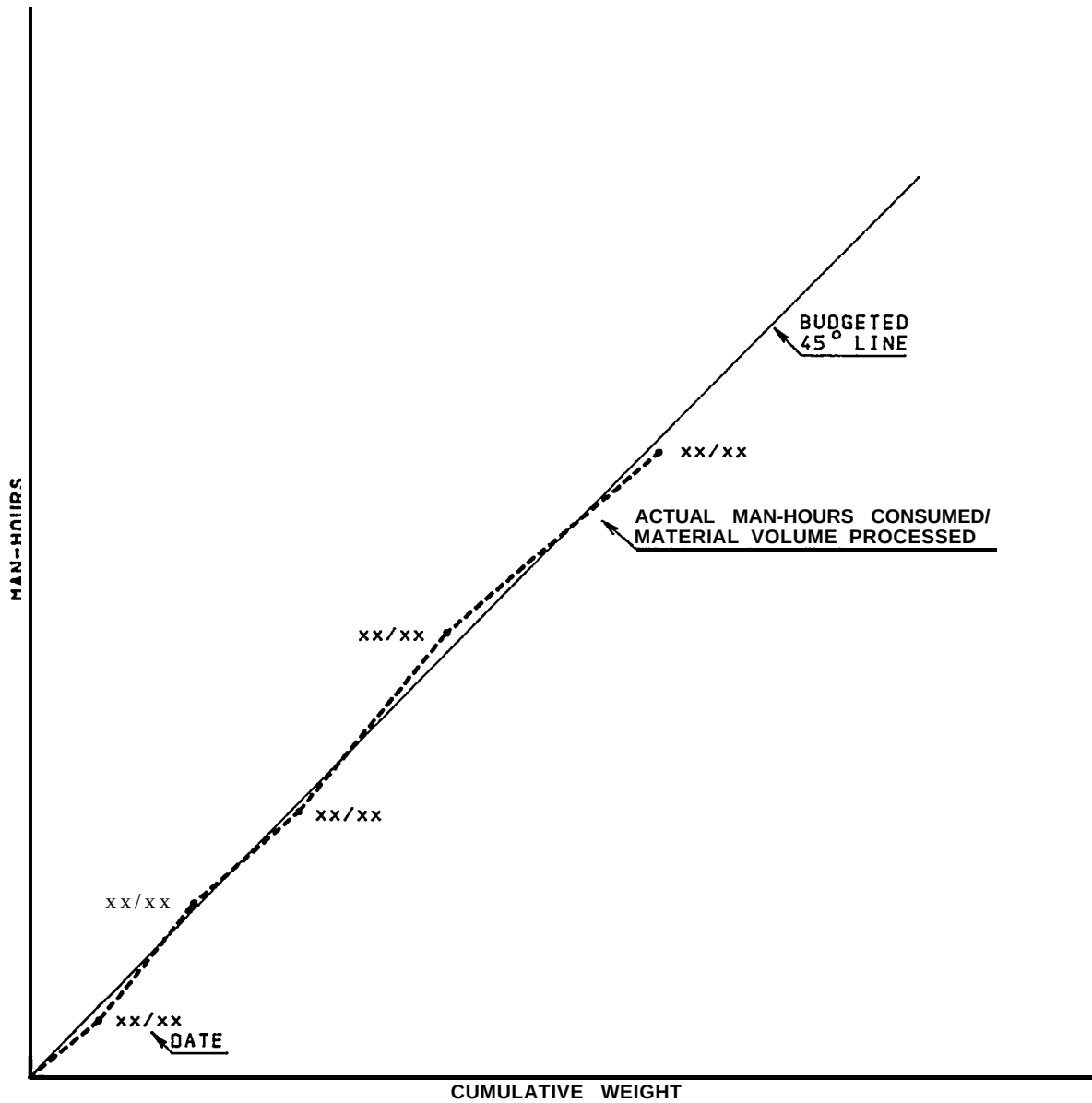


FIGURE 8-1: Production Progress expressed as Man-hours/Cumulative Weight for Pipe Piece Family Manufacturing.

9.0 FPI FOR INTEGRATED HULL CONSTRUCTION, OUTFITTING, AND PAINTING (IHOP)

The “IHOP Program” coordinates design, material procurement, and production information in order to achieve integrated hull construction, outfitting, and painting activities before launching as schematically shown in Figure 9-1. This effort, by the Production Control Department, brings together the thinking of diverse people having concerns for different disciplines so that they collectively focus on the total requirements for each hull block. The timing of all their activities per block is key information.

But, the IHOP program does not estimate and level manpower requirements. Instead, it focuses on integrated schedules which specify the sequencing, durations, and timing for required activities per each block and grand block while maintaining conformance with the Erection Master Schedule, Hull Construction Activities Timing Schedule, and Outfitting Activities Timing Schedule. These schedules are initially compiled by using basic drawings and preliminary block definition and are refined as design develops.

9.1 IHOP Groups

For effective operation of FPI, the group has to keep and update the following as a data base:

9.1.1 Reference Data

. Activities Timing and Duration Records

These are records of activities timing, sequences, and

durations from lofting to hull erection. The activities include fabrication, sub-block assembly, block assembly, sometimes grand-block assembly, on-block outfitting and painting for which data of past performances are filed by ship type and size.

This information is needed for preparation of a Preliminary IHOP Schedule and, subsequently, a Definitive IHOP Schedule. The preliminary schedule is idealistically prepared for a specific ship in the context of a Preliminary Erection Master Schedule and without waiting for coordination with the various section schedules. The Definitive IHOP Schedule is the one which reflects coordination with the section schedules.

9.1.2 Input Data and Timing

Input timing for the following is upon each contract award:

•Erection Master Schedule

This schedule advises of the type ship and the block erection sequence that will be used. It is needed for timing all activities.

•Hull Construction and Outfitting Production Plans

These plans define the processes for hull construction, outfitting and painting that will be employed and are needed to sequence the different kinds of work.

