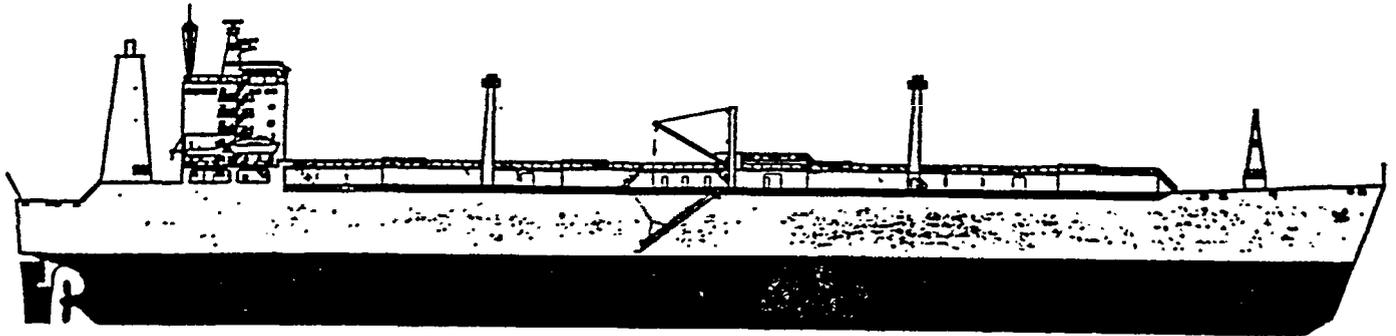


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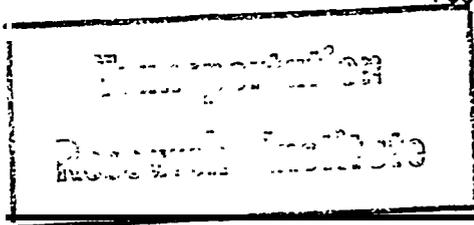
**A MANUAL ON PLANNING AND PRODUCTION CONTROL  
FOR SHIPYARD USE**

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**PRODUCTION ORIENTED  
PLANNING**

**EXECUTIVE SUMMARY**

**A MANUAL ON PLANNING AND PRODUCTION CONTROL  
FOR SHIPYARD USE**

## FOREWORD

This Manual is a direct result of research conducted as part of Task 0-2, Improved Planning and Production Control, of the Ship Producibility Research Program managed by the Bath Iron Works Corporation under the National Shipbuilding Research Program - a program jointly sponsored by the Maritime Administration and the U.S. Shipbuilding Industry. The information in this Manual was developed by personnel in the Industrial Engineering Department of the Bath Iron Works Corporation with subcontract assistance from CorporateTech Planning, Inc., Portsmouth, New Hampshire and Waltham, Massachusetts. The Manual was begun in January and completed in September, 1978.

This Manual is a treatise on planning and production control intended for use by the middle level managers and supervisors in a commercial shipyard. The basic theme is Production Oriented Planning, where planning for the use of resources is oriented squarely with the basic goal of the shipyard, which is to produce quality ships on time at a profit.

There is general agreement among shipbuilders that intelligently controlled application of four basic resources—manpower, material, facilities, and time—is the key to minimizing ship construction costs. Among these the effective management of time is critically important. If the construction schedule is highly compressed, costs will be inordinately high due to premium shift labor, crowded work stations, increased expediting, excessive rework to accommodate inevitable engineering changes, and other well known inefficiencies which compressed schedules always entail. If, on the other hand, schedules are unduly protracted, construction costs will also be high due to extended facility occupancy times, low labor and resource utilization, and carrying charges for high inventory and work-in-process. Between these extremes, there is an optimum schedule where construction costs are at a minimum. (Figure 1).

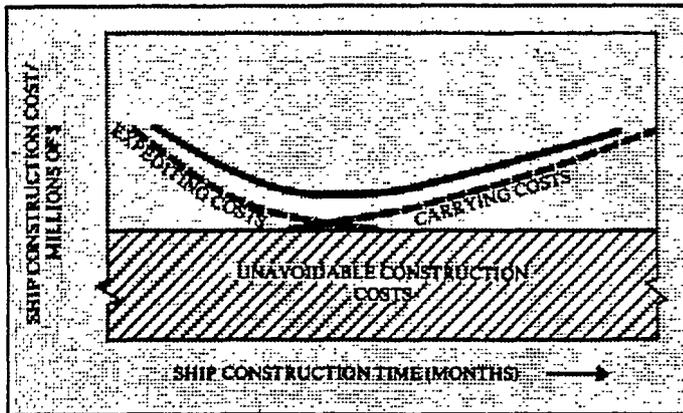


FIGURE 1: IMPACT OF SCHEDULED SHIP CONSTRUCTION TIME ON CONSTRUCTION COST

A striking parallel exists with construction labor budgets. If budgets are underestimated, then labor force manning levels will be inadequate to maintain schedules, and either delivery dates will slip, resulting in contract penalty costs, or labor must be diverted from other projects, causing delays and disruptions throughout the shipyard. If labor budgets are overestimated, it is a well known fact that labor costs will grow inevitably to match the budget. Similar cases can be made for each of the other two resources—material and facilities.

● Bath Iron Works Corporation, *Improved Planning and Production Control*, August 1977 - A Report of Research conducted under the SNAM/MARAD Ship Producibility Research Program managed by the Bath Iron Works Corporation.

For both budgets and schedules, then, there are optimum points at which construction costs are minimized. Each shipyard has a system for planning and production control. A basic question is whether that system is enabling management to make optimum use of time and labor in achieving minimum ship construction costs.

This Manual should help to answer that question. It discusses ways to improve shipyard performance through use of a planning and production control system based on engineered standards. It contains information on industrial engineering techniques used to measure overall shipyard performance and to evaluate whether system additions, deletions, or changes are needed.

The techniques described here were tried in a steel fabrication plant of one commercial shipyard with dramatic savings in fabrication costs and improvements in productivity and schedule compliance.\* The project on which the Engineered Standards were applied during the experiment was a contract for four 20,000 DWT commercial cargo ships. At the time the experiment was started, all steel fabrication work on the first two ships in the series had been completed. Schedule compliance and productivity indices were available for these two ships to provide the baseline for later comparison with experimental results. Engineered Standards were applied at the mid-way point in the fabrication of parts for the third ship, and carried over into fabrication operations for the fourth ship.

Before Engineered Standards were used for steel fabrication shop scheduling and loading, the completion of units averaged 3.2 weeks late. For the three month period in which Engineered Standards were used for shop scheduling, average time late was reduced to zero weeks. (Figure 2)

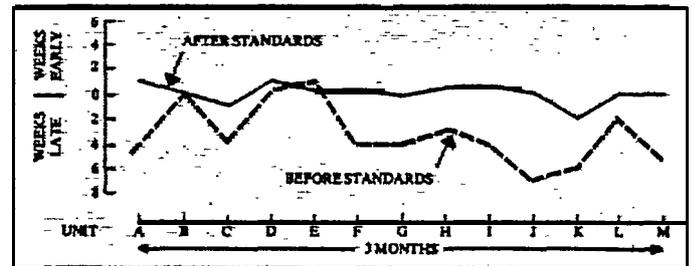


FIGURE 2: IMPACT OF ENGINEERED STANDARDS ON SCHEDULE COMPLIANCE

Equally impressive were improvements in productivity. Here application of Engineered Standards resulted in a projected reduction of 21% in man-hours-per-ton (Figure 3) beyond normal learning effects.

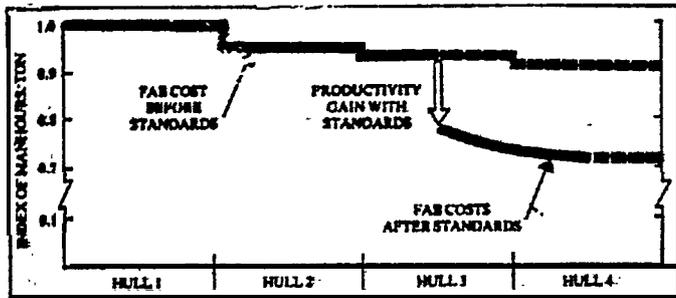


FIGURE 3: PROJECTED PRODUCTIVITY IMPACT OF ENGINEERED STANDARDS

As a direct result of the favorable experience gained, this Manual was produced to round out and complete the research effort that prompted the experiment. No attempt has been made to prescribe an optimum system for planning and production control in all shipyards, because system design depends on product mix, facilities and equipment, labor force size and type, management outlook, and other particulars which vary among shipyards. A spread of possibilities is presented, along with techniques for controlling the control system, and making it self-regulating. Guidelines and priorities for system improvement are included; those most useful can be extracted and applied toward improvement, supplementing or replacing techniques already in use.

Volume I comprises the basic text of the Manual. Volume II contains appendices covering background and related material to assist the reader in understanding the total subject. The appendices are referenced at appropriate locations in the basic text.

Further breakdown of Volume I is as follows:

Part I describes a problem that is common in shipbuilding, illustrating the difficulties involved in applying the proper resources in the right amounts at the correct time. It also describes the research experiment mentioned earlier, which was the basic motivation for preparing this Manual.

**Part II discusses an** approach to shipyard improvements by summarizing the basic shipyard function, problems encountered in tightening up the existing planning and production control system will assist in resolving those problems. It also looks at shipyard operations from the production point of view, and describes the benefits that might be accrued through production oriented planning.

**Part III contains guidance for improving an existing** planning and production control system. Specifically, how to evaluate an existing system, how to develop the basic relationships between cost and duration that are needed for measuring improvements, how to identify those locations and functions needing improvement, and how to assemble the engineered standards needed to support the basic improvement process.

Part IV treats the question of overall system effectiveness by developing a method for cost benefit analysis to measure shipyard-wide improvements of a tighter system, along with identification of those areas or features that do not pay for themselves and therefore should be abandoned or modified... The use of automatic data processing is discussed in the context of the economic benefits it may provide. Also covered is how engineered standards will benefit specific portions of shipyard operations, and that the extent of their usage can provide a real measure of overall effectiveness.

Volume II, the supporting appendices, covers the following:

- A - General Shipbuilding Method
- B - Budgeting
- C - Scheduling
- D - Performance Measurement
- E - Evaluation of Production Performance
- F - Planning Group - Organization and Composition
- G - Generation of Sample Engineered Standards
- H - Automatic Data Processing
- I - Basic Statistical Concepts

There is also a glossary of commonly encountered terms, and a Bibliography of information related to planning, production control, and industrial engineering matters. Reference to more rigorous treatment of specific points can be found in the Bibliography. Admittedly, some latitude was taken in this Manual to make the information useful to a wider audience than those who specialize in it.

The material can be used for individual self-study, or can be incorporated into a shipyard training program. It is not intended solely for production control and industrial engineering specialists. On the contrary, this Manual contains basic information helpful to the broad spectrum of middle level managers and supervisors in improving their grasp of the total shipyard planning and production control process and their particular role in it. It is through

such basic understanding of this extensive and somewhat complicated process that a shipyard can achieve the unity of purpose among its personnel that is vital to successful performance.

There is a message in this Manual for planning and production control specialists, too. It is to keep a careful focus on the user. Otherwise, the refinement and extension

of control that they impose may suffocate the production work force and greatly impair shipyard performance. There is a heavy and continuing responsibility incumbent on every member of the team to keep the interests of the whole shipyard in view, and to see that an efficient, effective operation is maintained. This responsibility is heaviest for those who can affect the actions of others and shape the posture of the shipyard in the process.

## PREFACE

Extensive research has been directed during the past few years into the details of commercial ship production. Although there is general agreement throughout the U.S. shipbuilding industry that intelligently controlled application of the four basic resources - manpower, material, facilities and time - is the key to minimizing ship construction costs, there has been no single guide book or reference which explains clearly the principles and practice of effective resource planning and budgeting. This Manual is written to serve that purpose.

Construction of a commercial ship directly or indirectly involves everyone in the shipyard. Planning for use of resources should be oriented squarely with the basic goal of the shipyard, which is to produce quality ships on time at a profit. This action is entitled Production Oriented Planning.

Part I describes a problem that is common in ship building, illustrating the difficulties involved in applying the proper resources in the right amounts at the correct time. It also describes an experiment conducted in the same identical problem area where some of the techniques explained in this manual were actually implemented. The favorable results of that experiment were the basic motivation for preparing this Manual. Part II discusses an approach to shipyard improvements by summarizing the basic shipyard function, problems encountered in ship building, and how tightening up the existing shipyard planning and production control system will assist in resolving these problems. It also looks at shipyard operations from the production point of view, and describes the benefits that can be accrued through production oriented planning.

Part III contains guidance for improving an existing planning and production control system. It describes how to evaluate an existing system, how to develop the basic relationships between cost and duration that are needed for measuring improvements, how to identify those locations and functions needing improvement, and how to assemble the engineered standards needed to support the basic improvement process. Part IV treats the question of overall system effectiveness by developing a method for cost benefit analysis to measure shipyard-wide improvements of a tighter system, along with identification

of those areas or features that do not pay for themselves and therefore should be abandoned or modified. The use of automatic data processing is discussed in the context of the economic benefits it may provide. Also covered is how engineered standards will benefit specific portions of shipyard operations, and that the extent of their usage can provide a real measure of overall effectiveness.

Volume I contains the Parts described above. Volume II contains several appendices of background and related information that may be helpful to some readers as refresher information or as guidance in areas unfamiliar to them. The appendices are referenced at appropriate locations in Volume I to aid in maintaining continuity of the material.

The expected users of this information are the middle level managers and supervisors in a commercial shipyard. No attempt has been made to prescribe an optimum system for planning and production control in all shipyards, because system design depends on product mix, facilities and equipment, labor force size and type, management outlook, and other particulars which vary among shipyards. A spread of possibilities is presented, along with techniques for many aspects of commercial shipbuilding with guidelines for selection of those portions and priorities most suitable to individual needs. The pieces of a workable system are described, with how they interact to make a complete system. Those most useful to a particular shipyard can be extracted and applied toward improving, supplementing or replacing techniques already in use.

The information in this Manual was developed by personnel in the Industrial Engineering Department of the Bath Iron Works Corporation with subcontract assistance from Corporate-Tech Planning Inc., Portsmouth, New Hampshire and Waltham, Massachusetts. Special acknowledgement is given the selected industry representatives for their evaluation and important comments. This group, comprised of representatives of the marine industry, provided valuable guidance and direction to the early phases of this project. An earlier draft of the Manual was reviewed by them in depth, and this final version reflects the suggestions and comments which resulted from that review, and which were most constructive and helpful.

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**PRODUCTION ORIENTED**

**PLANNING**

**VOLUME I**

**A MANUAL ON PLANNING AND PRODUCTION CONTROL**

**FOR SHIPYARD USE**

## PART 1

### INTRODUCTION AND BACKGROUND

This part describes a typical problem in shipbuilding that can be related to many others. The problem is examined to determine its essential parts. The results of an experiment to test improved techniques are discussed. This material serves to introduce the remainder of the Manual.

## CHAPTER 1

### A COMMON SHIPYARD PROBLEM

#### 1.1 Description of Setting

Consider a steel fabrication plant, part of a large commercial shipyard employing about 200 craftsmen. The plant manager is responsible for all the crafts that work there. This plant is physically separated from the shipyard, but uses the same processes, like welding, as the rest of the shipyard.

The functional flow of material, and the sequence of processing operations conducted at this plant is shown in figure 1-1.

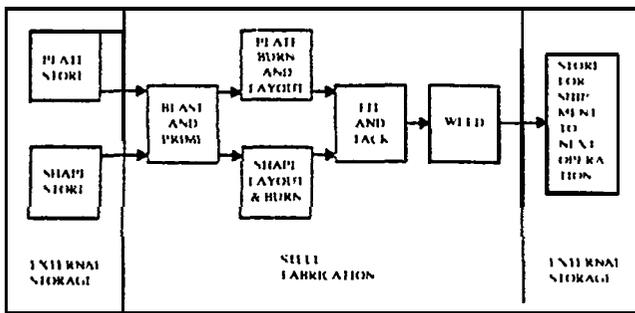


FIGURE 1-1: PROCESS SEQUENCE WITHIN STEEL FABRICATION PLANT

Specific operations performed within this plant include:

- Initial receiving and storing of plates and shapes
- Blasting and then coating with a weldable preconstruction prime
- Optical, numerical control, and hand oxygen-fuel gas cutting
- Forming
- Small part assembly (panels, foundations, webbs, to a maximum of 20 tons and approximately 8' x 8' x 60' in size)
- Welding

Size and weight of steel output is restricted to limits set for overland transportation to assembly areas on the waterfront. The usual planned capacity of the plant is 640 tons-per-week.

The shipyard is currently building four identical 20,000 DWT cargo ships. Steel for the first two ships is being worked in the plant now.

The basic instrument of management control within the shipyard is the Work Package. For steel fabrication

● Sometimes a unit.

operations, the work package consists of all parts required for an erection block.\* An erection block is the largest assembly of steel that will be handled as one piece and lifted into position for attachment to other assemblies. Because of material handling limits in this shipyard an erection block does not exceed 200 tons.

A single work package may produce several hundred different parts, each of which is identified with a drawing and piece number. The central planning department in the shipyard assigns budgets and schedules to the work package. Planners within the steel fabrication plant are responsible for budgeting and scheduling operations within the plant. Establishing fabrication work package labor and machine hour budgets and scheduling work packages through the plant are conducted as two semi-independent operations. The controlling construction schedules are usually established first. These are used for scheduling production work in the plant, and also for scheduling planning operations so that work package plans are available when production work is supposed to start.

Fabrication schedules are set as follows. The Master Schedule, Figure 1-2, contains the principal contract events such as start erection of first block, launch,

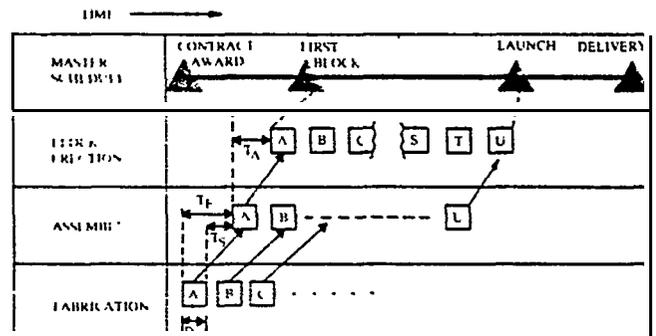


FIGURE 1-2: FABRICATION WORK PACKAGE SCHEDULING USING SET BACK TIMES  
T<sub>A</sub> FOR ASSEMBLY AND T<sub>F</sub> FOR FABRICATION

complete outfit, trials, etc. These events set the basic framework within which all subordinate activities and events are set.

The block erection schedule is the next level of scheduling detail. Standard back-Gff factors are applied to events in the block erection schedule to establish dates

for each assembly within a block. The same back-off technique is used to establish completion dates for fabrication of the pieces in each assembly. Standard back-off factors are shown in Figure 1-2 as TF for fabrication, and TA for assembly. The time allowed for fabrication, TF, is somewhat longer than the actual predicted fabrication time, DF, so that small delays in completing fabrication of the pieces will not impact assembly. Ts represents this safety time.

The only dates for fabrication operations that are provided by central planning are the fabrication completion dates, that is, finished weld and move to storage. The central planning department does not set dates for fabrication of the pieces themselves within the plant. These in-plant dates are set by the plant planners.

Given the scheduled completion date for the fabrication operations, the plant planners schedule using the rule that one week is allotted for each fabrication operation required, as illustrated by Figure 1-3. An extra week is

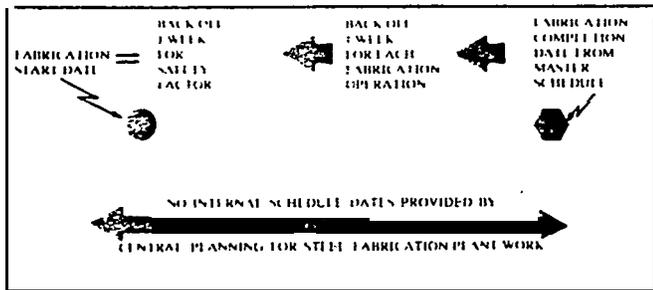


FIGURE 1-3: FABRICATION DATES DEVELOPED BY FABRICATION PLANT PLANNERS FROM CENTRAL PLANNING COMPLETION DATES

allowed if a unit is particularly complex. This produces a latest possible start date. The throughput weight of the units is also considered to make sure that the shop will start enough steel to meet the 640 tons-per-week goal.

The schedule for each week is also adjusted to make groupings of plates by coating type. A blast/paint sequence sheet is prepared each day. Plates are blasted and primed following this sequence, and are stored in a buffer area to feed follow-on operations.

The burning machine supervisor schedules the jobs on the burning machine in such a way that plates requiring the same torch setup (tip size, bevel, gas pressure, etc.) are run sequentially. This may not be the same sequence followed on the blast/paint line, but the buffer stock of primed plates permits resequencing of plates without interrupting the flow of material through the burning

machines, as shown by Figure 1-4. The load on the burning machines is calculated using a single value of 1.7

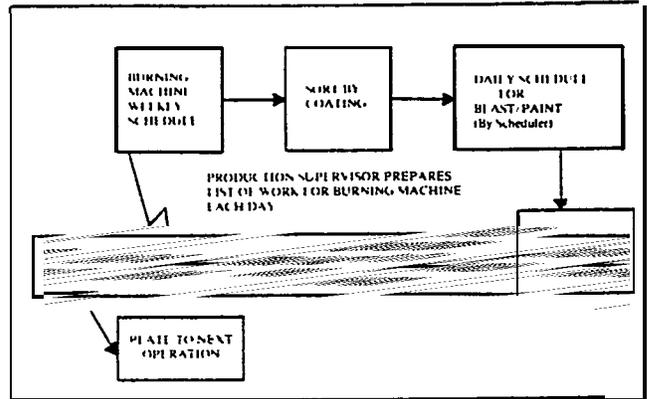


FIGURE 1-4: SCHEDULING OF BURNING OPERATIONS WITHIN STEEL FABRICATION PLANT

machine hours per plate. If the load exceeds the capacity of the machine, an attempt is made to start the processing earlier. After the plate is burned, the follow-on operations are scheduled by the first and second level supervisors in the plant who direct those operations.

Budgeting at the plant is done at two levels of detail. The primary, and most fundamental level is gross plant load. This is the total throughput per week, which as noted earlier was targeted for 640 tons-per-week. This number was obtained from records kept on previous contracts, and is the historical gross throughput in tons-per-week. Sometimes the product mix, Figure 1-5, varies

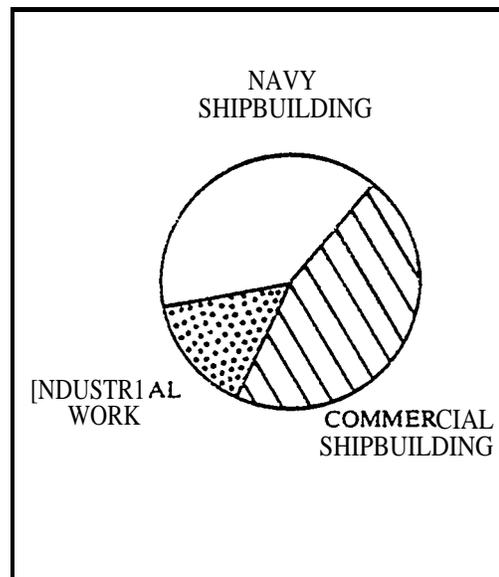


FIGURE 1-5: STEEL FABRICATION PLANT PRODUCT MIX.

the throughput, and so the second level of detail, a finer breakdown, is used for budgeting. It is necessary to identify the manhours involved in each type of work. A manhours-per-ton figure is available for commercial ship construction in general. One also is available for Navy work. The budgets for industrial work are derived from the manhours used in the bid. The required average weekly throughput for the plant is calculated from the schedule dates, the type of work, and the individual weights of the pieces produced. These numbers are usually prepared in considerable detail.

### 1.2 How Well Does It Work

Based on actual data from the plant described above, actual performance can be demonstrated. Figure 1-6 shows schedule adherence over a three-month period. The

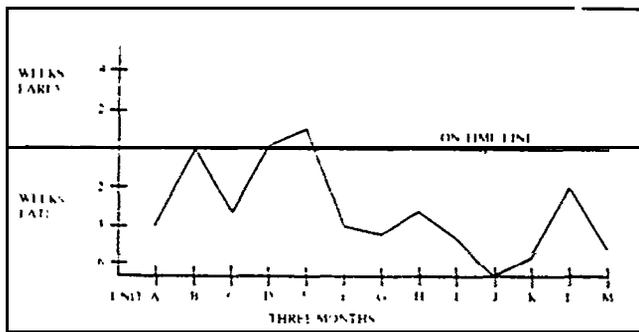


FIGURE 1-6: SCHEDULE ADHERENCE PROBLEM! USING HISTORICAL FACTORS

impact downstream is obvious. The plant manager recognized some of those units as potentially late items, and although he issued an expedite list to generate extra effort toward minimizing the lateness, schedule adherence was still not good. Sixty-two percent of the units were more than four weeks late, which was disruptive to follow-on work at the waterfront assembly area and the hull itself.

During this three-month period, the weekly throughput requirements were being met fairly well, although overtime was needed to keep up with throughput demands. The short visibility of workload prevented any long range planning or level loading of the plant work areas and machinery, even though the historically derived factors were being used faithfully according to the plan. Since there were no intermediate or start dates provided by central planning, work was scheduled only to a completion date. Production supervision in the plant had

to work backwards from the completion date to establish the start dates.

This left plant management in somewhat of a dilemma. Everything was being done according to the plan, but schedule adherence was still a big problem. What alternatives were available?

- o Weekly tonnage throughput was already up to the level obtained from records of previous contracts, so an increase was not very probable.
- Overtime in substantial quantities was already being used, with only a little more advantage available by increasing the amount used.
- The machines were handling the material at the predicted rates, which were already close to machine capacity.
- There was not much hope for more facilities and machinery, because there were periods when the equipment was not used at all, which weakened the argument for more facilities.
- s The workload visibility was so short that there was no way to plan the work to level load\* work areas and equipment.
- The same short workload visibility left too little time to arrange for contractor assistance to help get over the peaks in the workload.

A brief look at this steel fabrication plant surely suggests that there are opportunities for improvement. .

### 1.3 The Problem Is A Common One

Although the example presented here concerns one steel fabrication plant serving a commercial shipyard, the same problem symptoms may be found in other parts of shipbuilding. The specifics may change, but the problems are the same—how to match the capability with the needs.

Undoubtedly similar situations exist in other shipyards which can be related to the information given here. The real question, though, is not whether problems exist—because they do—but rather what can be done to improve overall performance. The next Chapter will present experimental evidence of results based on use of the techniques presented in the rest of this Manual.

\*Bath Iron Works Corporation, *Improved Planning and Production Control*, August 1977, a Report of Research conducted under the MARAD Ship Producibility Research Program.

•Level loading is the process of scheduling the correct amount of work for each shift equal to the manhours available.

CHAPTER 2

IMPROVEMENTS ARE REAL

2.1 Results of An Experiment

An experiment<sup>1</sup> was conducted at a steel fabrication plant to see whether application of engineered labor standards\* for scheduling purposes would produce improvements in planning and production control. Actual "before and after" data was collected. The "before" data has already been discussed in Chapter 1. The "after" data is discussed here. This manual is a direct result of the favorable experience gained from this experiment.

The experiment showed that engineered standards provided large performance improvements. In terms of schedule compliance, before engineered standards were used, work packages averaged over three weeks late with a maximum lateness of eight weeks. After engineered standards were introduced, average lateness was reduced to zero and maximum lateness was reduced from eight weeks to two weeks, as illustrated by Figure 2-1.

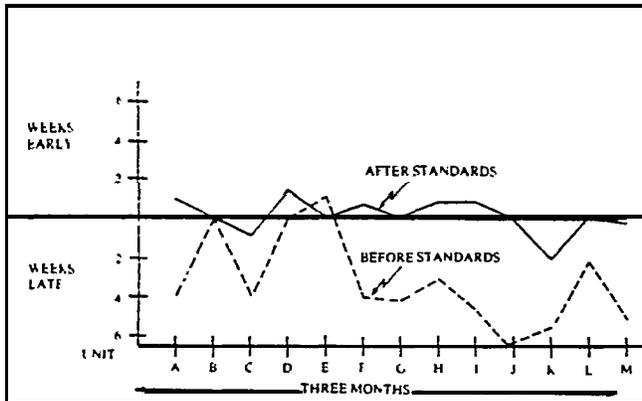


FIGURE 2-1: IMPACT OF STANDARDS IN SCHEDULE COMPLIANCE

Improvements in productivity attributable to the use of engineered standards were even more significant, with engineered standards only partially implemented on the third of the four ship series, a reduction of 21% in the labor hours of the fabrication work packages was projected from the data collected. Improvement on the fourth ship was projected to be 30%. Improvements were many times greater than would have been experienced via normal learning effects based on the traditional rules alone. Projected productivity impact is illustrated by Figure 2-2. Eighty-five percent of the steel fabrication

manhours in the plant were subjected to engineered standards during the experimental period.

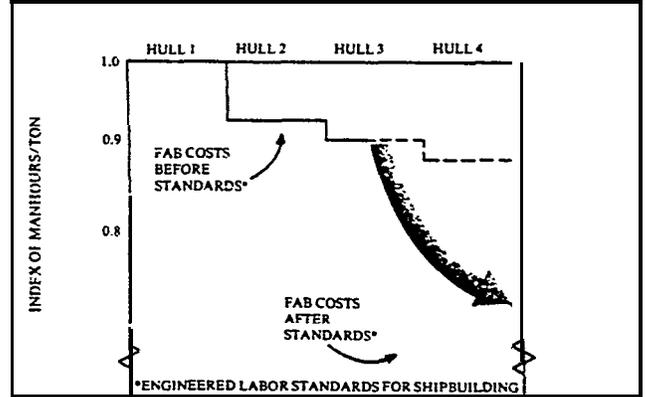


FIGURE 2-2: PROJECTED PRODUCTIVITY IMPACT.

it is also of interest to note the benefits engineered scheduling standards had on smoothing the work load. Loading the fabrication plant on the basis of tonnage output needed to satisfy erection schedules resulted in extremely erratic output compared to planned output schedule, as shown by Figure 2-3.

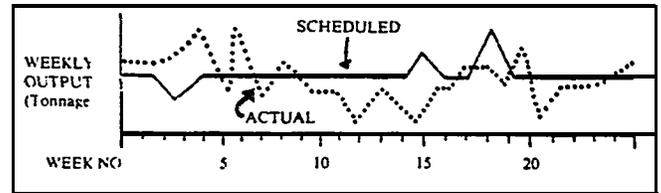


FIGURE 2-3: ACTUAL VS. SCHEDULED OUTPUT FROM TONNAGE LOADING RULES.

The peaks in planned load were imposed by demands of the erection schedule; overtime was scheduled to work them off. Excursions in actual output were the direct result of differing work content and material characteristics of the block fabrication work packages. When the actual work content of blocks scheduled through the steel fabrication plant during the experiment was measured by engineered standards, manhours varied from one week to the next by as much as 5,400 manhours or 135 people. This created a combination of two situations:

- (a) The Master Schedule was ignored in favor of producing the goal tonnage.

<sup>1</sup>Bath Iron Works Corporation, *Improved Planning and Production Control*, August 1977, a Report of Research conducted under the MARAD Ship Productivity Research Program.

\* Chapter 7 defines several types of engineered standards (process, production, scheduling, planning, cost estimating) and discusses their usage.

(b) The Master Schedule was followed as well as possible with massive amounts of overtime necessary.

What really did happen was that neither goal was successfully accomplished. The inadequacy of tonnage rules to provide accurate long range forecasts made it impossible to vary the work force or fill in with overtime to the degree needed.

The effect of level loading the plant based on work content as determined from engineered labor standards was quite impressive. On-time completions of units improved to the point where the schedule was actually adhered to. As more on-time completions were accomplished, confidence in the schedule and the scheduling method grew. This in turn caused production supervision to strive all the harder to remain on schedule. During the experiment overtime expenditures decreased as emphasis was shifted from tonnage output to scheduled output.

## 2.2 Cost and Savings

The experiment was conducted on a representative sample of fabrication work packages taken from the last two ships in the four ship construction contract. Extrapolating savings measured from the sample to estimate full savings for the last two hulls yields the projected savings shown in Table 2-1.

COST ELEMENT	HULL 1	HULL2	HULL3	HULL4
1. standards dev. development	-	-	3	0
2. Standards Application	-	-	22	-
3. Performance Data Collection	-	-	11	11
4. Cost of Standards	-	-	\$ 63	\$ 11
5. Fab Costs w/o Standards	\$1,300	\$1,210	\$1,160	\$1,120
6. Projected Fab Costs w/Standards	1,300	1,210	1,010	840
7. Projected Cost w/Sids. (Including Cost of Standards)	1,300	1,210	1,073	851
PROJECTED NET SAVINGS	-0-	-0-	\$ 87	\$ 269

TABLE 2-1: CALCULATED PAYBACK FROM USE OF ENGINEERED STANDARDS IN STEEL FABRICATION OPERATIONS (Dollars in Thousands).

Lines 1, 2, 3, in Table 2-1 cover the costs of standards development and application. Note the full cost of standards development and application has been assigned to Hull No. 3, when realistically it should be prorated over all contracts for which operations covered by the standards are required.

Line 5 represents total fabrication costs of all four hulls with learning effects applied to the follow-on hulls, but without the benefit of standards. Line 6 contains costs of

fabrication operations for Hulls 3 and 4 reflecting savings projected from use of standards. Line 7 is the projected fabrication costs of Hulls 3 and 4 including the cost of standards from Line 4. The bottom line in the table is the net savings from the use of standards. The full cost of developing and applying the standards is fully recovered on the first hull (Hull 3) to which they are applied and still standards yield an 8% "profit". The "profit" on Hull 4 in about 25070.

## 2.3 Conclusions From Experiment

The experimental results led to the following conclusions:

1. Productivity Improvement Potential - The use of engineered standards in planning and production control can offer a reduction in the cost of steel fabrication operations of about 20-30% over comparable operations planned and controlled using traditional tonnage rules. The cost reduction operations divide into two categories:

- Methods Improvements - From increases in productivity due to improved and better controlled production processes, a cost reduction of 10-15% of labor costs is easily obtainable.

Planned Scheduling-Improvement An additional factor of 10-15% above process improvement should result from improvements due to more efficient flow and performance of works

The total 20-30% overall improvement is the sum of methods and planned scheduling improvements.

2. Improved Schedule Adherence - Improvements in schedule adherence following the imposition of engineered standards are dramatic. Use of engineered standards instead of tonnage rules provides a more accurate method for estimating fabrication plant capacity and provides much smoother plant loads. The average work package schedule delinquency was reduced from an average of over three weeks late to zero weeks late. The maximum lateness was reduced from eight weeks to two weeks.

3. Cost - The cost of developing and using engineered standards can be recovered very quickly. These costs are divided into three categories:

- Cost to Develop Process Standards\* - The cost of developing process standards is a one-time cost for a shipyard. These standards are changed only when

1 See chapter 7 for definition and usage.

machines or processes are changed. For 85% coverage of all fabrication operations in the steel fabrication plant, cost of establishing process standards was 4,800 manhours.

- Cost to Apply Production/Scheduling Standards\*  
- The cost of setting labor and machine budgets for steel fabrication work packages was 3,300 manhours. As a general rule of thumb, cost per contract should not exceed 5% of fabrication costs for the first hull in a contract and should be virtually zero for follow hulls (exclusive of changes).
- Cost of Data Collection - Use of engineered standards for production control requires collection of additional data above and beyond that required using traditional tonnage rules. Estimated cost of collecting this data is about 1% of total fabrication costs. This is a recurring cost on both lead and each follow hull.

4. Payback - The payback from use of engineered standards for planning and production control is such that savings from increased productivity on a single hull are more than enough to recover standards development and applications costs and still yield a net reduction of 5-10% in fabrication costs. Thereafter, cost reduction should equal 20-25% of fabrication costs.

#### 2.4 Preparation of This Manual

The experimental results of using engineered standards were quite favorable, and led directly to the preparation of this Manual. It describes the generation and use of engineered standards in shipbuilding, and techniques for determining how overall shipyard operations are proceeding. The central theme of this text is production, hence the term used here, "Production Oriented Planning." This idea will be discussed more fully in the next Part.

## PART II

### AN APPROACH TO SHIPYARD IMPROVEMENTS

This part describes the shipyard function, problems encountered in shipbuilding, and how those problems might be resolved. Included is a discussion of what is needed from the production point of view, how that need might be satisfied, and what benefits might thereby be realized.

## CHAPTER 3

### AIMING IMPROVEMENT EFFORTS

#### 3.1 The Shipyard Function

A shipyard exists to make money at building ships. Clearly, the way to get the best ship out of a shipyard for the least cost is to get everybody in the shipyard pulling in the same direction at the same time.

There are two general types of people in a shipyard, the “Thinkers” and the “Doers”. Generally speaking, the “Thinkers” are the Designers, Planners, Estimators, Schedulers, Material people, Financial people, and the like. The “Doers” are the Production people and their supervisors who physically construct the ship from the material according to the plans, schedules, budgets, and other supporting paper. The smaller number of “Thinkers” are there to support the “Doers” by planning what needs to be done and how to do it—much as an electrical relay controls heavy electrical power with only a small electrical signal.

The “Thinkers” must keep in mind that their purpose in the shipyard is to serve the needs of the “Doers” in such a way that the ship gets built on time and at a cost below contract price. They must not lose sight of that purpose for even a minute. If they do, the many pieces of effort involved in producing the ship will not be supportive one to the other, and waste and inefficiency will set in. On the other hand, the “Doers” must keep in mind that the only reason the “Thinkers” produce all that paper is to help get the ship built the best way in the shortest time for the least cost. If the “Doers” fight the idea of paper directions without giving them a chance, progress will stop.

Construction of a commercial ship has two major segments: steel erection and outfitting. Each type of activity is handled in a similar manner in that the whole is broken up into pieces that are handled individually and later joined together to form the whole ship. The terminology and Techniques used for the two major segments are different, however, and are sometimes a source of confusion.

The terminology used throughout the Manual has been selected for consistency with that used in most of the commercial shipbuilding industry. Additional explanations of shipbuilding processes and information in certain specialized areas related to planning and production control have been included in several Appendices located in the last half of this Manual. Some readers will benefit substantially from this additional supportive text, or as reference material to further explain each subject as it is encountered. The reader is encouraged to use these

Appendices, which are referenced at appropriate locations in the Manual.

- Appendix A describes the general approach to shipbuilding, how steel erection and outfitting are carried out, and how these two principal activities are integrated for construction of a ship. Also included is a section on how resources might be oriented and aligned to best serve production needs.

- Appendix B covers the process of budgeting the four basic resources available in a shipyard manpower, material, facilities, and time. Budgeting is an iterative process, usually carried out at several levels of involvement until the final plan emerges.

- Appendix C explains the process of scheduling, which is usually done in several levels of detail from the top down that is, from a long-term coarse schedule covering the entire shipbuilding effort toward shorter-term detailed schedules covering smaller amounts of work that interfuse to form the whole. Also included is a look at bottom-up scheduling which involves initial determination and scheduling of all the individual items of work needed to build the ship, followed by arrangement and consolidation of these pieces to build up a broad-ranged schedule for the total effort. Bottom-up scheduling offers the potential for a major breakthrough in the scheduling process if the complexity involved can somehow be managed.

- Appendix D outlines measurement of performance by considering why measurements are necessary, what needs measuring, and typical ways to measure the expenditure of manpower, use of material and facilities, and performance against the schedule.

- Appendix E discusses techniques for evaluating production performance, and describes the use of variance tolerances, variance patterns, the use of moving averages to smooth out variance data and show short term trends, and basic information for evaluating the impact of late work package completion on successor events.

#### 3.2 Shipbuilding Problems

A list of things needed to build a commercial ship looks something like this:

- Contract specifications
- Contract commitments
- Design data and specifications
- Drawings

- Schedules
- Budgets
- Ž Work packages

From these rather obvious ingredients the resources needed to carry them out can be determined. The four basic resources in a shipyard are:

- Ž Manpower
- Material
- Facilities
- Ž Time

By allocating the proper amount of each resource to each work package, staying within the budget, following the schedules, and complying with the drawings, the design data and specifications will be satisfied and a ship that meets the contract specifications and commitments will be produced. The three main aspects of carrying out this process are:

- Planning—which produces the paperwork or “plan” that describes what, how, when, where, and with what the work should be done.\*
- Ž Production—which does the actual work.
- Production control—which measures how production is doing along the way, and describes which spots need improvement.

To be sure, there are several other contributors to the overall effort, but the purpose of this Manual is to harness these three. First, though, recall the steel fabrication plant in Chapter 1 and some underlying problems that need solutions:

- Schedule adherence
- Budget compliance
- Resource utilization
- Workload forecasting

Each of these will be explored in a little more detail.

Schedule adherence is a fundamental problem in shipyards, which may have some of its roots in inaccuracies in workload forecasting. Job durations, though, are the critical factors in establishing credible production schedules. Since scheduled events are often not met, and rescheduling of jobs is done all too frequently, it follows that improved determination of job duration is needed to obtain a smooth flow of construction activity.

Budget compliance is needed to maintain the essential balance in resource utilization, especially the application of

manpower which is normally the resource easiest to manipulate. There is usually a time delay between accomplishment of the work and preparation of labor expenditure reports. Such time delays mean that overrun conditions can exist before management is aware of the fact via the return cost reports. The point at which corrective actions should have been taken is therefore passed, and recovery measures must be focused on work remaining. This causes disruptions in the plans for the downstream work. Improved visibility of budget compliance is needed to allow corrective action in a more timely manner at the point where the compliance is lacking.

Resource utilization is closely related to workload forecasting. Accurate measures of resource usage, along with resource capacity, are needed in order to schedule the work in such a way that the resource is being used effectively. Widely divergent output rates from a single resource, such as the steel fabrication plant in Chapter 1, experienced from week to week when demands were thought by central planning to be both smooth and well within resource capacity limits, suggests that serious problems may exist not only in load forecasting, but also in specification of resource capacity. The impact of these fluctuations is, of course, uneconomically low resource utilization during some periods, and production delays caused by resource congestion and uncontrolled backlog buildup during other periods. Although fluctuations in output of a resource reflect uneconomic use of the resource itself with the associated impact on elevating costs, this problem may not be as severe as the disruption to the schedule of follow-on production activities where indeed wider fluctuations in workload may well be induced by the smaller fluctuations in upstream activities.

Workload forecasting provides a projection of resource needs. Forecasts related to working off contract backlog are central to the shipyard function. The accuracy with which these are made determines, in a large measure, the profitability of the shipyard on the one hand, and the ability of the shipyard to meet contract commitments on the other. If the *workload forecast* is on the high side, then the resources—particularly, manpower—mustered to satisfy the forecast will be excessive, and costs will be higher than necessary. If the forecast is on the low side, then the resources obtained will be inadequate to handle the actual workload. Contrast dates will not be met or resources will be shifted from less critical projects disrupting systematic control of production.

These four problem areas have elements in common with each other, as shown in Figure 3-1, and so require treat-

\*Planning is further defined in the Glossary and in Appendix F.

ment as an interlocking set. This requirement, though, is really an opportunity. The more overlap that can be achieved, the better. Large overlap is a reflection of an efficient, well directed, and well executed process.

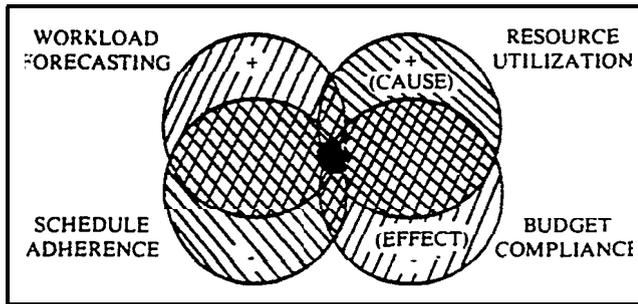


FIGURE 3-1: INTERRELATIONSHIPS BETWEEN PROBLEM AREAS

Considering all of these factors, the following sections will investigate whether system improvements in planning and adjustment techniques are possible.

### 3.3 Tightening Up The System

In the steel fabrication plant example from Chapter 1, scheduling was done by allowing one week for each distinct process step. In the real world, labor expenditures and actual schedule durations are random variables which have a definite and pronounced variation about their historically determined mean value, as illustrated by Figure 3-2. They are not fixed, nor always worth one week of effort. It follows, then, that when one week duration for each work package is planned ( $D_h$  in Figure 3-2), as many jobs will be finished early as will be finished late. Anticipated lateness is accommodated by including a safety factor of perhaps one or two weeks in the planned duration ( $D_s$  in Figure 3-2). Even so, a significant per-

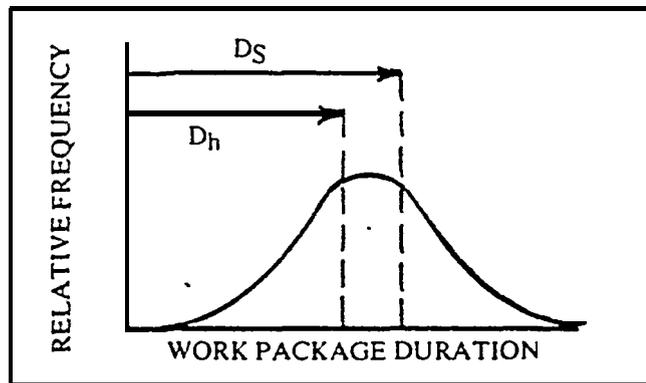


FIGURE 3-2: REPRESENTATIVE DISTRIBUTION OF WORK PACKAGE DURATIONS

<sup>1</sup> Variance is the difference between planned and actual values.  
<sup>2</sup> part III will discuss this point in more detail.

centage of the work packages will either be completed late or will require unplanned overtime to meet completion dates.

Both early and late work package completions have unfavorable impact on construction costs. Work that is completed early must be stored, thereby incurring unnecessary material handling costs and inventory carrying charges. Work that is completed late usually entails expediting and overtime costs.

Reducing the variance\* of work package duration distributions, the width of the bell curve in Figure 3-2 (but not necessarily the work package itself) will permit tighter scheduling of work, thereby reducing the cost of early and late completions, as shown in Figure 3-3\*\*. This is a primary objective of improving the accuracy and reliability of the planning and scheduling process. In order to do that, however, a firm and reliable basis is needed for determining the amount of real work in each package, and how long it will take to accomplish it. Planning and scheduling can be tightened up ONLY if such a basis exists. Otherwise the plan will simply misrepresent the real duration, and scheduling will be even less credible than it was before.

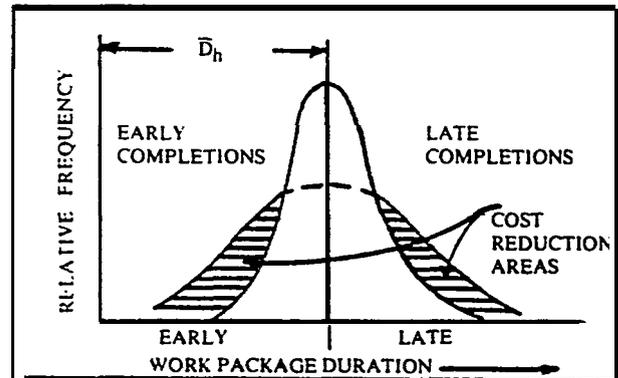


FIGURE 3-3: BENEFIT OF COMPRESSING DISPERSION OF WORK PACKAGE DURATION

Another benefit of tighter planning and scheduling is the ability to recognize the need for, and to carry out, corrective actions when the work is not proceeding as desired. Again, the same reliable basis is needed in order to tighten up.

A pattern of performance like Figure 3-4(a), represented by shots in a target, is not useful to production, even though the average of the shots is a bullseye. A tight group like (b) is much preferred, even though off the mark,

because the common error can be corrected. This message was heard many times during the experiment described in the last Chapter as production people repeatedly asked for consistent budgets.

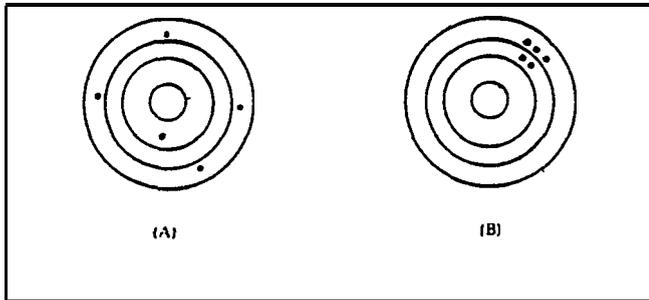


FIGURE 3-4: GOOD AVERAGE VS. GOOD GROUPING

### 3.4 Focus on Production

With general knowledge of shipbuilding in hand, consider the production process from the point of view of the production people that carry it out. Since they are the largest controllable variable in the shipbuilding effort, alignment of planning and support with their needs seems likely to produce the most efficient and effective overall arrangement for the shipyard.

The first requirement is to know what the production worker can do when he is allowed to do it. Fortunately, shipbuilding is accomplished through repetitive performance of several processes and methods. Each process, or at least most of them, can be isolated and examined to find out how many workers are needed over what period of time, what access requirements must be satisfied, what material is needed, what facilities and equipment are involved, and what other ingredients are necessary for successful performance of that process. Non-productive time that is part of the process can also be included, like lunch breaks, personal time, setup and breakdown periods, and similar items that go to make up the real performance of that process under actual conditions. Once all this information is collected, it must be put in a form that is easy to use the next time around. This will provide a basis for improving the information as process performance improves, and also allow use of the information by other people in the shipyard. Ideally information should be available on each and every process and method used in the shipyard, but in reality there may never be a complete set. The more information that is available, though, the more that will be known about what the production people can produce".

Next, this information must appear in the drawings and schedules that production will use to build the ship. Since the pieces of information are based on what production can actually produce, then the compilation of the pieces in the plans and schedules should accurately reflect how the work will really be done. If the plans and schedules both fit the pieces together without gaps, or overlaps, without conflicting demands for work sites or facilities, do not demand people who are not available and conversely keep everyone busy, and material supplies keep up with demands, then an effectively executed production effort should result. How big is the "If" in the last sentence? This depends on how good the planning is, how good the scheduling is, how good the budgeting is, and how good the supporting items are—like material being at the right place, at the right time, in the right quantity, and in the right condition. These are all things that production people should not have to worry about.

Budgeting the four resources as described above, through use of individual process information documents, can produce results that have improved accuracy. More accurate budgets can form the basis—a production oriented basis—for more accurate scheduling. More accurate scheduling will result in less variance between planned and actual performance, because planning and scheduling are based on what the production department can actually produce.

- Schedule adherence will be improved, since there is less difference between planned and actual performance.
- Budget compliance will be improved, since the budget is more closely aligned with what the production department is capable of producing.
- Resource utilization will be improved, because the planned usage is based on what production will actually need to do work.
- Workload forecasting will be easier and more accurate, because contract backlogs will be reduced by improved schedule compliance, and a smoother flow of production effort is easier to predict.
- A more reliable basis will exist for measuring and evacuating performance, and for identifying corrective actions, because the variance in performance is reduced, as explained in Appendix D and E.
- Since production is performing better, less time will be spent by production management in explaining why the target was missed. This leaves more time for useful effort like doing the work, improving the processes, and further enhancing the performance posture of the shipyard.

•A reasonable benchmark is about 75-85% of Production operations covered by detailed information, based on the experimental experience gained from the steel fabrication plant described earlier.

Now, the contrary point of view must be given equal time. It costs money and takes time to produce those individual process information documents—which are usually called engineered labor standards\*. Having produced the process standards, there is continuing danger that they will be misused by overzealous planners, schedulers, or managers who wish to force better production performance by shaving resource allowances. There are those who will attack the basic information in the process standards as being padded, and overly generous to the producers. There is absolutely no doubt that this sort of treatment can demolish such a system, and very quickly.

From the production point of view, it would seem that the potential advantages are extremely large, and that the disadvantages are relatively small. Such a system would provide a way to reshape planning and rescheduling to better represent what production can actually produce. And with production people participating in the generation of process standards, and agreeing with their content before they are established (see Chapter 7), the risk involved seems small. The key, of course, is more accurate and more reliable INFORMATION on which to base planning and scheduling actions. This would appear to benefit production most of all.

One thing is fairly certain, though. Such a system and its vital ingredients cannot be produced without the support of production people at all levels. They have the biggest investment in what the future will bring under this system. If production personnel feel that it is just another loaded gun aimed at them, then their support cannot be expected. On the other hand, if such a system can be seen and understood as a major advantage to the shipyard, then production personnel will likely be the strongest supporters of it, if not the principal protagonists.

### 3.5 What Benefits Are Possible

The whole is the sum of its parts. So it is with ship building, except that there are two different aspects to successfully making a whole: (1) how well each piece is produced; and (2) how well the pieces are joined together. The first aspect is heavily influenced by production; and the second aspect is heavily influenced by planning. The two together make up the main effort which eventually produces the ship.

Making each piece of the whole depends on the application of resources according to a certain process or method. Many individual processes are involved in

building a ship, most of them repeated over and over again. It may be at a different place, at a different time, under different circumstances and influences, but it is the same process. Since many processes are repetitive, it is important to have accurate information on each one, e.g., how long it will take, how many people are needed, how much material is involved, how long it will tie up a facility or piece of equipment, and similar performance information. Whether this information is in the form of engineered standards, developed jointly by planning and production, or whether it is based on historical performance data, it is most important that it truly and accurately reflect the production work needed to carry out the process. Then, and only then, will this basic building block be available to use in planning for future performance of the same process.

This basic information also allows refinement and improvement of the production process, but this aspect is really a side benefit and not a vital one. Certainly process improvement is important, but performance prediction is MORE important. Perfect performance is less important than NOT KNOWING what performance will be. Credibility is based on truth, not perfection. Planning must be based on what production can be expected to produce. There is a time and place for production process improvement, but it is definitely not in the middle of the planning process.

Putting the pieces together is where the pay-off comes in a production oriented planning system. When there is confidence in the ability to produce the pieces as planned, the assembly of the pieces can be more closely meshed. Timing can be tighter, and much improved over what it had to be to accommodate the unknowns. Of course there will be pieces of the effort that do not lend themselves to treatment as measured processes, but far fewer than might be expected. At the very least, the so-called unknowns can be minimized and their impact on the system thereby reduced.

The first and most significant advantage will occur in production where the plan becomes more performable. It is carried out with less frustration and lost motion on the part of the workers, and with less disruption and delay in the overall effort. As other areas are added to the system, confidence in the planning grows and so does the efficiency with which the work is done.

The planner now has better tools for creating the plan. He can predict quite accurately what production can

\*Table 2-1- on Page 2-5 describes the costs associated with standards development, application, and performance data collection for steel fabrication operations during the experiment. These operations constituted 85% of the total performed at the steel fabrication plant, and about 25% of the total operations performed at the shipyard.

produce. He can select the appropriate pieces of process information and put them together to form the plan for the package of work. Since the plan is composed of reliable and agreed-to pieces, the risk of production rejecting it is greatly reduced. This enables more confident planning, and the planner is encouraged by the better reception of his product.

As work continues, there is a better basis for in-process adjustments to keep matters on track. Variance measurements have a reliable reference point. Visibility of progress is improved. Determination of corrective actions is more rational; so is the exercise of in-process control, and measurement of response to it. The system can now be

extended and fine-tuned for further improvements, as long as the return on investment remains favorable as discussed in Part IV.

Again, the main thrust of this Manual is improved planning and production control for shipyard use. The aim is to orient planning for improved production through better application of resources, which has been termed Production Oriented Planning. This will allow better resource utilization by production, improved methods, and more accurate level loading of the workforce. It is not a revolutionary idea, but rather an evolutionary one. It is something to work toward, rather than something that can be done immediately. The next Part will discuss how system improvements can be achieved.

## PART 111

### THE PRODUCTION ORIENTED PLANNING SYSTEM

All shipyards have planning and production control systems. The question, then, is not whether a system should be installed, but rather how to tune an existing system to best satisfy the needs of production. This part addresses the need for reliable and consistent planning and budgeting rules (engineered standards), how they are developed, and finally how their use is kept in harness so that the shipyard does not become a standards factory at the expense of production.

## CHAPTER 4

### EVALUATING AN EXISTING SYSTEM FOR PLANNING AND PRODUCTION CONTROL

#### 4.1 System Structure

All shipyards (and all manufacturing and construction companies for that matter) have planning and production control systems\*. The system may be highly complex or very primitive. It may be formally established and recognized by management; or it may be represented by informal arrangements between shipyard personnel. It may provide an effective vehicle for controlling production, or it may not. Nevertheless, it always exists if only in the heads of the production superintendents; and it always performs the same functions (Figure 4-1).

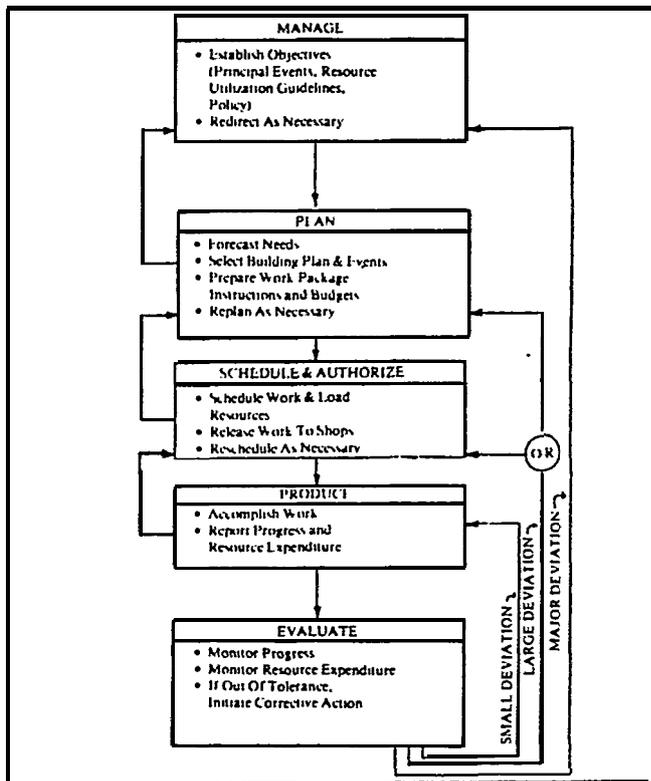


FIGURE 4-1: PLANNING AND SCHEDULING  
IN THE MANAGEMENT CYCLE

The desired output of the productive effort is defined -usually in terms of drawings of the items to be produced.

● The word "system" is used here in the broadest sense to designate a collection of people and facilities with interconnecting communications organized to perform specific functions.

\*\*The word "cost" is used here in the most general sense to mean resource expenditure which is measurable in physical units (e.g. manhours, tons of steel, etc.) as well as the derivative monetary units. Cost in the financial sense is controllable if expenditure of physical resources is controlled. Also note that controlling quality of the construction process and of the items produced is the responsibility of the Quality Assurance and Production Quality Control System; so it is not included here.

\*\*\*See Appendix E for evaluation of production performance which is a necessary part of system performance.

The production effort is methodized, that is, broken down into a sequence of productive operations. Required materials, tools, facilities, and labor skills are identified-sometimes with and sometimes without associated budgets. Completion dates for the productive effort are set with perhaps intermediate dates for the completion of intermediate tasks. Progress and expenditures are monitored either by a formal system of reporting and measurement or by casual observation. When things are not going right, that is, not proceeding in accordance with plans and schedules, some type of corrective action is taken.

The issue concerning implementation of planning and production control systems is not whether a shipyard should have one because they all do; otherwise construction of a ship would be impossible. Rather the issue is one of deciding whether an existing system is in need of improvement, and if so, where and how it should be done, and what investment is warranted.

In reviewing the existing system to determine whether improvement opportunities should be sought, two questions arise:

- (1) How effective is the current system, and
- (2) What does it cost to operate it, that is, how efficient is it?

Measuring system effectiveness and improving system performance are the subjects of the next few Chapters; consideration of efficiency is deferred until Part IV.

- Appendix I explains several basic statistical concepts used below.

#### 4.2 Measuring System Performance

The primary purpose of a production planning and control system is to "control ship construction cost and duration\*\*". Accordingly, the performance\*\*\* of the planning and production control system should be measurable in these terms, namely its effectiveness in controlling cost and duration.

The system establishes budgets (allowances) for the four major resources—material, labor, facilities, and time—and the schedule for performance of the various tasks identified in the construction plan. The system also provides the vehicle for collecting progress and cost data for comparison against schedule and resource budgets. Thus the effectiveness of the system should be measurable in terms of the extent- to which actual production operations adhere to schedules and budgets.

Performance to budget, P, is measured as the ratio of resource allowance (RA) to resource expenditure (RE), that is,  $P = RA + RE$ . When expenditure equals allowance, then  $RA + RE = 1$  and performance is on target. If the performance factor, P, has a value greater than 1, then production costs are less than budget. The project is under control, and should be completed within planned cost. If, on the other hand, the value of P for the various tasks in the project is consistently less than 1, project costs are exceeding budgets and the project is in jeopardy of an overrun\*. This information is summarized in Figure 4-2.

$P = \frac{\text{ALLOWANCE}}{\text{EXPENDITURE}}$ <p><math>P &gt; 1 = \text{UNDER BUDGET}</math></p> <p><math>P = 1 = \text{ON TARGET}</math></p> <p><math>P &lt; 1 = \text{COST OVERRUN}</math></p>
--

FIGURE 4-2: PERFORMANCE TO BUDGET, P.

This performance measure can, however, be very misleading. If it differs from 1, then either the allowance (RA) may have been unrealistic or the production operations themselves may have been inefficiently executed. The performance measure, P, by itself, gives no indication of which is actually the case. Furthermore, if the value of P consistently equals 1, then the allowances may be too fat, and although it appears that everything is under control, the project could very well be costing more than it should because work is being spread out to use up the allowance.

How well the planning and production control system is performing can be determined by looking at the variance\*\* in addition to the average. Assume for a moment that a ship construction project has been subdivided into a

thousand work packages which range in size from five hundred to fifteen hundred manhours each, with an average of one thousand manhours. Further assume that one hundred of these work packages have been completed, and performance against budget for each has been measured. If the performance values for these one hundred work packages are plotted, a distribution like that shown in Figure 4-3 might result. The horizontal axis represents the measured performance of the jobs completed. The dashed vertical line is target performance. It has a value of 1.0 by definition.

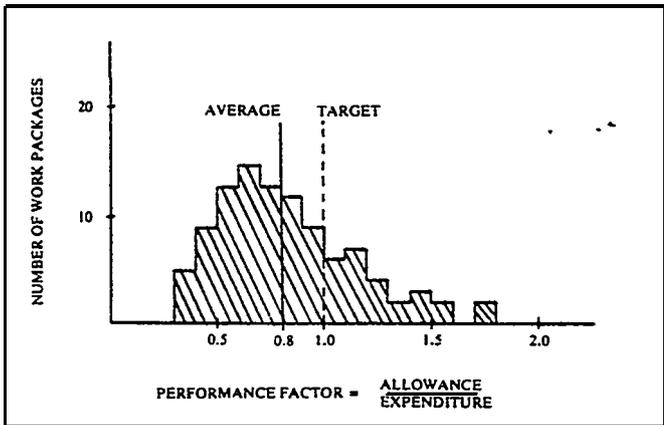


FIGURE 4-3: A TYPICAL DISTRIBUTION OF ACTUAL PERFORMANCE TO BUDGET (TOTAL SAMPLE = 100).

The vertical axis identifies the number of work packages; the outline of the shaded area in the center of the graph represents the number of “work packages in the sample which had the performance factor indicated on the horizontal axis. For example, only two work packages had Performance factors lying in the 1.7 range, while eight work packages had performance factors in the 0.4 range. The average performance factor for this sample distribution is about 0.8, which indicates that on the average, actual expenditures exceeded budgets by 25%.

There are two features in the sample performance plot in Figure 4-3 that would be of concern if the plot represented a real situation. First, of course, is that average performance exceeds budget by a factor of 25070, a harbinger of a serious cost overrun condition. Second, the spread of actual performance around the average is an indication that there is little correlation between planned and actual

\*Sometimes performance to budget, P, is defined as expenditure over allowance. This means a value greater than 1 is poor performance since costs are more than budget. Unfortunately, there is no industry agreement on the definition of P.

\*\*“Variance” is used here in the statistical sense as a measure of the dispersion, or spread, of the performance distribution taken from a number of samples

performance. This is a strong signal that something is seriously wrong with the planning and production control system itself.

The fact that there is little correlation between planned and actual expenditures is better shown by means of a scatter diagram (Figure 4-4). The vertical axis represents the planned values for the work packages; the horizontal axis the actual expenditures the dots in the body represent the combined planned and actual expenditures for each of the one hundred work packages in the sample. For example, Point A has a planned manhour allowance of 750 manhours, while actual expenditures were 938 manhours. The performance factor for Point A is 0.8. If there were perfect correlation between planned and actual expenditures, then all points in the figure would fall on the diagonal line. The more they are scattered around the line, the poorer the correlation between planned and actual expenditures.

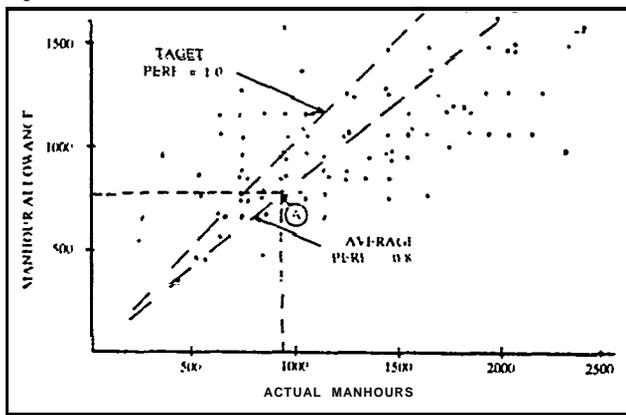


FIGURE 4-4: SCATTER DIAGRAM OF ALLOWED VS. ACTUAL EXPENDITURES

If the system were actually providing a reasonable plan (budgets) and controlling production, we would want far less dispersion in the distribution than is exhibited in the sample, as illustrated by Figure 4-5.

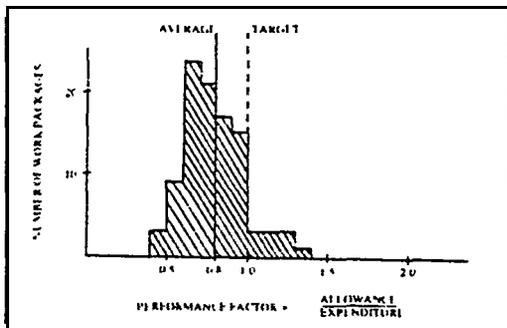


FIGURE 4-5: A DISTRIBUTION OF PERFORMANCE SHOWING MORE EFFECTIVE CONTROL.

Figure 4-6 is a scatter diagram for the improved distribution shown in Figure 4-5. Note that Point A is the same, but that the other points are more closely clustered around an average performance of 0.8.

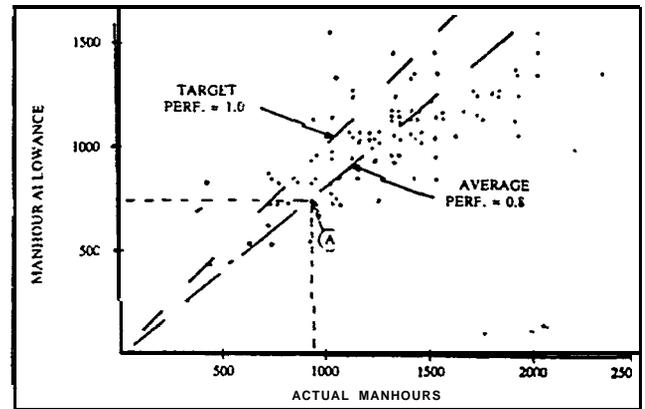


FIGURE 4-6: SCATTER DIAGRAM OF ALLOWED VS. ACTUAL EXPENDITURES.

Figure 4-7 is a combination of Figures 4-3 and 4-5 using smooth curves, which are accurate enough for purposes here. The distributions, A and B, have the same average value of 0.8, and represent the same number of work packages, i.e., the areas under the two distributions are equal. However, B exhibits far less dispersion than does A, which indicates a much stronger correlation between budgets and actual expenditures. The difference in average actual expenditure and budget of 0.20 performance points for B represents strong and consistent bias. This bias may reflect a conscious decision on the part of management to set budgets that will always challenge the labor force. In either case, since the bias is consistent, compensation to bring it closer to zero is a simple matter.

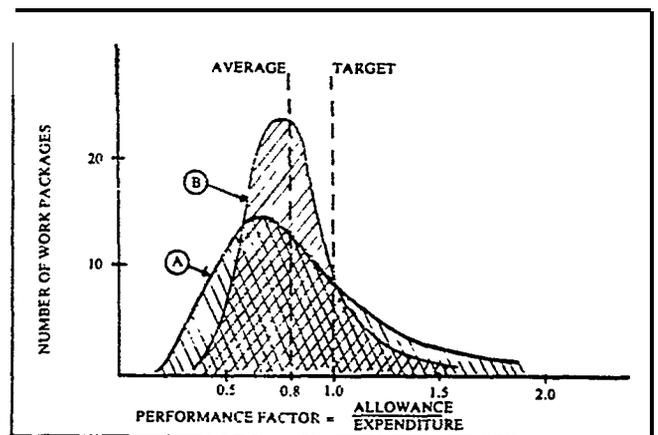


FIGURE 4-7: SAME AVERAGE — DIFFERENT DISPERSION.

The important point here is that variance in performance provides a much better indicator of system effectiveness than does average performance. If the variance is large, then improving the system should be seriously considered. Guidelines for doing so are discussed in Chapter 6. On the other hand, if variation in performance of the productive

effort is small, it may well be that the system is over elaborate and more expensive than necessary. If so, then the expense of operating and maintaining the system may well exceed the benefits it provides in controlling construction costs. This issue is discussed in Part IV.

## CHAPTER 5

### BASIC RELATIONSHIPS BETWEEN COST AND DURATION

#### 5.1 Why Is Scatter Bad

Scatter\* in performance is usually wide, which is a problem even if the average is on target. Scatter is bad because it is caused by factors which contribute directly to excessive shipbuilding costs. Figure 5-1 represents performance to schedule. Note that in this figure, the average of the distribution of time lates (earlys) is 0, i.e., the average performance is on target even though there is considerable spread. As discussed in Chapter 3, early completions and late completions both tend to increase shipbuilding costs.

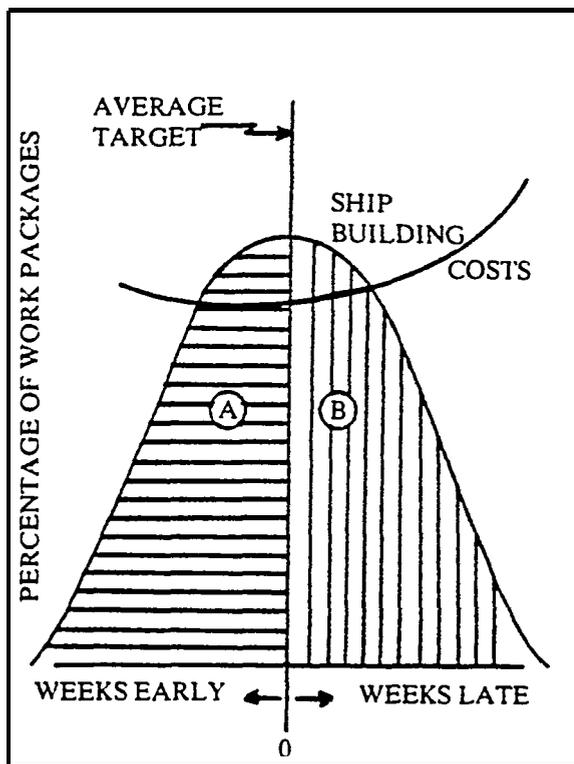


FIGURE 5-1 : IMPACT OF DEVIATION FROM SCHEDULE ON SHIPBUILDING COSTS.

Late completions have an even more serious impact on cost, as the shipbuilding cost curve in Figure 5-1 suggests. There are several reasons for this, in addition to the obvious penalty charges if the ship is delivered late. Introducing a few new concepts at this point will help to explain the cost impact of late completions.

\*See Appendix 1.

First, assume that there are four production steps in the construction of a ship (Figure 5-2). Assume also that if each of the four operational steps is unaffected by the preceding steps, then their schedule compliance profiles would all look like that shown in Figure 5-1. This assumption is unrealistic because the impact of missing schedules for operational steps creates waves through the whole construction project. We use this assumption only to show the nature of the impact and its magnitude.

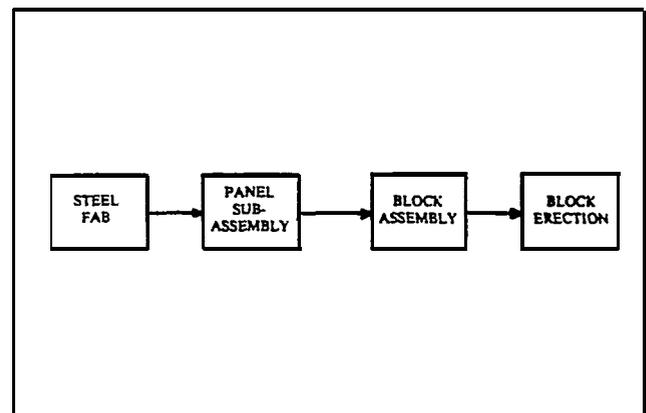


FIGURE 5-2 SIMPLIFIED SHIP CONSTRUCTION SEQUENCE

The discussion of time duration budgets in Appendix B shows that each work package is assigned a duration of time by the planner within which time allowance all work in the work package should be completed. The planner usually determines duration of a work package by first determining the manhour (and/or machine hour) requirements to accomplish the work covered by the work package. He then assigns a standard time to accomplish the work, which may vary somewhat depending on labor content of the work package. If the work package involves a few hundred manhours he will assign a duration of one or two weeks. If it is larger, three weeks to a month. The production scheduler uses the duration, the manhour budget, and the projected work load on the resource to establish calendar start and completion dates for the work package.

The assigned duration may or may not include slack (Figure 5-3). If the time allotted for the job is exactly equal to the estimated time required to accomplish the work, the time allotment has no slack. Then if the job actually takes

longer than the planner's time estimate and, hence, the time; he allotted for it, the schedule is impacted.

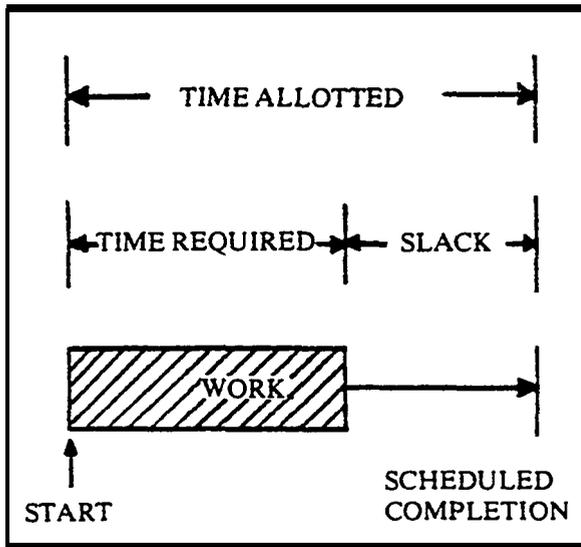


FIGURE 5-3: SLACK

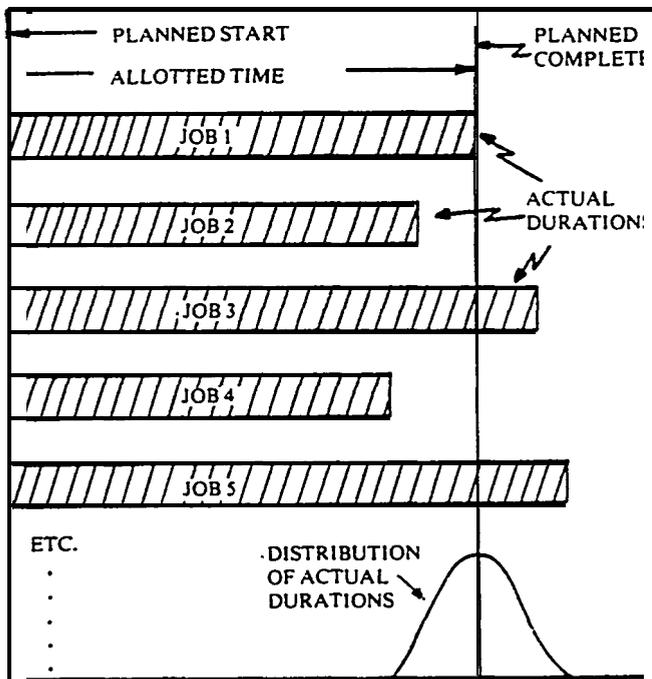


FIGURE 5-4: DISTRIBUTION OF ACTUAL JOB DURATIONS — SINGLE SHOP

Suppose now that time allotments for fabrication, panel, block assembly and block erection have no slack. Then any late completions in fabrication will impact panel sub-assembly completions. And since panel subassembly completions will vary randomly even if they are not impacted by fabrication completions, then actual completion dates will be combinations of the usual variations in the panel subassembly completions plus variations in the completions of the fabrication operations that precede them.

These relationships are shown in Figures 5-4 and 5-5. Figure 5-4 shows how actual job durations might vary at each of the four construction levels if each operation is totally independent of preceding operations. Figure 5-5 illustrates the impact of variations in job completions in one shop on completions in another shop fed by the first. In this example, the first is the Fabrication Shop; the second is the Panel Shop.

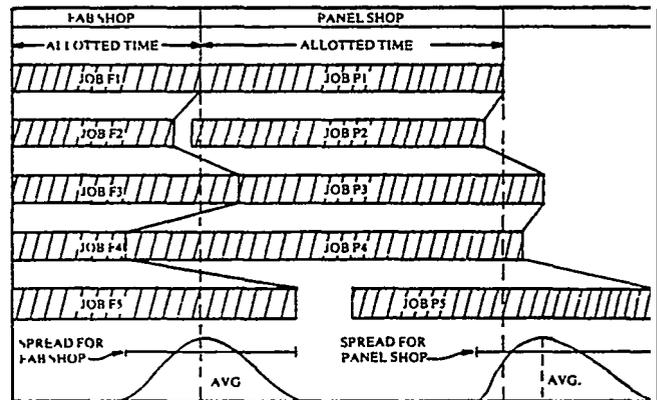
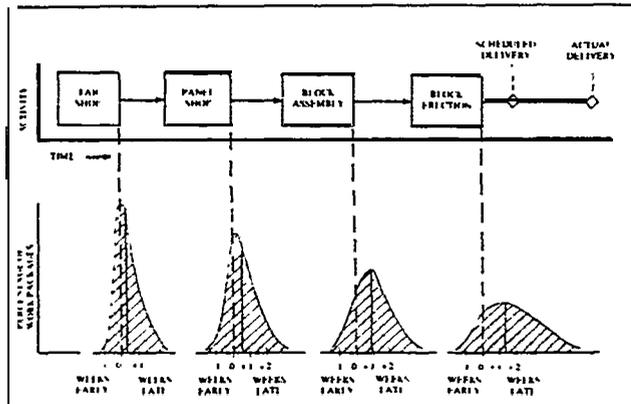


FIGURE 5-5: IMPACT OF JOB COMPLETIONS IN FAB SHOP ON PANEL SHOP COMPLETIONS.

Note that the distribution for the Fabrication Shop in Figure 5-5 is the same as that shown in Figure 5-4. The distribution of job completions for the Panel Shop, however, is now quite different in three important respects. First, average time late has drifted to the right and is no longer on target. Second, the spread is somewhat greater than it would be if there were no departures from schedule in the arrival of material from the Fabrication Shop\*. Third, the distribution is no longer symmetrical about the average but has developed a bias toward lateness. The reason for this is that even if the Panel Shop gets a job ahead of schedule from the Fabrication Shop, the Panel Shop cannot necessarily start on it immediately because they may still be working on Panel Shop jobs that either started late or did not complete on time.

\* See Appendix L. Statistically, the combined variation of two distributions is always greater than the distribution of either taken independently.

The combined impact of variations in actual job durations on all four shops operating in tandem, as they do in a shipyard, is illustrated in Figure 5-6. In the figure, performance to schedule for the Fabrication Shop is quite



DISTRIBUTION OF JOB COMPLETIONS

FIGURE 5-6: CUMULATIVE IMPACT OF VARIATIONS IN JOB DURATIONS.

good. Its performance of all shops were independent of their predecessors, then curves of performance-to-schedule for each would be quite similar to the curve for the Fabrication Shop. However, because of the assumption of no slack in the schedule, each does, in fact, impact the successor shops. Performance to schedule becomes progressively worse from Panel Shop to Block Assembly and finally to Block Erection. Average late time increases as does the spread around the average.

At erection the problem becomes very serious indeed, because blocks are erected in a fixed sequence. Early arrival of blocks is of little advantage because they cannot be erected out of sequence. Since all blocks must be erected and joined before launch, the blocks completed last are controlling and have a direct impact on the delivery schedule.

### 5.2 The Use of Slack

Shipbuilders have long recognized that “heel-to-toe” scheduling of the type illustrated in the last section would be financially disastrous. They have, therefore, intentionally introduced slack into the time durations allotted to the work packages to reduce the impact of variations in work package completion dates on follow-on operations. Slack acts as a buffer which dampens the impact of variations in completions in one shop on the schedule adherence of the shop that performs the follow-on work.

Figure 5-7 illustrates the point. Case A represents heel-to-toe scheduling of jobs with no slack included. The

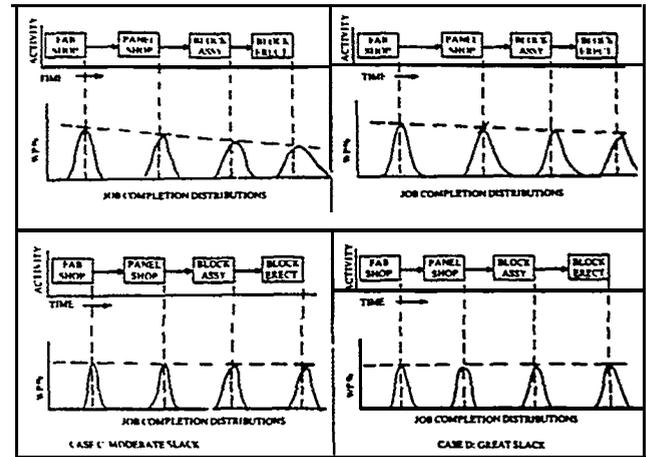


FIGURE 5-7: IMPACT OF SLACK ON SCHEDULE ADHERENCE.

schedule adherence of the Panel Shop is thus directly impacted by schedule slips in the Fabrication Shop, etc. Case B reflects the incorporation of a modest amount of slack in the scheduled duration of the jobs; Case C includes still more slack. When the shapes of the completion distributions in Cases A, B, and C are compared, note that the bias in the distributions and the average lateness factor both decrease as the amount of the slack is increased. Enough slack can be introduced (as in CASE D) that performance of the shops becomes independent of their feeder shops,

As more slack is introduced in standard durations allotted for the work packages, planned delivery dates and actual delivery dates become closer to each other as shown in Figure 5-8. Although actual construction time increases as the amount of slack introduced in the schedule increases, the difference between Planned and actual construction time decreases.

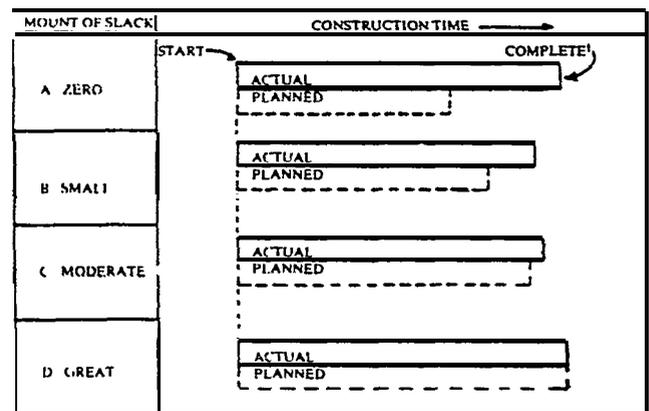


FIGURE 5-8: IMPACT OF SLACK ON SCHEDULED VS. ACTUAL DELIVERY

It is a well known fact that the longer the construction time, the higher the cost of the ship. Thus the cost of a ship scheduled under CASE D would be considerably more than one scheduled under CASE A. On the other hand, if a ship were originally priced in accordance with CASE A scheduling, then construction would entail a serious overrun, whereas actual cost under CASE D scheduling would be on-target. The problem with CASE D scheduling is that any bid based on these costs would undoubtedly be non-competitive, and no shipyard would ever have the opportunity to perform under such a relaxed schedule.

It might appear from Figure 5-8 that the case of zero slack is preferred, because actual construction time is the least. The cause of the shorter construction time, though, is a common experience in shipyards during the final stages of construction. As it becomes clear that the planned delivery date for the ship is in jeopardy, management will become more and more involved in the direction of day-to-day operations. Overtime will be scheduled; size of work crews will be increased; work that can be postponed until after launch will be postponed until then. Thus management, in order to minimize the impact of earlier problems on final delivery, will take extraordinary measures which increase costs beyond the original estimates, but reduce actual final costs below what they would be if completion had not been expedited. The cost of these extraordinary actions becomes less and less as the difference between expected completion and planned completion dates is decreased. The difference between planned and actual costs can be reduced by incorporating more slack in the original construction schedule, as discussed earlier. Although this action is tempting, total actual costs will go up in the process, which might price the shipyard out of business.

Figure 5-9 shows the relationship between actual cost and planned construction time, and also cost overrun for each of the four cases illustrated in Figures 5-7 and 5-8.

### 5.3 Managing Slack and Variance

After this long, but necessary, excursion into the relationships between schedule adherence, slack, and ship building costs, it should be clear as to why scatter between planned and actual job durations is bad. Practically speaking, the greater the amount of scatter, the greater the panic in the shipyard as the scheduled delivery date ap-

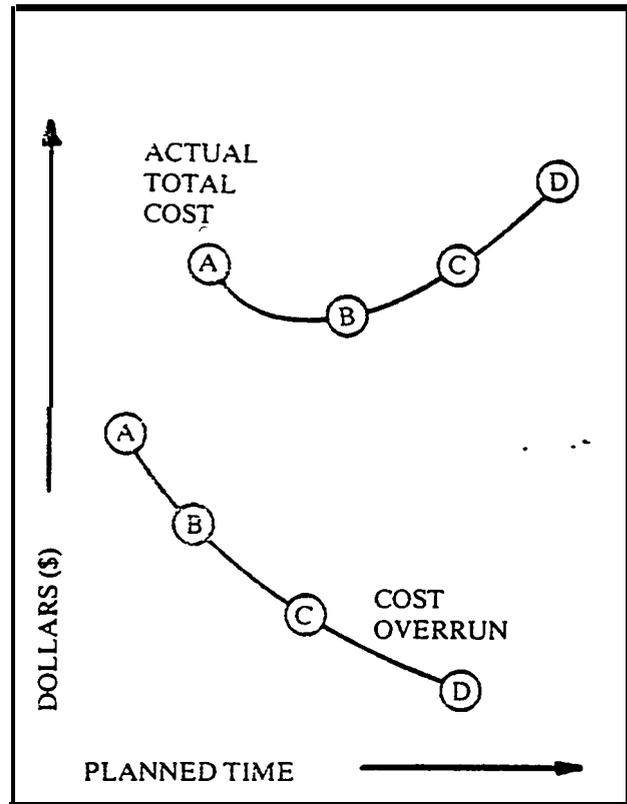


FIGURE 5-9: IMPACT OF PLANNED TIME ON SHIPBUILDING COST

preaches. But panic is only the surface reflection of basic underlying economic factors. Increasing the slack in the schedule would have dampened the panic but, because it would have increased the cost base of the original bid, it is likely that the contract would not have been awarded—in which case there would have been no panic, but possibly no shipyard either. A shipyard must be cost-competitive to win contracts and stay in business. This can be done by reducing the variance between planned and actual duration, which in turn permits reduction in slack. A certain amount of slack is always necessary, but an objective must be to minimize the amount necessary to keep shipbuilding costs competitive and at the same time keep the difference between planned and actual costs within manageable bounds. This involves reducing and managing variances, which is discussed in the next Chapter.

\*L. D. Chirillo of Todd Shipyards (Seattle Division) has pointed out that an impact of \$20,000 per day is probably a minimum based on the cost of money to finance a \$50 million ship.

CHAPTER 6

IMPROVEMENT NEEDS AND OPPORTUNITIES

6.1 Identifying Problem Areas

Assume that there are two shops A, and B, with the output of A feeding B as shown in Figure 6-1. Assume further that the distribution of schedule adherence is as illustrated in the figure. Since the distribution for B does not exhibit bias, and since the average of the distribution is on target, it can be concluded (for reasons developed in the previous chapter) that there is enough slack in the scheduled durations of the jobs loaded on A that B's performance is independent of A's.

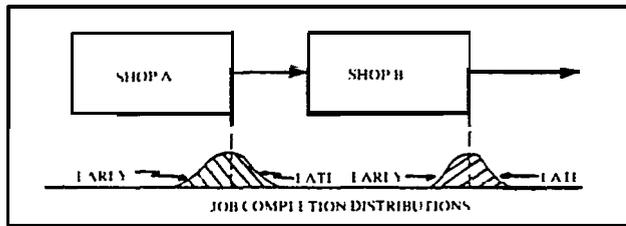


FIGURE 6-1: DISTRIBUTION OF SCHEDULE ADHERENCE

If ship construction time is to be reduced with potential savings of possibly \$20,000 per day<sup>4</sup>, then the amount of slack in the schedule must be reduced. This could be done directly by scheduling the start of B's jobs closer to the scheduled completion dates for A's. But as slack is removed, B's performance will become more strongly influenced by A's, and will begin to deteriorate. Scatter will increase and the average will begin to show bias toward lateness. Perhaps some time would be squeezed from the overall construction period, but it would be questionable whether the disruptive impact on Shop B could be justified on the basis of reduction in construction time.

Fortunately there is a much better way of compressing the schedule that avoids disrupting shop operations. That is by first reducing the scatter in Shop A's performance, and then reducing slack in the schedules. Note that if A's distribution of performance to schedule had no scatter, then B's jobs could be scheduled heel-to-toe with A's, and the only variation in B's output would be due to B's performance. This is illustrated in Figure 6-2. Here the distribution of A's performance-to-schedule is a spike.

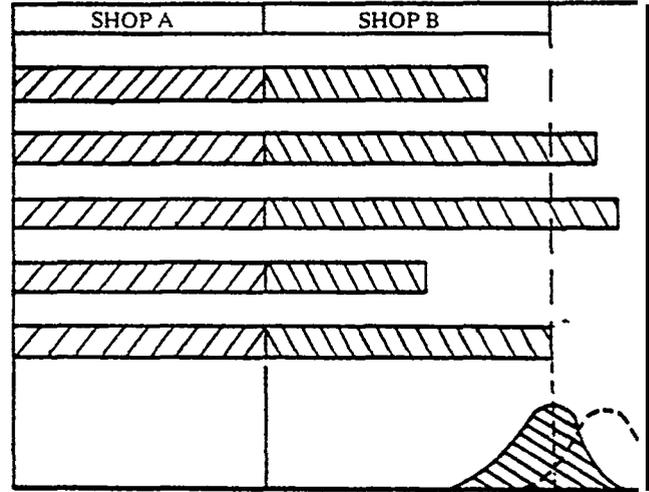


FIGURE 6-2: THE ULTIMATE SOLUTION

This suggests that the proper way to approach compressing ship construction time is to focus on the first shop (or operation) in the construction sequence; improve performance there; and then eliminate as much slack from the intershop schedules as possible without significantly disrupting operations in the next shop. Following the same procedure, each shop would be attended to in sequence until all shops had been treated. This is illustrated in Figure 6-3<sup>5</sup>. Since the key to achieving these reductions in time (and consequently cost) lies in compressing the variation in performance-to-schedule, the problem of how this can be done must be addressed.

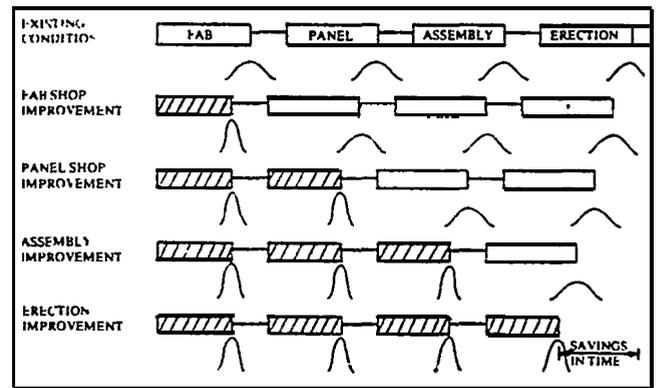


FIGURE 6-3: SHARPENING PERFORMANCE AND REDUCING SLACK

<sup>4</sup>See reference on page 5-4.

<sup>5</sup>The original Bath Iron Works research in Improved Planning and Production Control under the MarAd Ship Productivity Program followed this sequence with considerable success.

6.2 The Feedback Control System As A Model

To improve performance-to-schedule, which has been argued repeatedly to be equivalent to reducing variation about the average, the causes of the variations must be identified. In doing so, recognize that a planning and production control system is really a type of feedback control system whose essential features are shown in Figure 6-4. Scatter in performance is measured by the information

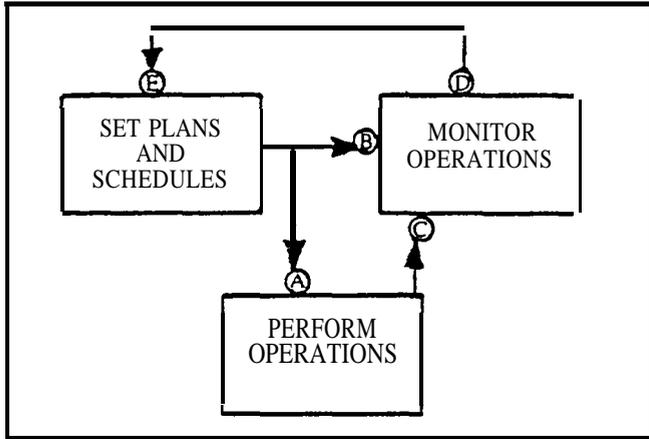


FIGURE 6-4: THE INFORMATION FEEDBACK LOOP IN PLANNING AND PRODUCTION CONTROL

available at point (D) in the figure, and results from a comparison of information that comes from two distinct sources:

- (1) Output from the planning and scheduling function (Point (B)) which provides the planned values, and
- (2) Reports from or measurement of operations (Point (C)) which provides the actual values.

Now if there is a wide dispersion in actual performance about the average, realize that the cause may be either in the information fed to point (B) from planning or into (C) from production. or from a combination of the two.

To be truly interested in improving the system it is essential to assume that something is wrong at (B), and only charge production with causing the problem when convinced that the information at (B) is absolutely correct and beyond reproach. Remember that a wide variation in performance indicates that the system is not truly exercising control, so there is a good and logical reason to suspect (B) before suspecting (C).

Point (E) must also be looked at because there may be a breakdown in the feedback loop, in which case control is being exercised on the basis of erroneous, obsolete, irrelevant, or null information.

Variations in scheduled performance are tied directly to variations in job durations (Figure 6-5) which, in turn, are tied to variations in labor or machine hours. For the Fabrication Shop, for example, assuming that there is a sufficient supply of plates and shapes in the steel yard to satisfy the shop's input needs, then the variations in job duration and/or labor content is due solely to factors within that shop, and to the characteristics of the jobs it undertakes.

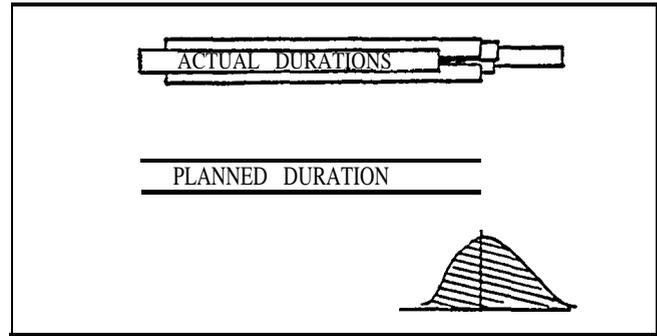


FIGURE 6-5: ACTUAL PERFORMANCE

6.3 Analyzing Variances as Errors in Budgeting Rules

Because of the perspective which is focused on the planning and performance monitoring of the system rather than on production, exactly the same data (Figure 6-5) can be looked at in quite a different way. Assume, for example, that each job is manned at the optimum level and takes exactly as long to complete as it should have taken. That is, production performance is perfect. The problem then lies not with production, but with planning which budgeted the labor hours and duration for the jobs. Time and labor allotments for some jobs were too small, for others about right, and for still others too much. From this point of view, Figure 6-5 becomes a distribution of accuracy in estimating and budgeting (Figure 6-6) rather than shop performance to schedule. The variance of the distribution becomes a characteristic of the estimating error. The broad spread shown in Figure 6-6 suggests that rules used for estimating labor content and job duration are quite unreliable and should be improved.

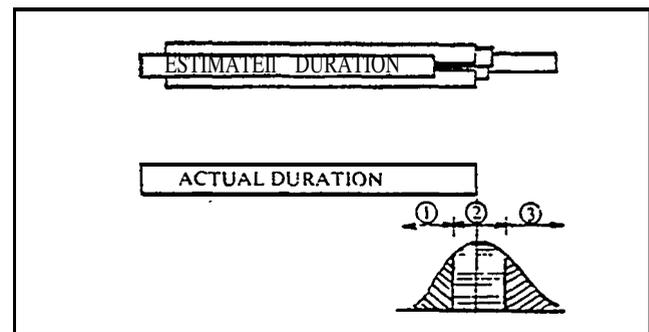


FIGURE 6-6: ACCURACY IN BUDGETING

The jobs to which the budgeting rules are applied must be examined to see if there are any significant differences in work content which can explain why budgets are reliable for some and unreliable for others. Some tolerance limit must be established which specifies an acceptable amount of error in the budgets. For example, variations of  $\pm 5\%$  from the average\*,  $\bar{p}$ , might be acceptable, whereas any deviation beyond this limit would be investigated.

Now, divide the sample of jobs into three groups, Figure 6-7:

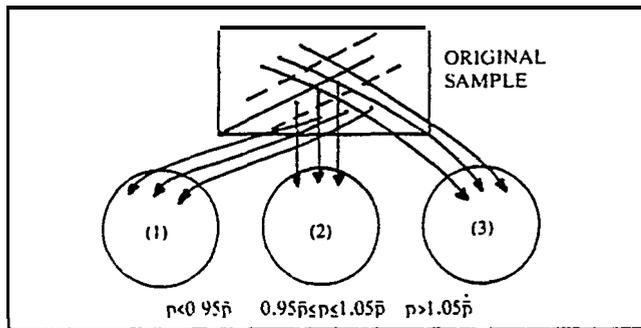


FIGURE 6-7: GROUPING WORK PACKAGES FOR ANALYSIS OF DIFFERENCES

- (1) Those whose performance factors are less than  $0.95\bar{p}$ .
- (2) Those whose performance factors lie inside the range  $0.95\bar{p}$  to  $1.05\bar{p}$ .
- (3) Those whose performance factors are greater than  $1.05\bar{p}$ .

Now study the work content of the jobs in each of the three separate groups to see if there are any consistent differences between the groups that explain why Group (1) performance is less than acceptable, and why Group (3) more than acceptable\*\*.

For example, if the labor budget was determined by taking steel tonnage of a work package and dividing it by the long-term-manhour tonnage rate of the shop, the amount of burning, fitting, and welding in Group (1) might be greater than that of Group (2). The work content might be the same in both cases but with lighter weight

materials used in Group (1), so that applying the tonnage rule for establishing the labor budgets results in an unrealistically low labor allowance. The reverse situation might apply for Group (3) where budgets are excessive.

Assuming that significant differences in work content are found in the three groups of work packages, the next thing to do is to adjust the budgeting rules (standards) so that the budgets developed by the new rules approximate more closely the labor and time expenditure averages collected for each of the three groups of work packages. (Procedures for developing more reliable standards are described in Chapter 7.) Finally labor and time budgets for new work packages are established using the new rules. Time and labor expenditures are collected as the new work packages are released to the shops, and the analysis process is repeated to check for improvement.

The improvement process is thus reiterative as shown in Figure 6-8, and is continued until distributions of labor and durations are fairly sharp (Figure 6-9). The interesting thing to note about Figure 6-8 is that it has exactly the same form as Figure 4-1, which is the total planning and production control loop. But in Figure 6-9, the process for which improvement is sought is now the planning and production control process itself, rather than production operations in the shops. This means that the apparatus in the planning and production control system can be used for its own self improvement, if it is designed so that it collects the right information. If this is the case, then the system becomes self-regulating and progressive, systematic steps can sharpen performance and eliminate the slack in production. The feedback characteristics of the system (Figure 6-4) can be used to sharpen performance (Figure 6-9) which achieves the reduction in construction time illustrated in Figure 6-3.

The principal ingredient needed for this process is a set of engineered standards. They provide a more accurate assessment of work content which in turn narrows the dispersion in work performance. Engineered standards are a norm against which actual performance can be measured and the need for corrective action recognized. Control can then be exercised. The next Chapter discusses a system of engineered standards.

\*The target could have been used as the point of reference, but first the distribution should be sharpened and then the problem of bias attacked.

\*\*There are more effective statistical methods for the analyses of variance, but these are beyond the scope of this Manual. The reader is referred to the list of references in the Bibliography for more rigorous treatment.

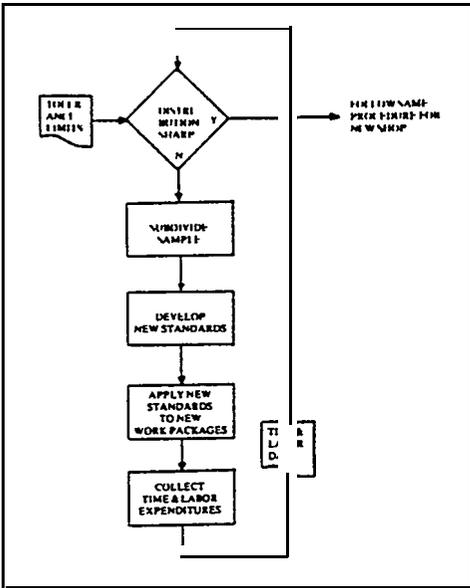


FIGURE 6-8: THE PLANNING IMPROVEMENT CYCLE

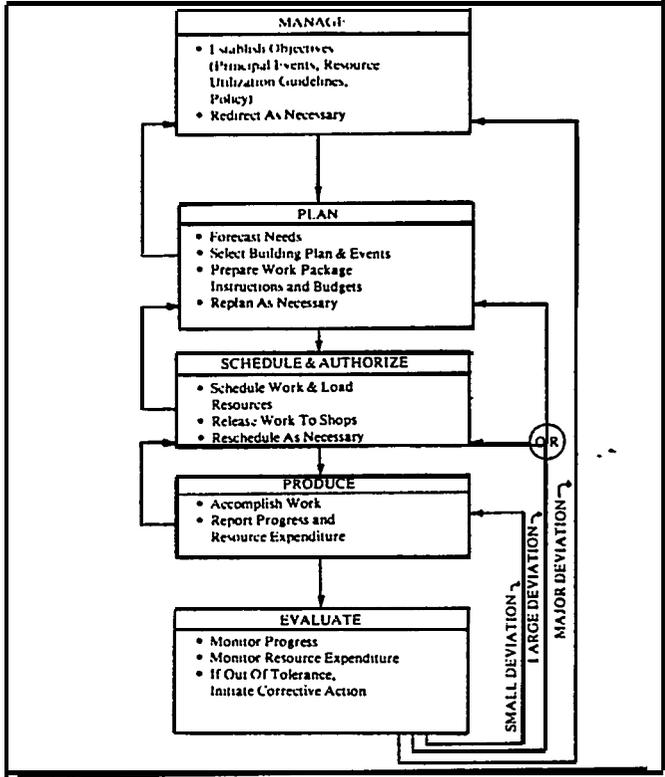


FIGURE 4-1: PLANNING AND SCHEDULING IN THE MANAGEMENT CYCLE

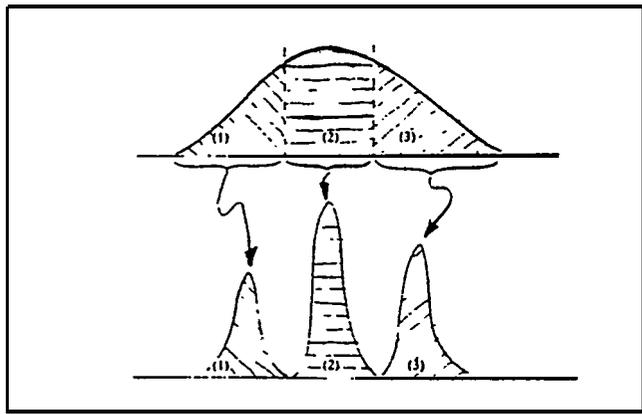


FIGURE 6-9: IMPROVING PERFORMANCE BY GROUPING WORK PACKAGES IN TERMS OF WORK CONTENT

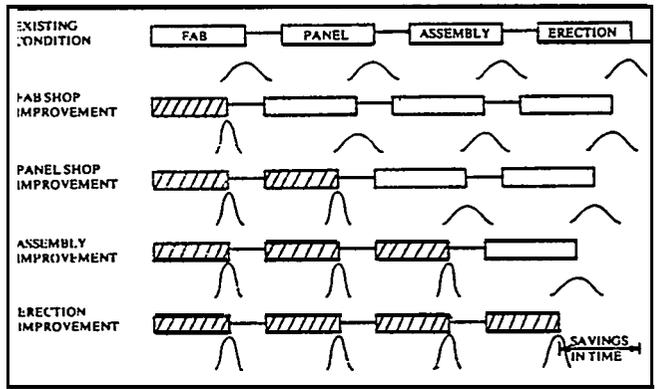


FIGURE 6-3: SHARPENING PERFORMANCE AND REDUCING SLACK

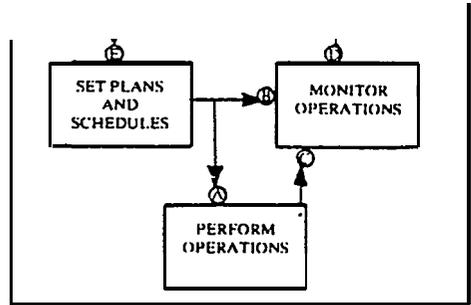


FIGURE 6-4: THE INFORMATION FEEDBACK LOOP IN PLANNING AND PRODUCTION CONTROL

## CHAPTER 7

### A SYSTEM OF ENGINEERED STANDARDS

#### 7.1 A Standards Program

Several ingredients are needed to have an effective standards program\*:

- Engineered Standards the building blocks of the system
- **People - who understand the use of standards**
- A Starting Point - a geographical area or organizational function where system implementation will be initiated.

A set of engineered standards is needed to cover whatever portion of the shipbuilding effort will be initially involved in the system. As more standards are accrued, wider portions of the shipyard can be included in the system until the desired coverage is attained. Extensive coverage by standards will allow the biggest advantage to be gained through their use. It is not unlikely that desired coverage will eventually include every manhour and dollar charge in the shipyard, both direct and indirect, which can serve as an ultimate goal for the standards program.

It is probably best to generate standards for the early production processes, as during the experiment described in Chapter 1, and grow in the direction of follow-on operations.

For example, the natural breakdown shown in Figure 7-1 might be useful, where the Fabrication Shop would be placed under the system first, then the Panel Shop, the

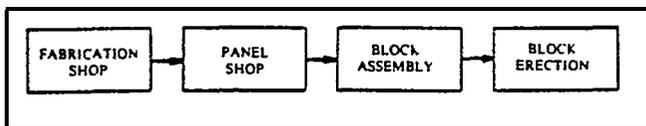


FIGURE 7-1: ORDER OF PRODUCTION PROCESSES

Block Assembly, and then Block Erection. It should not be necessary to cover one area completely before going on to the next, but there is a practical lower limit to partial implementation of the system. Enough standards must be available and in use to allow generation of advantages in the planning process. Since covering each area will take several weeks, at the very least, there is no need to rush the decision of where to cover next. Extending the system can

\*Standard has many diverse meanings, but in this text the following definition applies when referring to standards used for production control purposes.

A standard is an accepted rule, model, norm or benchmark which is used as a reference for the purpose of comparing actual results with desired results.

be done thoughtfully and deliberately as the capability to do so is acquired.

One of the principal users, if not originators, of standards is the planning group. They may be assigned to work with production people in generating the basic process data, and assembling it to create the engineered standards. In any event, planning is the function that will use engineered standards extensively. The planning group, then, must be knowledgeable and supportive of the production oriented planning system in order for it to be successful.

• Appendix F discusses the organization and composition of a planning group, and conditions needed to promote successful planning.

#### 7.2 Sources of Standards

There are basically six sources of standards dictated by how they are developed.

- Market place
- Emotional
- Edict
- Historical
- Modified Historical and Expert Judgment
- Engineered

Market place standards are common in shipbuilding. Many specifications say "according to accepted marine practice" or "of marine quality." The trouble with these standards is they are not universally accepted. The meaning may not be the same from user to user. They cannot be quantified, or objectively measured in many cases. Some have been developed sufficiently to overcome these objections, but not usually. In addition, market place standards may not represent the best solution. They are often compromises, used because they work, but exclude better solutions which may be available just because these better solutions do not carry years of precedence for shipbuilding.

Emotional is when the boss comes charging in and says, "Do it my way or else." This is a standard, which often changes before it is used. Often it is not the same for all the people involved. And usually the emotional standard causes grief to many other people involved.

Edict is when the customer just says, "It is going to be this way." He has set a standard by edict. Hopefully it is a good one and he does not change it before the job is done. Unfortunately, changes are often made to edict standards, and not everyone involved is informed of the changes. The edict may be unfair or unreasonable, but it is a kind of standard that has to be met.

Historical standards are used extensively in shipbuilding. Planning, and cost data are taken from the previous jobs. Any inefficiencies that existed are built in. Consider the case of two pipefitters who were given a budget of 40 manhours to install antifreeze in a certain hydraulic system. The allowance was because they had to carry all the one-gallon cans of antifreeze down into the ship. The buyer and pishop foreman got together and decided that buying the antifreeze in barrels and pumping it down to the system would save significant time. So that was done. The job now took about 16 manhours. The budget remained at 40 manhours, and the manhours saved were applied to the steering gear installation which was in trouble. For the next 5 ships, the fitters were still receiving a skimpy budget in the steering gear installation work package because the planners didn't know about the waterfront shuffle. Historical numbers are important to shipbuilding, but there are significantly better choices available.

Modified Historical standards result when the ship changes or when conditions change. When historical numbers yield unsatisfactory results, planners often modify the numbers to suit the new situation. These modifications make it possible to continue to use obsolete history or to apply historical numbers to new situations. In one shipyard, a qualified planning expert was hired to supply modified historical numbers from other shipyards in an attempt to determine whether use of imported numbers would be more satisfactory than use of in-house modified numbers. The results' indicated that imported numbers were of little or no benefit, and were difficult to apply.

Engineered standards turn out to be the most satisfactory of all standards. They are the most time consuming to develop, but the resulting savings are significantly greater, and more than justify the extra effort. Engineered standards are standards which have been developed by qualified engineers using the appropriate techniques as discussed in Appendix G. Engineered standards take into account the required work content of a job, safety limitations, methods which must be employed, pace, allowances, etc. A search of the literature reveals that there have been almost no attempts by shipyards to use

engineered standards although their use is quite common in other heavy industries.

Engineered standards are the most useful and provide the greatest opportunities for cost control. Of all the types of startdards discussed above, engineered standards do the following things that other standards do not:

- Engineered standards describe what an operation should cost independently from what it has been costing. This allows attention to those areas where the greater opportunity for cost savings resides.
- Engineered standards provide the detail necessary to test methods with minimum risk.

### 7.3 Types of Standards and Numbers Needed

Of the several sources described above, standards developed from engineered data offer the greatest range of uses. The basic data may be combined in many ways to make it more convenient to apply to different planning and production control problems. One such family or group of standards would have these five levels:

- Process Standards
- Production Standards
- Scheduling Standards
- Planning Standards
- Cost Estimating Standards

This group of standards derives from the same common base of engineered data. There is a carefully developed audit trail from one to the other. The format of presentation and the amount of detail used to present the basic data is simplified and reduced from process standards to cost estimating standards. Figure 7-2 shows the numbers of standards one might expect in such a grouping.

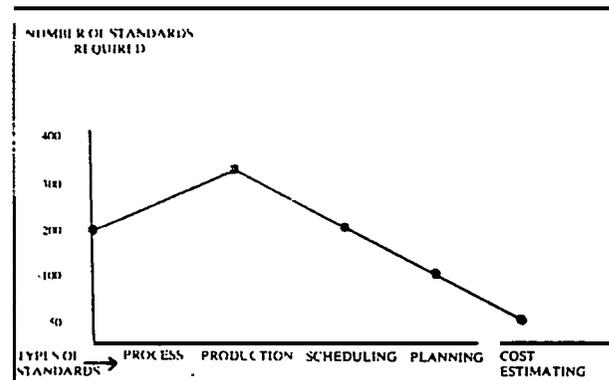


FIGURE 7-2: TYPES AND APPROXIMATE NUMBERS OF STANDARDS TO COVER ALL SHIPYARD OPERATIONS

' Bath Iron Works Corporation, *Improved Planning and Production Control*, August 1977, a Report of Research conducted under the MARAD Ship Producibility Research Program.

There are many similarities between the levels in this group. Process, production, scheduling, planning, and cost estimating standards are based on the following common elements:

- Definition of the work method
- Statement of quality tolerances
- Degree of detail determined by desired accuracy of results, by end use, and by information available to the user.

A standard can express a resource budget value for labor, material, facilities or time needed to build any part of the ship. The more information that is known about the ship, the more detail that can be included in the standard. Because of the greater amount of detail in lower level standards, there are more of them than higher level standards, as seen in Figure 7-3. Each type of standard is briefly described below:

DIFFERENT TYPES OF STANDARDS SHOW DIFFERENT ELEMENTS OF DETAIL (WELDING EXAMPLE SHOWN)		ELEMENT IN THIS STANDARD		CONTAINED TYPE OF		
		PROCESS	PRODUCTION	SCHEDULING	PLANNING	COST ESTIMATING
ELEMENT	EXAMPLE					
Type of Process	(fluxcored, SMA, etc.)	•	•	•	•	•
Electrode	(7016, 7019, etc. 1/4", 28", 50" etc.)	•	•	•	•	•
Type of Edge Prep	(bevel)	•	•	•	•	•
Position	(downhand, vertical)	•	•	•	•	•
Work location	(shop, ways)	•	•	•	•	•
Work Conditions	(cramped, windy)	•	•	•	•	•
Fatigue Allowance		•	•	•	•	•
Move Distances	(walk 3')	•	•	•	•	•
Material	(primed steel, HY80)	•	•	•	•	•
Part of Ship	(bow, stern, tank)	•	•	•	•	•
System on Ship	(steering gear, hydraulic)	•	•	•	•	•
Scrip Loss	(pounds in, pounds out)	•	•	•	•	•
Cost of Material	(\$/lb.)	•	•	•	•	•
Cost of Electrode	(\$/lb.)	•	•	•	•	•
Labor Rate	(\$/hr.)	•	•	•	•	•

FIGURE 7-3: TYPE OF STANDARD VS. CONTENT

Process standards cover a work process as, for example, a standard might be developed to cover the hand burning process. The work covered would be: set up torch, change tips, coil/uncoil hose, adjust pressure, ignite, burn plates, pierce, contour, clean up, etc. However, the work covered by this standard could be performed anywhere in the shipyard. When turned into a production standard for hand burning, the work in the burning process (as covered by the burning process standard) would be combined with the other process standards which represented the rest of the work in the burners job. Such other work elements might be walk to and from the job, pans handling, parts identification, lay-out burn lines, punch marks, etc. Selected portions of the process standards for these activities would be utilized in making the production standard for the burner. Normally process standards are used only to provide the data needed for production standards for cost comparisons. Figure 7-4 shows the content of typical process standards.

Production standards cover the work content of a production job, and are often made up by using various parts of several process standards. (See Figures 7-5, 7-6, and 7-7.) The production standard shown in Figure 7-4 for the burner would have a companion production standard for a fitter/welder to cover a two man crew (1 burner, 1 fitter/welder) who install small miscellaneous foundations. Production standards often show either standard manhours for individual workers or they show machine hours and crew size for work centers, depending on the control management wishes to exercise. Production standards are used as a benchmark for measuring worker performance and labor productivity.

Scheduling standards are put together by combining several production standards or by locking in certain allowances from production standards. The schedulers use scheduling standards to determine elapsed time for certain operations or for work stations. The numbers disclose how long a crew will work on a certain unit. Scheduling standards are used to load shops and crafts so that the workload will be constant or level from day to day. Scheduling standards provide the data for making the schedules which are used to measure schedule performance. (See Figure 7-8.)

<p><b>HAND BURNING</b> Set up torch Install/Remove tip Clean tip Ignite Adjust gas &amp; air</p>	<p><b>MOVE PARTS - STANDARD ALLOWANCE</b> Allowance for hot parts, Sharp parts, oily parts, awkward parts, precision parts</p>
<p><b>LARGE PARTS HANDLE</b> Select &amp; return pendant crane Position over load Hook &amp; Unhook Move load</p>	<p><b>DESLAG</b> Hand remove Edge Slag Select and restore deslagging tool Does not include parts handling or clean up</p>
<p><b>CLEAN UP WORK AREA</b> Select &amp; set aside broom, brush, dust pan, etc Sweep area, pick up and dispose of rubbish Reposition tools, etc</p>	<p><b>JOB PLANNING AND REPORTING</b> Read instruction drawings, etc. Fill out "Work Completed" and Fill out "Time Change Sheet" Get verbal instructions Plan work</p>
<p><b>MEASURE &amp; MARK</b> Select and set aside tape, square, markers, templates, etc Measure Mark Punch Identify</p>	<p><b>ALLOWANCES</b> Personal time Rest room trips Fatigue Breaks (as authorized) Lunch (if paid)</p>
<p><b>SMALL PARTS HANDLE</b> Move parts by hand Time required as a function of part weight, distance of move height</p>	

FIGURE 7-4: SEVERAL TYPICAL SHIPYARD PROCESS STANDARDS AND THE WORK ELEMENTS THAT ARE INCLUDED

Planning standards are less detailed than the scheduling, production, or process standards. They are used to select the ship construction process. Strictly speaking, planning standards do not show budgets. They show the preferred (lowest cost, lowest risk) sequence of operations for carrying out a task. The relationship to other activities

might be reflected in a standard network for producing a certain type or class of ship. If the standard plan could not be implemented for some reason, such as interference with another construction contract, alternatives could be worked out using planning standards.

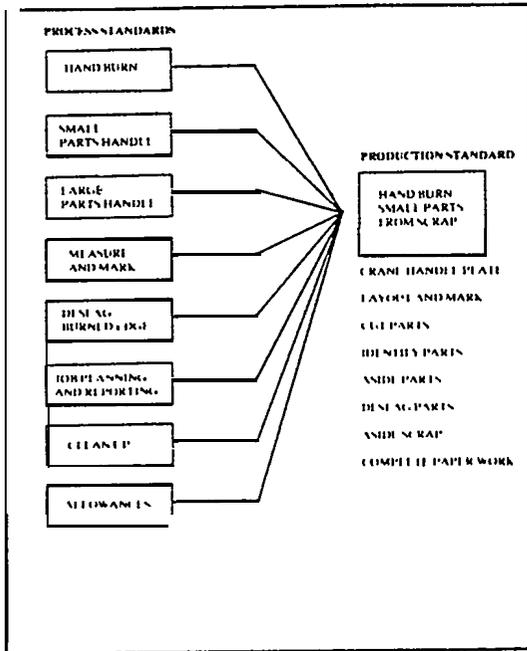


FIGURE 7-5: ELEMENTS OF SEVERAL PROCESS STANDARDS ARE USED TO DEVELOP STANDARD FOR BURNING SMALL PARTS FROM SCRAP

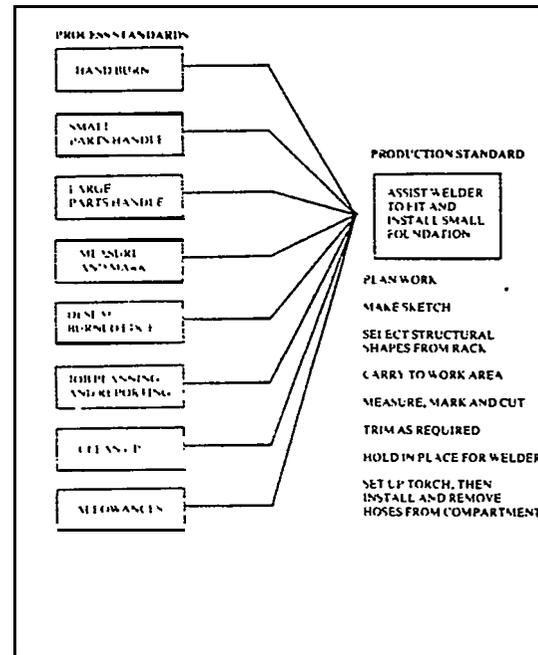


FIGURE 7-6: ELEMENTS FROM THE SAME PROCESS STANDARD ARE COMBINED IN DIFFERENT PROPORTIONS TO DEVELOP A PRODUCTION STANDARD

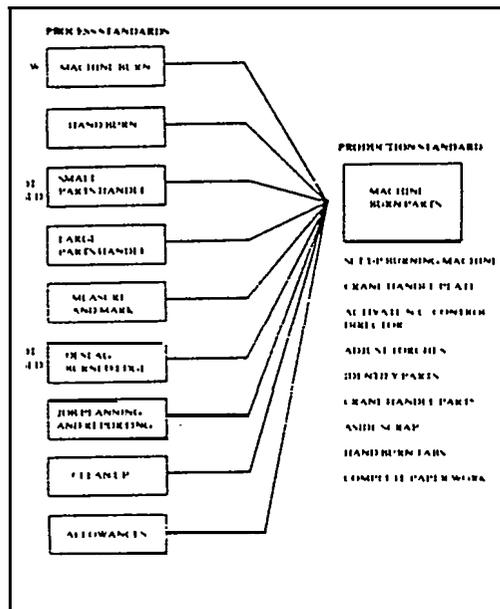


FIGURE 7-7: ELEMENTS FROM SAME PROCESS STANDARDS PLUS ELEMENTS FROM ADDITIONAL PROCESS STANDARDS ARE COMBINED TO CREATE A PRODUCTION STANDARD FOR N. C. BURNING MACHINE

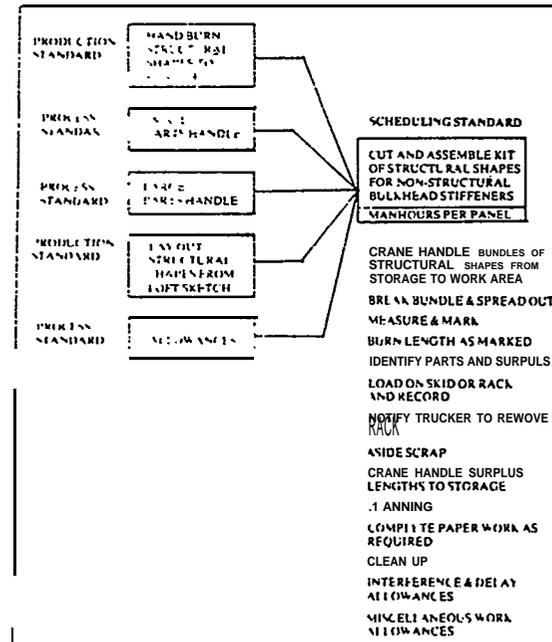


FIGURE 7-8: PROCESS STANDARDS AND PRODUCTION STANDARDS GO INTO A SCHEDULING STANDARD

Cost estimating standards are used to determine ship construction costs for original bids and some change orders. They are applied when the information about the ship is incomplete, as when only bid specifications and drawings are available. They are designed to minimize the time required to prepare cost estimates. Usually the standards are cataloged by ship system, similar to the typical work breakdown structure used by most shipyards for cost collection. They are not very sensitive (or responsive) to small changes in work content or work method since they are an average of many variables. Consequently, whenever sufficient detail is known about the ship to permit the use of lower level standards, such as planning and scheduling standards, they should be used for cost development.

Figure 7-9 shows how the different sources of standards contribute different amounts of usefulness to different types of standards. Figure 7-10 shows the types of engineered standards, their use, and the units frequently used in each.

TYPE	SOURCE				
	PROCESS	PRODUCTION	SCHEDULING	PLANNING	COST ESTIMATING
MARKET PLACE				2	1
EMOTIONAL		7	1	1	1
EDICTED	1	1	1	1	1
HISTORICAL		4	6	8	5
MODIFIED HISTORICAL	3	5	7		6
ENGINEERED	10	10	10	10	10

NUMERICAL VALUES IN ASCENDING ORDER OF USEFULNESS 1 - LOW TO 10 - HIGH

FIGURE 7-9: USEFULNESS OF STANDARD INCREASES AS SOURCE BECOMES MORE SCIENTIFIC AND FACTUAL

TYPE	USES	FREQUENTLY USED UNITS
1. PROCESS STANDARD	<ul style="list-style-type: none"> <li>BASIC BUILDING BLOCK FOR OTHER STANDARDS</li> <li>COST COMPARISONS</li> </ul>	MANHOURS MACHINE HOURS - (CREW SIZE) CONSUMABLES REQUIRED NORMAL SCRAP LOSS
2. PRODUCTION STANDARD	<ul style="list-style-type: none"> <li>PRODUCTIVITY MEASUREMENT</li> </ul>	MANHOURS FOR WORK PERFORMED USED TO MEASURE WORK AS IT IS ACCOMPLISHED
3. SCHEDULING STANDARD	<ul style="list-style-type: none"> <li>WORK PACKAGE BUDGETS</li> <li>SHOP LOADING</li> </ul>	CREW AND MANHOURS AND TIME DURATIONS USED BEFORE WORK IS ACCOMPLISHED TO DEVELOP WORK PACKAGE BUDGETS
4. PLANNING STANDARD	<ul style="list-style-type: none"> <li>MILESTONE AND KEY EVENT PLANNING AND SEQUENCING</li> <li>WORK METHOD DETERMINATIONS</li> </ul>	JOB SEQUENCE
5. COST ESTIMATING STANDARD	<ul style="list-style-type: none"> <li>NEW SHIP COST ESTIMATING</li> <li>CHANGE ORDER ESTIMATING</li> <li>SYSTEM COSTS ESTIMATING</li> </ul>	COSTS FOR SHIPS, SYSTEMS, AND OTHER MAJOR GROUPING. INCLUDES LABOR MATERIALS, FACILITIES AND TIME

FIGURE 7-10: TYPES AND USES OF ENGINEERED STANDARDS

### 7.4 Generation of Standards

Standards both simplify and complicate life. Survival in this high technology world would be impossible without standard plugs to fit into standard sockets, or without a "drive on the right" standard. On the other hand, standards can restrict creativity and innovation if they are not properly applied, but this is not the fault of the standards themselves.

The "control" portion of planning and production control requires standards. Some norm must exist so the need for corrective action can be recognized. The standards used in shipbuilding cover expenditures for labor, material, facilities, and time, with the heaviest emphasis being on the labor portion. The labor standards used by a shipyard are usually generated by the shipyard itself, using measured process data.

- Appendix G describes the generation of engineered labor standards, and includes a sample engineered standard to illustrate the type and extent of information normally included.

## PART IV

### MAINTAINING EFFECTIVENESS

This part discusses how to put engineered standards to work. It also deals with how to determine the overall shipyard impact of production oriented planning, and whether it is cost effective.

## CHAPTER 8

### PUTTING ENGINEERED STANDARDS TO WORK

Once they have been developed and published, engineered standards have many uses. The extent to which engineered standards are used by the various components in a shipyard (Figure 8-1) can provide a measure of the advantage gained by having produced them originally. The more use they receive, the more return on investment will be accrued.

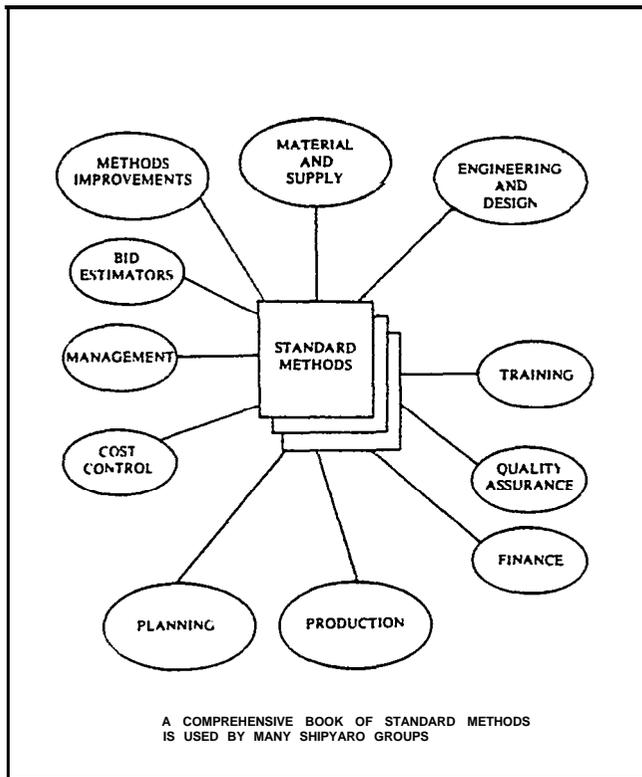


FIGURE 8-1: USE OF STANDARD METHODS.

Some of the shipyard uses of engineered standards are listed below. Examination of the affected areas in each shipyard can reveal whether engineered standards are being used there effectively, or whether additional attention to their use might be appropriate.

#### 8.1 Improving Management Control

##### •Management by Objectives (MBO)

The use of engineered standards offers an opportunity to manage objectives, that is, to quantitatively measure achievements toward stated goals. Similarly, the person striving to reach the objectives and thereby achieve good performance under the MBO program significantly benefits from the objective measurement. He knows ahead of

time what the gauge is and the results are clear to him and to his management.

##### •Piece Rate Incentive Pay Systems

Engineered standards are useful when the existing piece rates have been used for a long time. Engineered standards reveal whether the original numbers were established in a systematic, rational, and scientific manner and whether required updating for methods change has been performed.

##### •Work Performance Measurement

Even when dealing with the non-incentive paid workers, the use of engineered standards for work performance measurement allows significant reduction in labor costs through performance improvement. Basic metal-working industries have experienced productivity gains from measurement alone in the order of 15% to 25%.

##### •Supervisory Performance Measurement

With a system of engineered standards, performance evaluation can be based on that portion of the task which is under the control of each supervisor. There is no more need for the “shot gun” approach to accountability. The norm for performance can now be applied to the controlling supervisor.

##### •Control of Work Methods

Engineered standards offer management a way to control work methods. Initially, the standards may be used to select the best methods for performing the work. After this has been done, work results should be compared to this standard for control purposes. Standard methods must include quality assurance steps and safety requirements.

#### 8.2 Improving Basic Function

•Engineering and Design people can incorporate features which will make the ship easier to build because they know what building process will be used. Detailed engineering is *de facto* planning. The location and design of hull seams and butts, outfit placement, and location of outfit joints are all engineering/planning decisions. The Naval Architect selects major lines and ship configuration, The Draftsman then has the job of detailing that design, and his details largely determine the cost to install each part. When he has available to him a selection of cost-effective (labor plus material) parts to use, he can incorporate them into the design. He can use construction standards to test the cost of alternative potential designs, and select the one most cost effective. There are two ship research reports which deal with this situation. One has

just been published relative to designing and bidding.' The second is under preparation.' Both contracts are administered by Bath Iron Works Corporation.

- Training can focus on the standard methods and processes that are in actual use, and avoid less satisfactory universal presentations. Teaching everyone to do every job in his field is expensive and difficult. Even where this is attempted, practical examples are needed. When these are drawn from frequently used production methods the worker is able to put his classroom experience immediately to work. The background data used to develop engineered standards includes a description of the best method, correct machine operations, safety, correct material use, and quality requirements. One industrial activity made it a practice to have the people who developed the process, production and scheduling standards present training courses to operators and supervisors to show them how the work should be performed to result in the best possible cost performance.

- Quality Assurance applies tests in varying degrees to "certain production work, depending on the process and the application. The degree of inspection depends on both the sensitivity of the application and the defect rate of the method. For instance, some welds are critical to the safety of the ship and must be 100% x-ray inspected. Some require partial x-ray inspection, while others may be inspected only visually. Some methods are more prone to defects than others. Quality Assurance must recommend work methods of sufficient quality to reduce re-work. When this is done, and planning for a job includes the specification of work methods, then testing methods can be tailored to suit the known characteristics of the work methods. For equal risk, the degree of testing and inspection should depend on the likelihood of defects. Knowing the work methods, and hence the reliability of the results, sampling procedures can be established and used which are often much less expensive for equivalent quality assurance.

. Finance people can use fixed work methods for risk assessment and cost projection, thus reducing the likelihood that they will be surprised by unexpected results. Large sums of money change hands many times during a ship construction project. This Manual is not concerned with the world of high finance, but rather how features of improved production planning can help the financial planners. One of the jobs of financial management is to provide money when needed to pay for material, capital equipment, and manpower. Over the long term, shipyard income must exceed outgo. But there is a perpetual delay

between buying material, equipment, and manpower, and receiving payment for the work that those resources are to serve. To do the best job of using money or making it available. financial planners need accurate estimates of projected needs or surpluses. Reliable planning and scheduling is what production oriented planning is all about.

. Cost Control requires that planned budgets be compared to actual costs and the variance controlled. The planned budget is derived from the work methods, which are now known. Cost estimators have a reliable basis for cost development.

- Bid estimators can use standard methods, even though bidding is done in less detail than eventual planning. The bidding target is narrow; too high will lose the job to someone else, and too low will bring in too little money. When the work differs from contract to contract, the existence of detailed planning methods and performance history can greatly assist bid estimators in arriving at values of time and cost that are close to actual shipyard capabilities. Of course, bid estimators do not have time or resources to analyze each prospective job in the same level of detail that the planners will use later on after the contract is signed. However, standard methods that describe the work as production does it, rather than as designers or planners think it should be done, will help assure that whatever level of detail is required by the estimators will be available, and will provide an accurate basis for bidding new work.

- Manpower planning is easier and more accurate with standard data available. Estimates of workloads by craft and even by skill level can be made with surprising accuracy. Producing needs early allows for compensating action. If a skill shortage is predicted, training might be arranged through a local school. Special work rules may be negotiated with the bargaining agent. Or a different type of work may be put under contract which solves the skill shortage or surplus. Because standard data can be put together to reflect innovations, the consequences of manpower planning can be predicted without the high risk associated with blindly trying the innovation.

- Material and supply are essential ingredients of shipbuilding. About 60% of the cost of a typical U.S. merchant ship goes to buy material. Although planning has little effect on the amount and kind of material needed, economies in procuring and distributing it are certainly worthwhile. The amount of work done on procured material varies widely from shipyard to shipyard. Some

<sup>1</sup> MacMillian, *Improved Design Process* by G.D. Quincy on Task D-2 (Apr. 77).

<sup>2</sup> Glasfeld, *Standard Structural Arrangements* by G. D. Quincy on Task S-11.

shipyards start with raw plates, shapes, and other stock, and manufacture both hull assemblies and outfit components. Other shipyards buy whole blocks, and create ships by assembling large procured units of hull steel and outfit. The essential characteristic of a shipyard is that it builds ships, regardless of the size or complexity of the pieces it procures. Many material items have long lead times, and planning helps to identify when the items are really needed. Ideally, material should never be late because it would then disrupt the production effort, nor should it be too early. Figure 8-2 shows schematically the relations involved. The cost of being late rises more sharply than the cost of being early, but being unnecessarily early is unnecessarily expensive due to warehousing, insurance, and deterioration costs. This leads to the creation of inventories that are large enough to allow for uncertainties. More reliable planning, though, can lead to smaller inventories that will serve the same purpose, because ordering can be determined more accurately. Some shipyards have reduced material storage to very low levels on series production contracts; in some cases, material is lifted directly from the truck or railroad car to the worksite. This technique is probably unreasonable for building in the current U.S. market, but gives an indication of the spread that is possible.

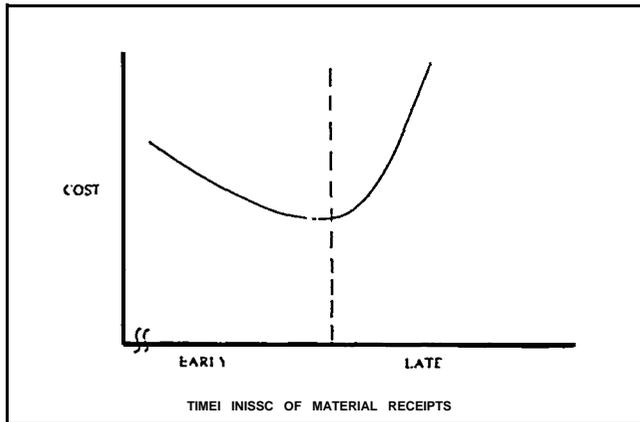


FIGURE 8-2: BOTH EARLY AND LATE MATERIAL RECEIPTS ARE EXPENSIVE.

Methods Improvement is aided by publication and maintenance of a set of standard work methods. Innovation is valuable, even though “new” is not necessarily “better”. Methods engineers must compare new methods with the old, and choose the best for the current situation. Systematic records of techniques provide a visible history of what has gone before. Often new methods were tried and discarded for reasons that only became apparent in actual use. When records also include proposed methods, whether implemented or not, the

methods engineers have a rich, readily accessible history for guidance when restraints on work methods are removed by new technology, relieved by new regulations, or when some new need must be satisfied. Contrary to a popular belief that standards inhibit innovation, standard methods with an update (revision) cycle actually promote an orderly and controlled improvement in methods. Because changes are evaluated before being applied, backward steps can be eliminated. One study of fabrication methods showed that when no control was exercised over methods changes, old methods returned as new methods two years after they had been superseded by new methods. This is change for the sake of change, and is worse than useless because it creates an atmosphere discouraging to even the most dedicated workers. A system of standard methods with controlled revisions allows increasingly improved methods for building a ship to evolve through the revision procedure.

Material scrap vs. recovery can be determined more effectively. Engineered standards can be developed which tell how much material should be used for a given part or product. With this information, the comparison of total product costs is more accurate. Controlling material usage through measurement against the standard prevents reduction in labor costs at the expense of increasing the material expenditure (Figure 8-3). Sometimes an increase in total costs will result when, in an attempt to minimize labor costs, material is wasted. Cuttings are scrapped instead of being used for small parts. Paint brushes are discarded rather than cleaned to save clean up labor costs. Many examples of this problem exist and often the problem is one of not knowing what combination of labor vs. material usage gives minimum total cost to the shipyard.

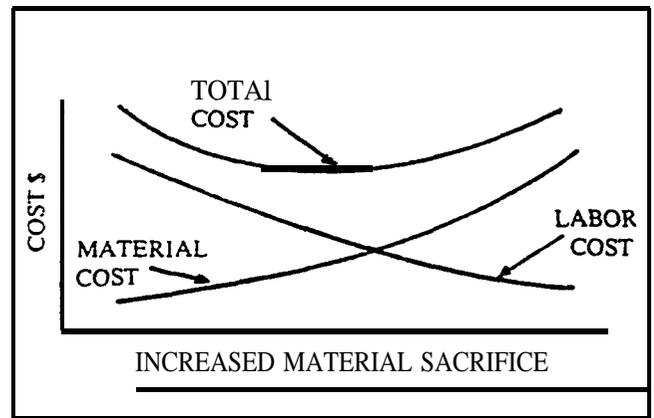


FIGURE 8-3: IMPACT ON TOTAL COST OF MAKING LABOR SAVINGS BY SACRIFICING MATERIAL.

• Make or buy decisions are easier and more satisfactory. Most shipyards do not have a systematic method

for determining all the relative impacts of a make-buy decision. Often one of the weakest areas of the analysis is the cost of the alternatives. For example, determining the in-house "make" costs for an item which has traditionally been a "buy" item is normally difficult or impossible. Since the job was not previously performed, no history exists to describe it. Standard process times plus pre-determined motion data can be used with accuracy to answer the question of what it will cost to manufacture the item in-house.

### 8.3 Predicting the Consequences of Change

Engineered standards can provide answers to questions which start, "What if we change \_\_\_\_\_?". By using the data developed through an engineered standards program, it is possible to analyze with good accuracy the cost of those changes.

Proposed new facilities can be evaluated using standard data. Some facility changes may be simple enough to be classified as jigs and tools. Other facility changes are major and involve costs of millions of dollars. In both cases, the stockholders want the money spent wisely with assurance of a reasonable return on their investment.

Usually jigs allow savings because they make it easier to hold parts in place, or because they permit work to be performed in an easier manner (for example, permitting downhand rather than overhead welding by using a jig which rotates the piece). Most jig designers understand how to analyze the mechanical features that should be incorporated. Often several choices are available depending on how much of the manufacturing process is to be encompassed by each jig. The use of engineered standards to compare the alternative cost and savings of the choices helps to find the optimum payback rate (See Figure 8-4).

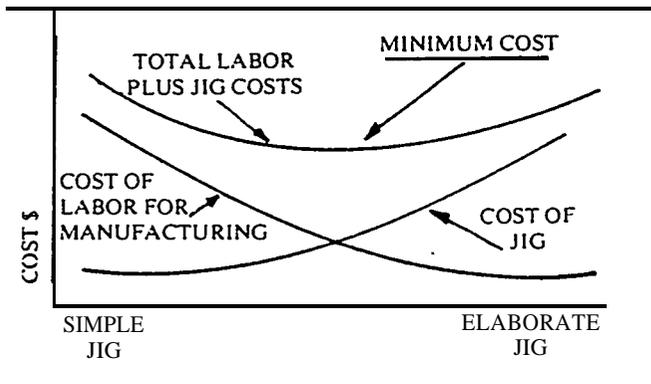


FIGURE 8-4: JIG TYPES AFFECT TOTAL COST. TOTAL COST TO MANUFACTURE A PART MAY BE MINIMIZED BY SELECTING THE CORRECT JIG.

Extensive changes in facilities should draw upon the same data bank of engineered standards. Facility changes reduce costs by substituting new equipment for less efficient equipment or labor, or else new facilities reduce costs by making possible a change in the fundamental process used to construct the ship. The former case is analogous to the jig-fixture example in Figure 8-4. There is a larger sum of money involved and good management would insist on a thorough analysis, but engineered standards (either process or production) can reveal the impact of a facility change on ship, construction costs. In the latter case, no historical basis exists for the comparison, and synthesis of data should be used for the cost comparison.

### 8.4 Supporting an Integrated Cost System

Another beneficial use of engineered standards is to support an integrated or closed cost system. A closed cost system is one of the accounting techniques revealed by the study of other industries. Under this concept, all expenditures are measured, based on the quantity of a product produced. A comparison of the actual cost and the standard cost is made and the resulting variance is charged to the accountable supervisor. Debit hours spent are compared with standard credit hours earned by the work which the crew completed. The ratio of standard earned hours to actual paid hours is called Labor Productivity. This measurement is made continuously and reported frequently. The supervisor who keeps his crew gainfully employed on productive work will earn more hours, and consequently his performance report will be superior to those who do not manage in this fashion. As a result, labor costs will be reduced. Table 8-1 shows Labor Cost Accountability.

NAME OF	SOURCE OF MEASURE OF ACTUAL	SOURCE OF MEASURES OF STANDARD	PERSON/GROUP ACCOUNTABLE
Quantity Used	Stores Issue Slips	Quantity Called for on design drawing	Shop Making Stores Withdrawal
Quantity Ordered	Quantity on Purchase Orders	Quantity Called for on Design Drawing	Buyer of this Item
Unit Price	Vendor Invoice Unit Price	Unit Price Used in Bid Calculation	Buyer of that Item
Bid Item Quantity	Quantity of item used in Bid? Preparation	Quantity called for on Design Drawing	Item Cost Estimator

TABLE 8-1. INTEGRATED COST SYSTEM - ACCOUNTABILITY FOR LABOR COSTS IS CHARGED TO CONTROLLING ORGANIZATIONAL POSITION

Similarly, other performance can be measured. Table 8-2 shows a few of the possibilities in material costs, which have traditionally been difficult to control because of a lack of accountability. The same methodology can be extended to other controllable expenditures. Some standard is established. Actual performance to that standard is determined. The position with control over that expenditure is charged with this goal attainment. When

NAME OF VARIANCE	SOURCE OF MEASUREMENT OF ACTUAL	SOURCE OF MEASUREMENT OF STANDARD	MANAGER ACCOUNTABLE
Labor Productivity	Hours of Time Earned as Used for Payroll	Earned Hours from Budget of Work Completed	First Level Supervisor
Bid Labor Hour Forecast	Labor Hours Budgeted in Work Packages (By WBS Element)	Forecasted Labor Budget Hours Used in Bid (By WBS Element)	Bid Estimator
Labor Productivity Goal Achievement	Actual Total Yard Labor Productivities	Goal Yard Labor Productivity as Forecast for Bid	Yard Manager
Staff Work	Actual Work Goals	Planned Work Goal	Staff Member

TABLE 8-2 INTEGRATED COST SYSTEM-ACCOUNTABILITY FOR MATERIAL COST IS CHARGED TO CONTROLLING ORGANIZATIONAL POSITION

engineered standards are used as the basis for rational evaluation, maximum results are obtained.

An integrated cost system provides a valuable by-product. One of the ways to make a manager nervous is to hold him accountable for an operation which he feels is not under his control. In order to control an operation he must:

- a. Know what is supposed to be done.
- b. Know what is actually being done.
- c. Be able to take corrective action when (b) does not match (a).

Use of an integrated cost system permits a manager to establish and maintain the degree of control that permits him to operate efficiently and scientifically. The system should do three things:

1. Define the task.
2. Define the methods.
2. Define the resources needed.

Engineered standards permit the next step to be performed efficiently: namely, evaluate the results. The manager must analyze the ratio of resources consumed to the standard resources allocated, see if any variances are out of tolerance, and decide what course of action to take in order to improve. If most of the measurement is provided for him by means of engineered standards, he can operate in a "control by exception" mode, and manage efficiently.

### 8.5 An Overview of Usage

This chapter has described many proven and potential uses of standards. When standards are in actual use, when measurements of actual performance are taken for comparison with planned performance, and when deliberate evaluation of performance is made to enable application of corrective actions necessary, then a productivity oriented planning system is in effect.

The more use that engineered standards receive, the better the return on the initial investment that produced them. Telling all shipyard activities that engineered standards exist, and how they can be used to advantage is a key element in realizing potential benefits. A good public relations program on engineered standards is vitally necessary. Many people are apprehensive about using standards because they fear being constrained and regimented. Once the users find that the engineered standards are effective and helpful tools, they will become the strongest supporters of the program. That kind of constructive atmosphere is essential to success, and is created by the users themselves. They are the ones to be convinced.

The next Chapter will discuss the overall cost benefit analysis needed to determine whether continued financial investment toward improvements in planning is worthwhile.

CHAPTER 9

COST BENEFIT ANALYSIS

9.1 The Economic Basis for Planning and Production Control

The emphasis of this Manual has been on improving production efficiency by improving the effectiveness of the planning and production control system. If there is a wide variation between planned and actual performance, the system is not doing much controlling and probably needs improvement. The real question that must be addressed is how much should be invested in improving the system.

The answer to this question derives from the fundamental objective of the planning and production control function itself, which is to reduce the cost and duration of ship construction projects to competitive levels, and then keep them there. How much should be invested, then, depends entirely on the expected return in terms of reduced ship construction costs and durations (Figure 9-1).

discussed in Part III. However, to determine whether or not increasing the planning effort is worthwhile, combined production and planning costs (curve ③ in the Figure) must be considered. As long as the total cost decreases as the amount of planning is increased, then the investment in planning is beneficial.' But when the total cost curve begins to rise, then additional planning is costing the shipyard more than is being recovered by reduced production costs. Theoretically there is an optimum level of planning effort where increases in planning costs are exactly offset by reductions in cost of the productive effort.

While Figure 9-1 illustrates the basic economic principles involved in evaluating both efficiency and effectiveness of a production planning and control system, it does not provide a method for determining directly whether money should be committed to system improvement. There are

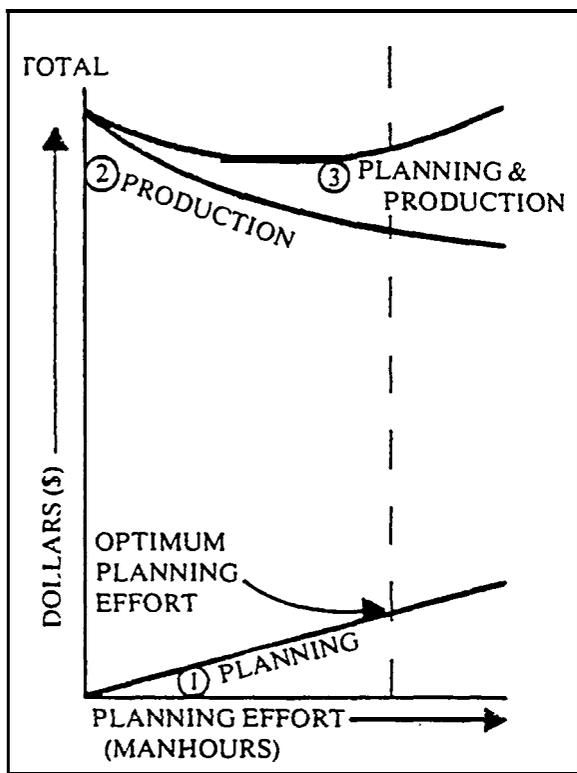


FIGURE 9-1: RELATION BETWEEN PLANNING AND PRODUCTION COST

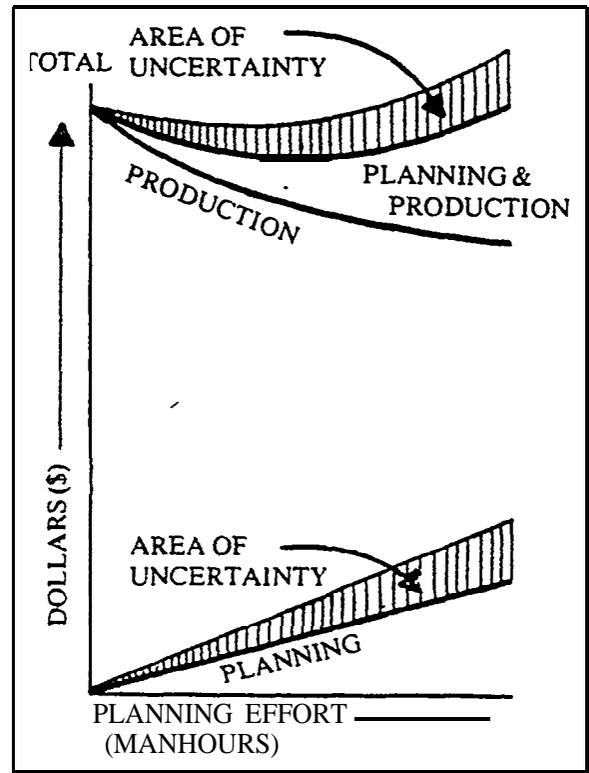


FIGURE 9-2: TYPICAL UNCERTAINTIES OF PLANNING/PRODUCTION COST RELATIONSHIPS

Increasing the planning effort (assuming that good quality is maintained) reduces construction costs for the reasons

two reasons for this. First, the shape of the curves is seldom, if ever, known. Usually the best that can be done is

'Aspects of the National Shipbuilding Research Program Which Impact on Owners, Designers, Regulators and Suppliers, SNAME (Northern California Section), by L. D. Chirillo, R&D Program Manager, Todd Shipyards Corporation, Seattle Division, 10 October 1977.

to obtain values of points on the curves which represent current experience. If adequate historical data were available and there had been significant changes in the level of planning over the period covered by the historical records, then curves for historical costs could be reconstructed. But the requisite data is usually not available; so the typical situation is like that illustrated by Figure 9-2, where the shaded area represents the uncertainty concerning impact of planning effort on total costs.

The second problem with the simplistic view illustrated in Figure 9-1 is that the cost of the planning effort can vary widely depending on the efficiency of the system which implements it. In Figure 9-3 are shown two planning cost lines—the lower one (A) representing an efficient system, the upper (B) an inefficient system. Both systems may be equally effective in terms of controlling production costs. The combined total cost curves, however, are quite different as illustrated by the shaded areas at the top of Figure 9-3. More frequently than not, the inefficient system also does not capture production cost-reduction opportunities, so actual practice is usually worse than illustrated.

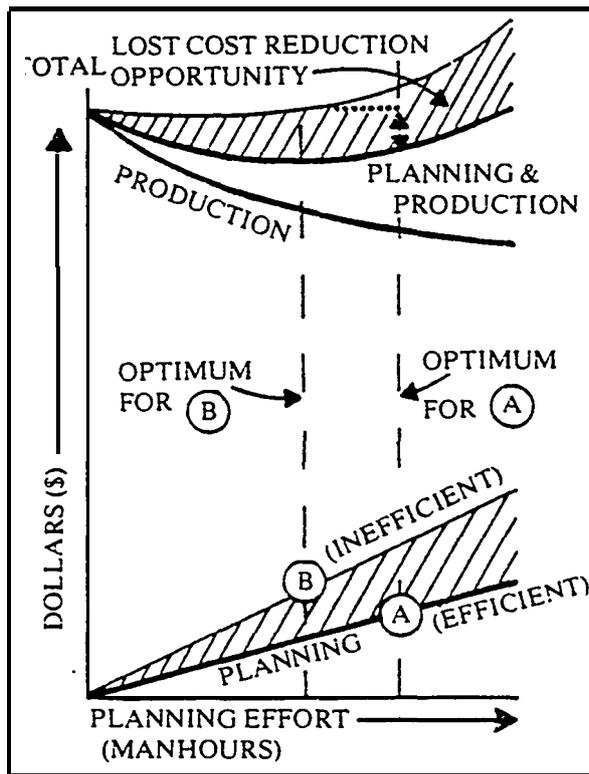


FIGURE 9-3: IMPACT OF SYSTEM EFFICIENCY ON PRODUCTION COST

The point to this discussion is that considerations of efficiency and effectiveness are of paramount importance in achieving a proper balance between the planning and production control system on the one hand and the productive effort it supports on the other. But measuring efficiency and effectiveness is by no means a simple exercise that can be casually addressed. It requires collection and analysis of planning and cost data over a significant period of time. Indeed the same type of effort expended on planning and production control should be expended on monitoring the planning and control effort itself and on continually searching out improvement opportunities.

Three points should be recognized during this discussion. First, production usually works at a steady level of effort—assuming a smooth flow of plans, instructions, material, and an available worksite. Studies have shown this to be true, at least in the general sense, and consistent production performance has been assumed here. This suggests, as the second point, a refusal to recognize the day-to-day influences and difficulties of the real world, which cause disruptions to the orderly progress of work.

Regarding the first two points it might be argued that since disruptions are real, and the level of production effort is not truly constant, a more refined measurement of production performance should be used. If it is, though, visibility of the overall proportions of performance will become unnecessarily clouded. There is simply too much data to contend with if all of it is included. In the overall analysis the small lumps and bumps are smoothed out. Average performance over a whole ship, or over a period of several months, can be dealt with more readily and more objectively. However, care must be taken to avoid too gross a measurement.

The third point is that production improvements do not appear immediately upon establishment of planning improvement. There is a time delay, perhaps as much as a year, between better planning and improved production performance because of that better planning. Curves like those of Figure 9-1 are actually skewed in time, a feature which is not easily illustrated.

The foregoing discussion has not included the finer points such as these three so that the explanation of shipyard performance dynamics given here might be clearer and more easily understood, although admittedly not precisely correct.

\*The required accuracy depends on what is being controlled, with general benchmarks as follows. The leadingman controls to a fraction of a manhour regardless of the size of the work package, and needs daily reports of performance. Shop management needs manhour accuracy of about 3%, and weekly performance reports. Shipyard senior management needs manhour accuracy of about 1%, and monthly performance reports.

## 9.2 The Cost Benefit Study

The first step in identifying improvement opportunities is to determine the actual cost of operating the existing system, which will form the baseline against which the marginal costs associated with changes can be measured. At the same time, current production costs and time must be measured in order to establish the production baseline so that any improvements in production that derive from changes to the system can also be identified.

Having the cost of system changes in one hand and the expected benefits in the other, one can then decide whether the benefits will be sufficient to recover the costs involved in changing the system. The return-on-investment can also be calculated. Expected return from improvements to the system can then be compared with other investment opportunities to pick the best.

Unfortunately, from a number of surveys of U.S. shipyards, it appears that few, if any, have an accurate idea of what their planning and production control system is costing them today. True they may know the cost of ADP\* and they may know how many planners\*\* and production schedulers are on the payroll, but these are not all of the costs by any measure. The time a mechanic spends filling out his time card is part of the cost. If the planning is not complete, then the time a supervisor spends figuring out how to do a job is part of the cost of the system as well. In fact, referring back to Figure 4-1, the only activity not included within the system is accomplishing the production work itself; all other activities fall within the scope of the system and contribute to its cost.

## 9.3 Data Required to Establish Baseline Costs

To establish baseline system costs and related production performance, it is necessary to specify a sample of work packages (perhaps twenty-five to fifty should suffice) for which all planning and production control costs can be collected, as well as actual labor expenditures against budget and performance to schedule for the productive effort covered by the work packages. The work packages should all have the same scope in terms of the kinds of resources to which they are applied; that is, they should all apply to the same shop or the same collection of shops. For example, if fab and panel operations form the continuous series of integrated operations for which single work packages are prepared, then each work package in the sample should cover both fab and panel assembly operations.

The next step involves collecting manhours used in planning and scheduling each work package in the sample.

- Automatic Data Processing
- See Appendix F

Special charge numbers may be needed for each work package against which planners and schedulers record their time. Collecting the other system costs such as:

- Clerical effort to support planning and scheduling,
- Shop planners' and schedulers' time charges,
- Cost to enter charge numbers and hours on mechanics time cards,
- Effort required for supervisors to validate time cards,
- Effort required to log labor charges against work package accounts for project control,
- Time required to analyze labor expenditure and progress information against budgets to identify required corrective measures (if any), etc.,

would probably best be handled by "time-and-motion" studies to obtain standard factors which can be applied to compute totals for these cost elements for each work package in the sample. For example, if time cards were submitted daily and it took one minute (a measured variable) to fill in job-charge numbers and hours worked against these numbers for each mechanic, and if an average work package covered 400 manhours of work, then the total time required to fill out time cards for the work package would be:

- (1)  $400 \text{ MHRS} \div 8 \text{ MHRS/DAY} = 50 \text{ time cards}$
- (2)  $50 \text{ time cards} \times 1 \text{ minute each} = 50 \text{ minutes of mechanic labor}$

Similarly, it should be possible to estimate the number of clerical hours (e.g., typing, filing, reproducing, distributing, etc.) required for each planner hour and each scheduler hour.

Finally, recognizing that the planning and production control system includes a feedback loop (Figure 4-1) for collecting and recording actual expenditure and progress data, baseline system costs would be incomplete if the cost of information feedback recording and analysis were not included. Any use of automatic data processing for these functions should, of course, be identified and incorporated as a separate and distinct element of cost.

Having developed system costs for planning, scheduling, collecting, and evaluating each of the work packages in the sample, then it is necessary to record actual production costs as the work packages are completed by production. For fifty work packages covering fabrication of about 100 tons of steel each, it might take as long as ten to twelve weeks to complete the last one in the sample and obtain the

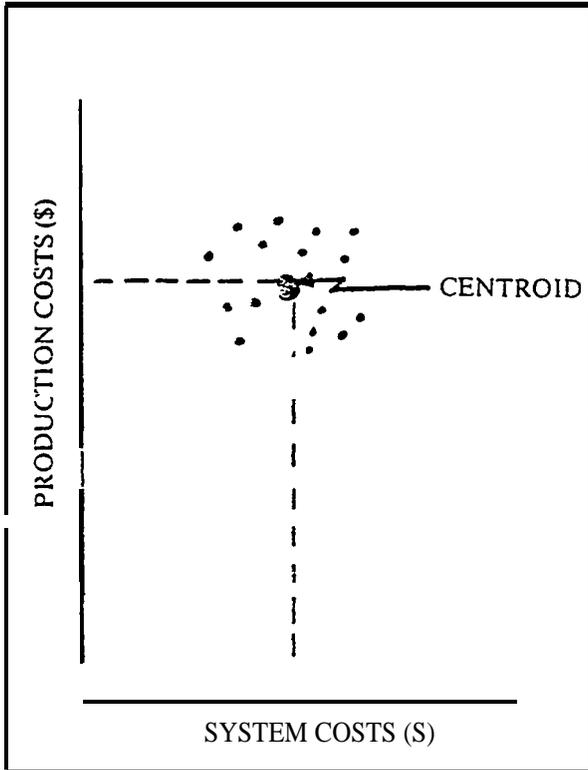


FIGURE 9-4: CORRELATING PLANNING AND PRODUCTION COSTS.

last labor cost data for analysis. Elapsed time for the data collection would thus be ten to twelve weeks plus the time required to plan and schedule the work packages prior to releasing them to production.

Once all the details are determined, a scatter diagram, as in Figure 9-4, is prepared which correlates planning costs with the production labor costs (or machine costs if that were the interest) for each of the fifty work packages in the sample. In this figure the heavy dot is the centroid of the distribution which represents the average work package in the sample. Reading downward from the P&PC system cost for this typical work package can be found. Simply reading across one can find the productive labor costs for the work package.

The discussion of the economic reasons for planning in Section 9.1 (with particular reference to Figures 9-1 and 9-2) argued that there should be an economic balance between production operations and the cost of the system

through which control over production is exercised. In collecting the cost data from the sample of fifty work packages, the first step has been taken toward finding this balance. Three points have in fact been established—one on each of the three as yet unknown cost curves (Figure 9-5)—from which the cost and benefits (if there are any) from improving the planning control system can be measured.

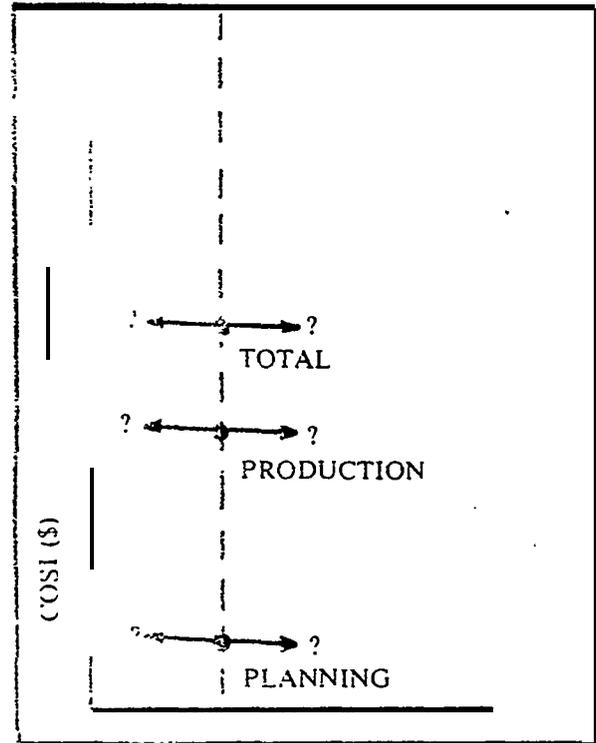


FIGURE 9-5: BASELINE COST DATA

#### 9.4 Analyzing Cost and Benefits of System Changes

Having obtained the baseline cost data, it is now time to try to improve system performance. Chapter 5 reasoned that a good indication of the need for system improvement was the amount of spread in performance for a particular job, because that spread could just as well be thought of as representing planning error. When the spread is significant, tolerance limits can be set which divide the work packages into three groups as described in Chapter 6. New planning rules (standards) can be defined and then used in planning a new set of work packages (Figure 6-9).

At the same time, planning and scheduling labor and associated clerical costs for the new effort must be

•Centroid - the point that may be considered as the center of the scattered data points.

••Planning and Production Control.

•••Planning and scheduling costs will increase because work packages are being analyzed to determine the proper standard to apply: scheduling has more work packages with adjusted durations to load on the shops.

collected. The work packages are released to production; new labor expenditure and performance-to-schedule information is collected; variances are measured to see if the scatter has been reduced. When this has been done, three new points can be entered on the cost charts and an initial indication of trends will become apparent (Figure 9-6). Assuming that this is the first time this exercise has been conducted, if there was considerable scatter in original performance, and if new planning standards were defined carefully, then probably performance would sharpen considerably as illustrated in Figure 9-6.

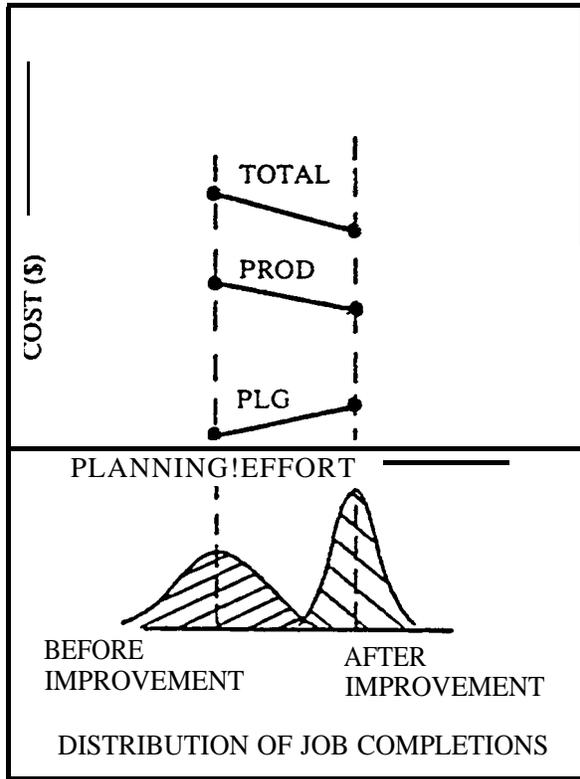


FIGURE 9-6: IMPACT OF IMPROVED P&PC ON COSTS.

To some extent this discussion has been an oversimplification because the true beneficiary of improved performance in the fabrication shop will be the shop which receives the fabricated parts. The successor shop will experience much less disruption to its operations because it will receive its material more closely synchronized to its schedule. So in collecting data to evaluate improvements, performance of the successor shop(s) (e.g., panel) must also be monitored. If performance in the successor shop is unaffected, then from the discussion in Chapter 6 it is clear that there is too much slack in the schedule which should be removed in all future schedules with the attendant savings in ship construction time.

● As found during research conducted under the MARAD Ship Producibility Research Program.

The procedure just outlined might appear overly complex and very expensive to apply. It is not really complex since it is used in planning and production control to measure performance of the planning and control functions themselves (Figure 9-7)-the only difference being that the spread in shop performance is being viewed as a measure of planning/scheduling accuracy instead of shop schedule adherence.

Regarding the collection of costs, exactly the same procedures are used for collecting planner and scheduler labor that were used for collecting shop labor. Again a slight change in perspective is required since now planner and scheduler time is recorded directly against the work packages they plan rather than against indirect or overhead accounts. To do so new charge numbers may be required for planner and scheduler use.

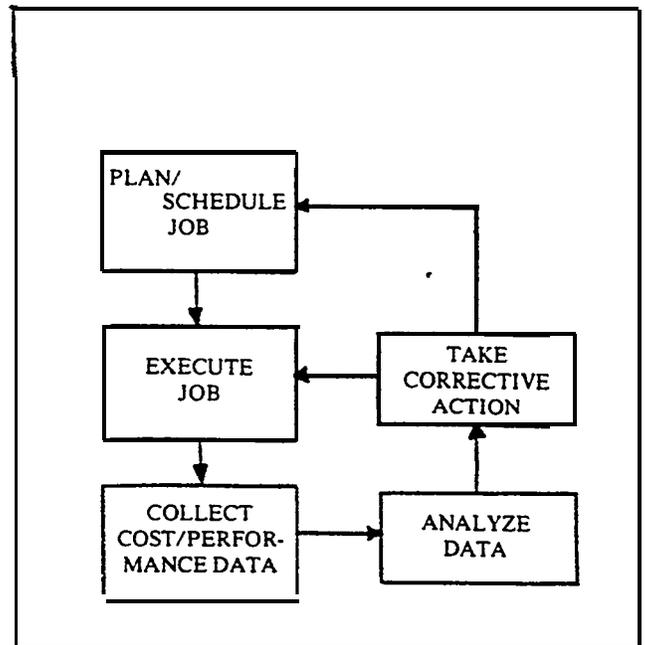


FIGURE 9-7: SELF-REGULATING ASPECTS OF THE PLANNING AND PRODUCTION CONTROL SYSTEM.

Regarding the cost of monitoring the planning and scheduling function, for the typical shipyard this could be accomplished by the equivalent of one person working approximately full time.\* However, monitoring of the planning and scheduling function is the natural responsibility of the supervisory planners and schedulers so no new functions are involved; only now the supervisors have good data to work with.

### 9.5 On the Use of Automatic Data Processing

It is curious that in the entire discussion of the production system there was no need to reference automatic data processing. The reason is quite simple. The logic and principles of planning and production control are quite independent of any particular form of implementation. If emphasis is placed on implementation modes first, then implementation problems may overshadow system objectives. This may result in the objectives being altered to suit implementation needs rather than the other way around as it should be. In other words objectives must be stated clearly first. Only then can implementation alternatives be objectively and impartially evaluated.

There are many different ways in which a system (or systems) could be implemented to achieve objectives. Some will cost more than others; and some will not perform as well as others. For example, one could implement a totally manual system or make modest use of ADP, or use ADP extensively. What is best is really a question of economics, namely, what is the least cost alternative of satisfying system requirements. To answer this question one must consider a number of alternatives, and estimate their respective costs. If the alternatives are designed to satisfy all requirements (i.e., here improvement objectives) equally well, then theoretically the "best" alternative is the one that costs the least.

It has been said time and time again that there is nothing a computer can do that a human can't do; only a computer can do it faster. This is quite true, but there are things that a computer can do simply because of its speed that a human or an organization can't do in a reasonable period of time.

If the Bell System had not automated telephone switching with computers, there would not be enough people on this planet to handle the telephone traffic in the U.S. alone. The problem here is not that a human can't operate a telephone switchboard, but rather that a human can't do it fast enough to keep up with the traffic load. With a human system, delays would become so great that the entire purpose of telephone communications would be defeated.

A similar situation exists with any planning and production control system. As observed earlier, this system should provide closed-loop control so that actual performance can be measured against plans (which include, of course, material, labor, facilities and time budgets) and schedules. It was also observed that more precise control means more detailed work packages which, in turn, demands the collection and processing of greater volumes of finer grained performance and expenditure data.

More detailed planning and collection of larger volumes of data can be handled manually. But as the amount of information collected and processed increases so should the size of the organization grow to collect and process it.

In a typical shipyard, management quite understandably demands good, accurate and timely information to exercise effective control over operations. Equally understandably, management is also reluctant to expand overhead staff. Planning and production control is then confronted with an overload condition. The feedback loop becomes clogged tell-tale signals are delayed; and management is unaware of mounting problems in production.

Ideally management should be forewarned of a problem before it occurs. With delays inherent in the congested feedback loop, not only does detection of a problem lag its occurrence by a significant period of time; but when corrective action is taken, it is made on the basis of obsolescent information.

The computer offers a solution here. Like any labor saving machine there is a certain production volume below which the machine will not pay for itself in terms of reduced labor cost. With production levels above this point, economies of scale can be captured and use of the machine becomes economically attractive. So it is with the computer for planning and production control; however, instead of supplanting direct labor the computer displaces clerical effort.

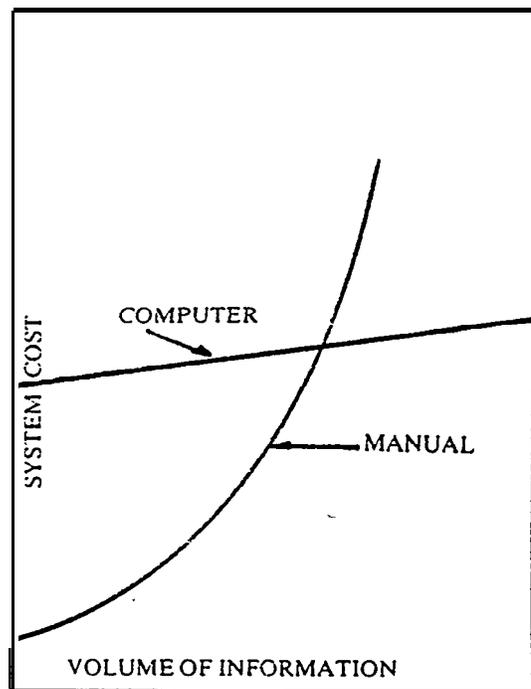


FIGURE 9-8: COST COMPARISON

Figure 9-8 contains two curves—one representing the cost of a fully manual implementation of planning and production control functions; the other for a computer-based system. The horizontal axis represents increasing precision in control which as noted earlier requires the collection and processing of increasing amounts of increasingly detailed information. The vertical axis represents the cost of implementing and operating the two kinds of systems.

The initial cost of introducing a computer-based system is high because of the cost of preparing the computer programs and purchasing the computer hardware. However, the cost rises only slowly thereafter because, if properly designed, changing the volume of information processed involves only incremental adjustments to machine capacity. Program logic need not be changed. Additionally, hardware costs are becoming less and less as the years go by, contrary to labor costs which only go up. The cost of setting up a manual system is small because all that is needed is a bright perceptive person or two, a desk or two, some procedures, pencil and paper, and telephones. But as the size of the group grows to handle

larger information processing loads, then problems of personnel administration begin to set in,\* because working level planners, schedulers and progressmen need supervision. The personnel department must adapt to and thereafter service new personnel categories, etc., etc. Productivity of the working level planners and schedulers goes down because they must now satisfy upward reporting needs.

So we find that the cost of a manual system increases much more rapidly than a computer-based system. Indeed there is a very definite crossover point\*\* where further expansion of the manual system no longer makes sense. The only alternative is to computerize—as the Bell System did in automating the switching function. Indeed, avoiding excessive delays in the feedback loop may depend on automation.

- Appendix H discusses the proper role of a computer in shipyard operations. A brief historical background of computer usage is provided, which reveals the compartmented nature of early usage and lack of a common focus. Present day capabilities are discussed, with suggested functions which can be automated effectively.

\*See Appendix F.

\*\*For example, it has been noted by James J. O'Brien in his *Scheduling Handbook*, McGraw-Hill, 1969, that for PERT/CPM calculations the break even point occurs when the number of activities to be scheduled is two-to-three hundred. Thereafter, processing on a computer becomes cost effective — particularly if updating is to be accomplished more than once a month.

**PRODUCTION ORIENTED**

**PLANNING**

**VOLUME II**

**APPENDICES**

Volume II contains nine appendices covering information closely related to the basic text of the Manual. This information may be helpful as background material for a reader unfamiliar with specific areas or subjects, or to refresh reader understanding of particular aspects of commercial shipbuilding as they are encountered in the text. Each Appendix is referenced at appropriate locations in Volume I.

Throughout the text and appendices, one basic consideration prevails. It is the planning pyramid or knowledge-layer situation commonly encountered in the management of large industrial activities. By this concept, which is analogous to the so-called work breakdown structure, broad considerations at high levels are successively divided into more detailed information at lower levels until the desired degree of refinement is achieved. Generally, four levels are employed in the planning process (as explained in Appendix A) to accommodate construction of a commercial ship. There is activity at each level of the pyramid, as well as between layers in both upward and downward directions until the requirements of all layers are satisfied and the final plan emerges.

A brief summary of the content of each Appendix follows.

- Appendix A - General Shipbuilding Methods

Steel erection and outfitting are the two principal activities in commercial ship construction. Each activity involves application of the four basic resources - manpower, material, facilities, and time - available in a shipyard. Typical methods for integrating these two activities are covered, along with alignment of the resources to best serve production needs.

- Appendix B - Budgeting

Application of the planning pyramid approach to budgeting the four basic resources is discussed, together with how the several levels interact during the iterative planning process.

- Appendix C - Scheduling

The same planning pyramid approach is discussed relative to scheduling the expenditure of resources. Scheduling is usually done from the top level downward to the lower, more detailed levels. A section is included on the idea of bottom-up scheduling where broader-scoped higher-level schedules are developed by aggregating schedules for individual work items.

- Appendix D- Performance Measurement

Certain measurements are necessary for planning and production control. What needs measuring, and why, is discussed along with general measuring considerations.

- Appendix E - Evaluation of Production Performance

Measurements provide a basis for evaluation of performance. The concepts of variance and tolerance are used in the evaluation process for manpower expenditure and schedule compliance.

- Appendix F - Planning Group - Organization and Composition

Several characteristics of a shipyard planning group are discussed, including the location, composition, and authority of those involved. Also covered is the use of planning work force size indicators as an aid to determining the proper number of people for a shipyard planning group.

- Appendix G - Generation of Engineered Standards

The process of developing each type of engineered standard is covered. An illustrated example of engineered standards is included.

- Appendix H - Automatic Data Processing

The historical trend in computer usage is discussed along with guidelines for determining what functions to automate in shipyard operations.

- Appendix I - Basic Statistical Concepts

Several terms and processes involved in statistical analysis are explained as an aid to understanding the descriptive material on the production oriented planning system in Part III of the text.

## APPENDIX A

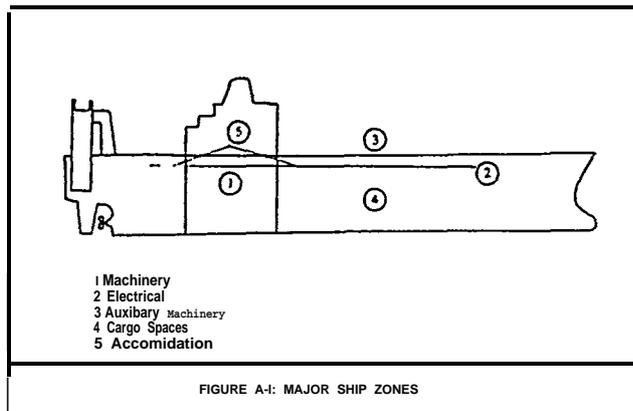
### GENERAL SHIPBUILDING METHODS

There are two basic activities involved in construction of a commercial ship, steel erection and outfitting. At some point these two major efforts come together, depending on the construction methods being employed. The process involves application of the four basic resources that are available in a shipyard: manpower, material, facilities, and **time**.

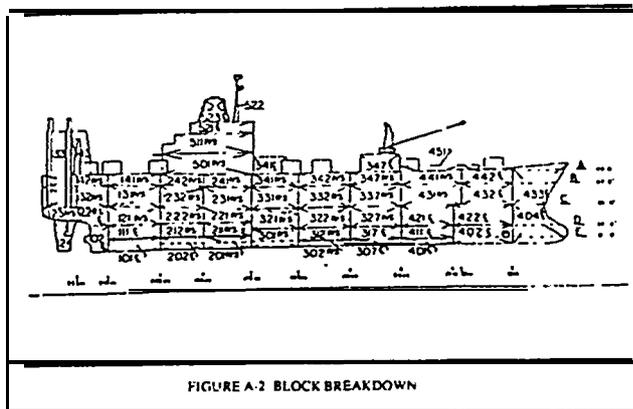
The manner in which all of the above is carried out is unique to each shipyard. The description that follows is typical of the methods used in the industry, and how those methods might be oriented to serve the needs of production.

### A.1 Steel Erection

The entire ship is subdivided into Zones\*, as illustrated by the simplified breakdown of Figure A-1. The Zones are divided into Blocks\*\*, which are usually the largest in-



dividual pieces that will be lifted or moved into place on the hull and later attached to adjacent Blocks. Typically about 100 Blocks are involved, as shown in the breakdown of Figure A-2. The breakdown of Zones into Blocks is done on a geographical basis, with careful consideration of how the Blocks will be fit together or erected on the hull.



Although some of the larger Blocks may, **for convenience**, be moved in two or three parts, the Block is treated as an individual piece from an overall planning standpoint. How each Block is put together depends heavily on the techniques used in a shipyard, and the facilities available. Some Blocks consist of panels, which are assemblies made from plates joined together in a shop area, attached to a supporting framework or to themselves. Some Blocks include the larger equipment foundations as a part of their structure. Some Blocks contain smaller assemblies which are not a part of the Block structurally, but will later support equipment at operating stations, machinery spaces

- A major planning subdivision of the structural portion of a ship.
- Sometimes called units.

and the like, and are best installed as part of the steel fabrication process. Directions for constructing each Block are provided by a set of Operation Sheets which detail the steel fabrication and assembly steps along with identification of the individual material pieces, operations performed on each, assembly sketches, and other information needed to build the Block. A typical Block may require 300 or so individual Operation Sheets to describe construction of that one Block. The sequence and calendar dates for assembling the Blocks on the hull are provided by the Hull Erection Schedule, which also describes any major divisions of the hull itself which may be constructed separately and then moved or floated together for joining into the complete hull.

The entire steel erection process is guided by about 2500 Work Packages. A Work Package contains the drawings, specifications, operation sheets, resource budgets, work sequences, relationship with adjacent effort, material lists and requirements, cost and progress reporting arrangements, and similar information needed to tell the producer what to do and how to do it. A Work Package usually covers work described on a single drawing (or portion of it) to be done by a single trade in a single geographical area of the ship or shop. Typical guidelines for Work Package duration and budget are three months and five hundred manhours, although shorter durations are often preferred, and 200-2000 manhours is not an uncommon range of involvement. A Work Package is usually the lowest element of work tracked by a shipyard production control system. The actual size of a Work Package is a reflection of the degree of control desired by shipyard management. Some shipyards identify Work Packages to a cost accounting system, in order to track costs in comparison to the contract price. Some shipyards identify Work Packages to an overall construction sequence and schedule, in order to track performance against delivery commitments. Some do both. The Work Package provides a reasonably sized, logically issuable, information unit that can direct work and also satisfy reporting and controlling functions.

Although the breakdown is carried out differently, and the individual details have a different appearance, the Work Package concept is used in outfitting just as it is in steel erection, as described in the following paragraphs.

### A.2 Outfitting

The entire ship is broken up into Zones, usually the same Zones as were used for steel erection (Figure A-1), the Zones are broken up into areas of the ship, or into ship systems, or both. The areas may be composed of several Blocks, as in the mid-body of the ship. There may be several areas within a single Block, as in the machinery

spaces. The breakdown is done on a system basis, with attention to the extent of interfaces, or preferably the lack of them, with equipment in adjacent areas. Ventilation would be grouped to minimize connections to ductwork in adjacent areas. Piping systems would be grouped to minimize the installation of couplings to piping in adjacent areas. Electrical systems may be grouped so that cables are run through many Blocks already erected on the hull in order to avoid the need for cable splices or electrical connectors. The breakdown into areas of the ship, or into ship systems, or both, is next divided up into Work Packages as needed to support the outfitting work. The description of Work Package content, duration, and usage given above under steel erection applies equally well to outfitting, including the typical number of work packages involved, about 2500 per ship.

The outfitting breakdown numbers-wise is a little different than with steel erection, even though each segment involves about 2500 Work Packages, for a total per ship of about 5000. The first outfitting breakdown is done at the senior management level and consists of the Master Construction Plan or **Key** Events Listing, either of which contains about 25 items, based on the overall building method and contract commitments. Each of these 25 items is next divided into about 10 pieces, aligned with areas of the ship, or ship systems, or both. This action results in about 250 areas or system pieces that can be handled as outfit units and still preserve the system-type nature of outfitting. Each of these units is then divided into about 10 Work Packages which collectively constitute the 2500 total Work Packages typically encountered in outfit work. The Work Package becomes the smallest breakdown of outfit work. Each Work Package may be supported by Manufacturing or Fabrication Orders that are used to produce the material needed to carry out the work package. These Manufacturing or Fabrication Orders are usually separated from the work package and grouped with similar orders for bulk processing. The total array is illustrated by Figure A-3, which shows a typical break-

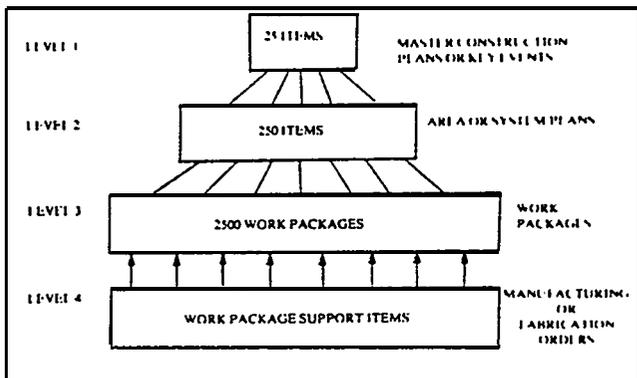


FIGURE A-3: SIMPLIFIED PLANNING PYRAMID

down structure, sometimes referred to as the Planning Pyramid. As the Figure shows, each level can be aligned with a discrete type of outfit planning: Level 1 with major construction events Level 2 with system considerations and areas of the ship, Level 3 with management of individual work packages; and Level 4 with Manufacturing or Fabrication Orders needed to provide material for each work package.

### A.3 Integrated Construction

Outfitting is usually done within windows of time determined by steel planning and actual hull erection. Outfit requires structure for installation. Although the outfit plan is most frequently tailored to fit the steel plan, outfit considerations sometimes must override structural considerations to avoid a "lock-out" by structural closure. Usually, however, U.S. shipyards give precedence to steel planning which sets rigid constraints on how outfit can be accomplished. Foreign shipyards, on the other hand, typically give equal weight to steel and outfit factors in establishing overall construction plans. The Japanese have been successful at doing outfit work on the steel Block before it is moved to the hull, and even on some

TYPE OF OUTFIT	STRUCTURAL WORK PHASES				
	Parts Fab	Panel & Sub	Block Assly	Post Erection Pre-Launch	Post Launch
LARGE DISCRETE (Boilers, M/E Eng)	X	X	X	E	D
MEDIUM DISCRETE (e.g. pumps, TG Sets)	X	D	E	E	D
SMALL DISCRETE (Hand-carry items)	X	D	E	D	E
RIGID DISTRIBUTION Heav (Piping)	X	D	E	D	D
RIGID DISTRIBUTION Light (Vent Duct & Light Pipe)	X	D	E	E	D
FEASIBLE DISTRIBUTION (Cable & Small Pipe)	X	X	D	E	E
ACCOMMODATIONS PAINT	X	X	D	E	E
ROUNDER WORK	X	X	E*	E	E

D = LEAST DIFFICULT  
 E = DIFFICULT  
 X = NOT FEASIBLE  
 \*PRE-ASSEMBLED DECKHOUSES

FIGURE A-4: WINDOWS IN STRUCTURAL WORK WHICH PERMIT INSTALLATION OF OUTFIT ITEMS

subassemblies that later compose the Block\*. Such integration requires very careful planning and precise knowledge of construction status, and is usually developed through several progressively improved attempts.

The required window size and spacing depends on the type of outfit material involved, as illustrated by Figure A-4. Within this general expression, outfit work packages have precedence relationships based on system considerations, access to the work sites, and sometimes test requirements. Access is usually planned to suit installation of piping, then ventilation, then wiring, and finally finish work, although the order is varied according to actual construction progress.

Having discussed the shipyard functions, the next section will look into alignment of available resources to best serve those functions.

#### A.4 Resource Orientation

The key to success in a shipyard is aligning the resources available to do the job so that they best serve production needs. There are obstacles and distractions that may tend to affect the alignment of resources, whether intentionally or unintentionally.

Four basic resources are available for use; Manpower, Material, Facilities, and Time. This section will discuss each resource in very general terms, and how it is aligned to best serve production needs. Other portions of the Manual will probe the alignment possibilities in more detail.

##### •Manpower

The resource most under shipyard control for alignment with actual needs during ship construction is manpower. The vast majority of manpower involved is the productive labor force. How efficiently and well that labor force builds the ship will depend on two things: (a) the ability of each worker to perform his function; and (b) how well the total productive effort fits together to build the ship. The first point depends on individual worker skills and training, and effective supervision of his work. The second point depends on careful and complete planning of the building effort, and accurate communication of that plan to the work force so they can carry it out.

The Work Package tells the producer what he needs for manpower to do the work. In arriving at the manpower allocation numbers for the Work Packages, the planner uses several pieces of information. Early decisions by senior management in contractual matters are supported by a preliminary manpower allocation for the project, and

overall shipyard manloading projections over four or five years. These are broken down into manpower allocations for block erection on the steel side and system construction on the outfitting side, from which predictions of shop manloading are made. A further breakdown produces manpower allocations for the Work Packages, and determination of shop manloading for the project. Fabrication Order manpower allocations then allow calculation of work center manloading.

As the planning process evolves the manpower allocation numbers, it is essential for the planner to remember that the manpower numbers in the Work Packages must be realistic and reliable. These numbers form the basis for sequences, schedules, progress determinations, performance measurements, cost analysis, and other similar items, and so the numbers must be credible. If they are not, they will frustrate the workforce and mislead the management. On the positive side, though, there are several ways the planner can arrive at good manpower numbers that truly reflect what the workforce will use to do the work. Historical data for comparable work can be used reliably, if it is adjusted to suit present conditions. Discussions with the producers can develop information on which to base sound manpower predictions. Best of all, however, is for the planner and the producer to get together and develop engineered standards for repetitive work based on actual measured performance of the process under controlled conditions. Standards provide the planner with accurate numbers based on actual work content, and give the producer confidence that the numbers he will see in the Work Package (and elsewhere) really represent what he will need to do the work.

An example will help to illustrate this point. Usually shop performance on a type of girder fabrication costs \$125 per unit, which includes \$60 per unit production labor cost, 100% overhead, and \$5 per unit profit. A senior manager buys a contract for \$95 per unit for persuasive reasons beyond this particular job. He then directs subtraction of \$5 per unit profit, 100% for overhead, and leaves the residue of \$45 per unit to cover the cost of production labor. When performance on the job does not measure up to the manpower allowance which was based on the money available, the manager blames the production supervisor for poor performance. Indeed, the nature of the work makes it impossible to produce for only 75% of the usual allowance, but this point is difficult to make from the bottom up in a contrary atmosphere.

Contrast this situation with the case where reliable information is available to predict production performance.

\*Also the Japanese have units - which are strictly outfit assemblies (Pipe, pumps, foundations, etc.) that are erected directly on hull. These are similar to packages, or system packages, in the U.S. Shipyards.

Suppose relevant engineered standards are used in developing bid values. The same contract may be bought at the same price of \$95 per unit for the same persuasive reasons. The \$5 per unit profit and 100% for overhead is subtracted, leaving the same unrealistically low residue to pay for production labor. But this time the labor allowance in manhours is set by the engineered standard, and performance is measured against this realistic allowance. The reason for the mismatch between contract price and fabrication cost is kept in view. The same manager does not waste his time blaming the production supervisor for poor performance, and the production supervisor has a totally different outlook on the work. In actual practice, performance under these circumstances has been observed to improve beyond the prediction of the engineered standards, when the true facts of the matter *were* made known to those affected by them.

#### •Material

Management of this resource means getting the necessary material to the work site on time, identified so that the producers can easily recognize how it fits into the Work Package. Steel work requires large quantities of a few types of material. Outfitting requires smaller quantities of many types of material. In either case, material selection by the designers, material specification by the planners, and material procurement by the supply people must be based on the eventual use of the material by production people. Ordering lead times must be consistent with need dates. Material selection must consider shipyard handling and storage capabilities. Specification and procurement must maintain material identification traceable to the ultimate use. Identification must allow the production people to easily associate the material with Work Package instructions so that time is not lost trying to match up the piece with the paper.

Generally, material is delivered to the production people by a separate specialized shipyard group of material suppliers. When properly done, this technique relieves the producers of a major burden and allows them to do more producing. Designers can help by not specifying different types of material for the same or similar applications unless it is truly necessary. This action can avoid costly handling, separation, and identification problems later on, while enabling bulk procurement which usually provides a cost advantage in itself. Despite the best efforts by all those in the material chain some items will not be available when they are needed. There is usually some latitude available to accommodate the problem provided the delay is recognized in time to do something about it. Often production people do not need all of the material at the same time and can work around missing items if they know ahead of time that

such action is necessary. The material suppliers must keep the producers well informed about potential delays, partial shipments, and other situations that may prevent delivery on the scheduled need date. Reliable information may not take the place of missing items, but it can reduce the impact on the production process.

Material delivery problems are common, and lead times for some items are becoming longer than the ship construction period. Planners must stay in tune with current trends, and provide their input for corrective action which, in the extreme case, could mean replanning the rest of the construction work. Short of the extreme, though, there are circumstances where very little progress is possible if production has to struggle along on their own. These are the *ones* where sensitive planners can provide just the right amount of help at just the right time simply by staying in close contact with the needs of production. Information and communication are the vital ingredients of this most necessary function.

#### • Facilities

Occupancy requirements of major facilities like building ways, docks, piers, overall shop capacity, special shop equipment, and similar shipyard loading items are determined as part of senior management contract deliberations. Thereafter some adjustment in particulars may be needed to suit refinements in steel or outfit planning, but the pattern for use of the major shipyard facilities remains reasonably stable during the ship construction period. Building method and overall sequence of major events both play important roles in facilities usage determinations. As planning progresses, shop loading information allows determination of usage for remaining smaller facilities and shop equipment, and also permits refinement of usage and occupancy requirements of major facilities.

Three points about the facilities resource are especially important:

- What the facility can handle in terms of capacity, functional characteristics, and limitations.
- Whether the facility will be available for a particular application at the time it needs to be carried out.
- That any change in facilities will heavily impact two other resources, time and manpower.

The first point is handled in some shipyards by assembling information on each facility into a booklet that is kept current. A page from a typical booklet is reproduced as Figure A-5 to illustrate the sort of information that has been found usable in one shipyard.

APPROVED	NO	
	DID	
	ASSISTED	
<b>MACHINE CAPABILITIES</b>		
<b>HARDINGS PLANT</b>		
<b>Telex #2 - West machine</b>		
Right or left hand burning or marking		
One fifth or one tenth scale template optical director		
Torches - 2 sets with 3.540" rotating heads each, will 15° - 50° bevel contour and square burn up to 3" thick		
	<b>Maximum</b>	<b>Minimum</b>
Length w. photomat on	40' 3"	0"
Width w. photomat on	121"	0"
Thickness	4 1/2"	1/16"
Rail travel	101"	0"
Beam travel	121"	0"
Can flame plane to 10' 5" width		
Can burn one plate on right or left skids		
Can burn one plate on right and one on left simultaneously to produce duplicate pieces (TSU) or mirror images (OSL)		
The two sets of torches on the right or on the left can burn simultaneously to produce duplicate pieces from one plate		
Minimum distance between torches 16' 0"		

FIGURE A-5: PAGE FROM TYPICAL FACILITIES BOOKLET.

The second point depends on facility loading information along with careful attention to maintenance and upkeep of the facility. Maintenance must be sequenced into periods when the facility is not needed for productive support, or else it becomes another obstacle for the producers. Cranes and lifting equipment need periodic maintenance which should be performed on weekends or off-shifts when production does not need them. More major items of maintenance may have a heavy impact on production if they are not factored into the planning process so that disruption is avoided. In some shipyards, facilities maintenance is carried out by a specialized group, like public works or plant engineering, organizationally separated from planning and production. Such an arrangement may add to the problem of coordination and information exchange, but does not diminish the need for careful planning of the maintenance work in order to keep production producing.

The third point must be kept in mind whenever changes to facilities are contemplated, or are unexpectedly encountered during the construction process. Time and manpower are usually tied closely to facilities usage. Both must be examined carefully to identify compensating adjustments needed when facilities usage is altered or impaired.

•Time

Contractual agreements usually set the boundaries for the start of construction and delivery of the ship. Senior management sets the major construction milestones of key events to be met by the shipyard, which establishes the basic time frame and goals to be met by steel and outfit planning. If senior management has accurate information upon which to base their determinations, and business arguments do not cause harmful distortion, then the major construction milestones or key *events* will be realistic and within the capability of the shipyard. Setting minor adjustments aside, what remains for planning is to arrange for steel and outfit work accomplishment within the time frame provided. Since time is an unreplenishable resource that is constantly running out, the task is a challenging one.

As planning proceeds through block erection and system construction, the work package becomes the basis of the plan. Since the work package is the smallest increment of work breakdown, it is also the smallest increment of schedule breakdown. Planning establishes a duration for each work package, and a preferred sequence for accomplishing each work package from a block or system standpoint with careful regard for interfaces between adjacent and related work packages. When calendar dates are applied to the sequence and duration information, the schedule emerges.

Clearly, now, the work package duration should be based on the actual work content involved, and not on such overall rule-of-thumb factors as feet-per-hour, or pounds-per-day. Inaccurate performance estimating at this point can only result in a useless schedule. The observations made a few paragraphs ago under Manpower about the benefits of engineered standards apply equally well right here under Time. Engineered standards provide the best basis for determining credible information about the actual work processes involved; when the schedule is published, production can be confident that it is based on the amount of time they will actually need to accomplish the work. In this situation there is a justifiable reason to expect that the schedule will be followed. Performance measurement and evaluation become sensible, and can provide means for corrections when they are really needed.

Since the schedule is the result of having done the planning, the schedule is the principal guideline for constructing the ship. The application of resources culminates in the schedule even though each resource may have been treated separately for management purposes. Time, then, assumes important proportions in the planning process, and must be oriented so that its biggest consumer, production, can use it efficiently.

## APPENDIX B

### BUDGETING

Four basic resources are available to a shipyard for ship construction purposes: manpower, material, facilities, and time. Budgeting is the process of determining the expenditure of each resource at a prescribed time in predicted amounts. This iterative process is a part of planning, and will be discussed at each of the levels involved. Although there is no firm basis for the number of levels that will produce the best and most efficient planning, the industry generally uses 4 working levels. A fifth level, which could be called Level O, is sometimes introduced to accommodate the determinations made by senior management and marketing personnel very early in the bidding process. Only 4 levels will be discussed here, however. Each resource will be considered separately. Where terminology is different, the information will appear as steel/outfit.

## B. 1 Manpower

Manpower is allocated to accomplish the work, but also to provide for reasonably level loading of the shop or craft involved. When taken together, these two principal requirements of manpower budgeting area little tougher to satisfy. The planning pyramid can accommodate the situation, by treating each requirement both independently and in combination until the most desirable and mutually satisfactory allocation emerges. Manpower is the resource which has the most flexibility in its application; material is generally pre-ordained, as are facilities. Time is somewhat flexible, but there is usually precious little of it with which to work. Manpower, then, becomes the most controllable of the four resources, and therefore, the application of manpower takes on major significance.

### Manpower - Level 1

The initial determination of whether a shipyard will undertake a ship construction project is made by senior management. This process includes consideration of shipyard backlog, capability, workforce and experience, along with the related business aspects of the project. Manpower quickly becomes an essential ingredient in early discussions, and usually takes the form of a preliminary labor estimate and associated expenditure curves, along with similar, but separate, treatment for the critical crafts. When these project requirements are matched against overall shipyard capacity and backlog, the first conclusions about undertaking the project are available. Further breakdown of manpower information by major weight groups of hull, outfit, and machinery may be carried out at this level, and forms the first gross estimates of block/system manpower allocations and shop manloading. The general time span of interest in Level 1 planning is typically three or four years, and the information developed and used is scaled accordingly. It can be seen, then, that manpower information at Level 1 does not have to be precisely correct to a manday, but the large increments of manpower that are discussed at this level should be accurate within 1 or 2 percent\* over the fairly long time frame involved.

### Manpower - Level 2

Planning at Level 2 produces (1) manpower allocations by block/system and (2) shop manloading by craft for the construction project, which typically spans over one year. Further breakdown of manpower information within a block, Figure B-1, or by portions of ship systems with each zone, Figure B-2, forms the first gross estimate of work package manpower allocations, which are determined by dividing up the block/system manpower figures to suit the approximate size and number of work packages in that

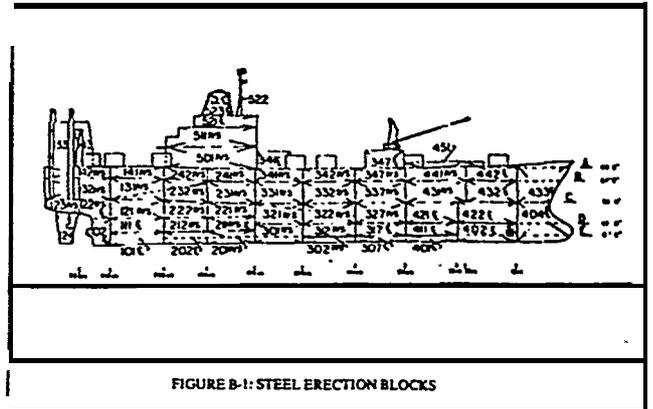


FIGURE B-1: STEEL ERECTION BLOCKS

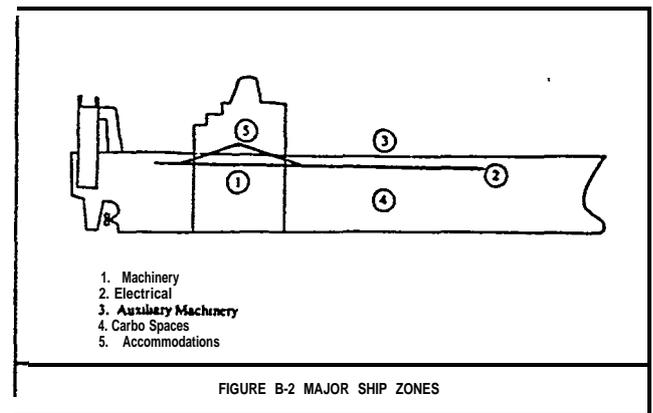


FIGURE B-2 MAJOR SHIP ZONES

area. Shop manloading by craft for the project can be combined with similar information for other projects to aid in sizing the overall shipyard workforce by craft. This is especially important in locations where the labor market is poor, or where personnel in certain crafts require time consuming qualification periods before they can be utilized. Manpower information at Level 2 does need to be precise, and reaches that condition by interplay with Level 3, whose work package manpower information is fed back to Level 2 for compilation into block/system information leading to refinement of Level 2 planning. Accuracy at this level should be about  $\pm 3\%$ .

### Manpower - Level 3

Using the first gross estimate of WP<sup>•</sup> manpower allocations from Level 2, and the actual content of each WP, this level determines the manpower allocation appropriate for each WP, preserving the earlier breakdown by shop, craft, block/system, and zone. Further breakdown of WP manpower information is made to accommodate fabrication/manufacturing orders necessary to support the WP. It is at this point that a refined com-

\*See discussion of accuracy in Appendix E, Page E-4.

<sup>•</sup>ZWork Package.

pilation of manpower requirements for the total project can be made. Problems of congested shops, insufficient craft personnel, crowded work stations, and similar items become apparent at Level 3. Corrective adjustments can be initiated both within this level and through discussions and negotiations with Levels 2 and 4. Accuracy at this level should be about  $\pm 5\%$ .

**Manpower - Level 4**

Manpower allocation for each fabrication/manufacturing order needed to support the WP is carried out at this level using the actual content of the work order along with the breakdown provided by Level 3. Information is then grouped by work center within each shop. This information needs to be precise, and interplay with Level 3 is carried out until the information is sufficiently detailed and reliable that it can be used to track against as a measure of actual performance. Once the manpower allocation to support each WP is established, Level 4 information can be grouped for bulk manufacture, work center manpower scheduling, facilities loading, and similar determinations. Accuracy at this level should be about  $\pm 5\%$ .

**B.2 Material**

Material allocations are based on the engineering details available, and are adjusted as engineering becomes more refined. Allocation has two parts: identification of the needed material; and associating the actual material with the Work Package that will use it. Two general types of material are involved, direct and stock. Direct material is procured and identified for a known usage. Stock material is maintained on an inventory basis, with high and low allowable levels, and an assigned economic ordering quantity. The allowable inventory limits of stock material are reviewed for each project in the shipyard that may use it, because there must be enough stock material on hand to satisfy everyone's needs.

**Material - Level 1**

Senior management attention to material matters is usually restricted to major machinery, long lead time components with known impact on the construction process, and broad categories of steel/outfit material. Planning at Level 1 produces a preliminary material list of these items, along with a procurement plan for obtaining them in the manner, and at the point in time, most suitable to overall construction needs. Contractual arrangement and functional design features for the ship also provide information for Level 2 material planning by block/system and major ship zone, as illustrated schematically by Figure B-3.

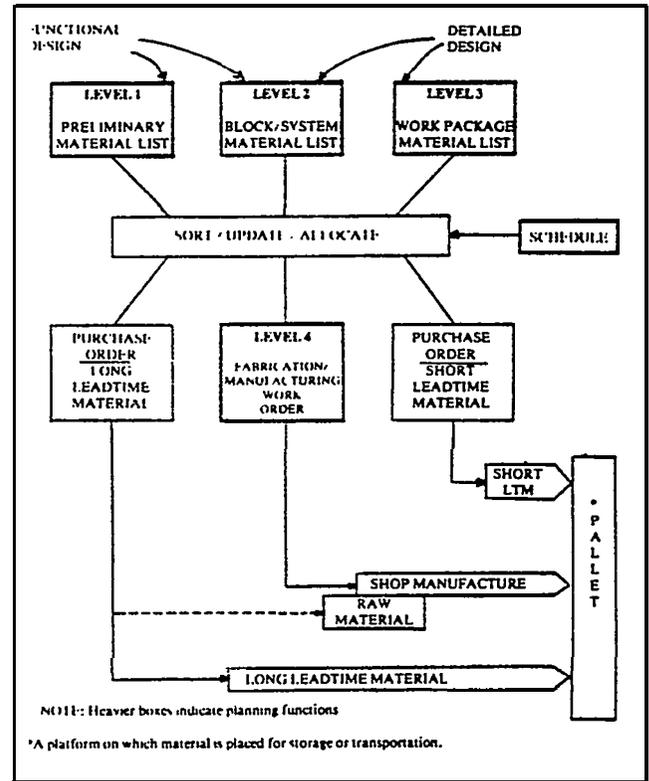


FIGURE B-3: MATERIAL SCHEMATIC

**Material - Level 2**

Planning at Level 2 produces (1) a bulk material list for block erection/material list for each ship system, and (2) a procurement plan for this material, taking into account the procurement decisions made at Level 1. Further breakdown of material information by individual block/portions of ship systems within each zone provides the initial estimate of Work Package material requirements which will be refined later on as Level 3 WP information is accrued.

**Material - Level 3**

Material requirements for each WP are determined at Level 3, and procurement of each piece is established. Some material procurement is determined at Levels 1 and 2, and some material will be fabricated/manufactured as Level 4 support to the WP. Procurement of the remainder will be in response to the Level 3 procurement plan. Material is usually procured by a shipyard group separate from planning (Figure B-3). Level 3 planning, though, must ensure that every piece of material needed for each WP is accounted for, and will be available when needed.

#### **Material - Level 4**

The fabrication/manufacturing work order material list is produced at Level 4, and consists of the material items produced in-house to support each WP. Once the fabrication/manufacturing work orders to support each WP are established, Level 4 information can be grouped for bulk manufacture, facilities loading, manpower leveling, and similar pre-production planning and scheduling determinations with assurance that the material can be physically assembled at the proper time to support accomplishment of each WP.

### **B.3 Facilities**

Facilities allocation is necessary to avoid overloading or overcrowding. Facilities include physical workspace, whether in the shop, block, or ship, as well as the more commonly recognized items of tools and equipment. Often facilities usage is a secondary consideration, but poor facilities planning may cause inefficiency and disruption of the work effort. Shifts in facility usage will directly impact other resources, especially manpower and time, and so must be carefully planned. A facilities booklet, as mentioned in Appendix A, is a big assist to facilities planning and allocation. It can provide the vital reminder of maintenance and upkeep requirements, as well as the more commonly used items like capacity, functional characteristics, and limitations. Good planning will factor all of these items into the process so that disruption is avoided.

#### **Facilities - Level 1**

Occupancy requirements of major facilities, like building ways, docks, piers, and special shop equipment, overall shop capacity, and similar shipyard loading items are determined at Level 1. Thereafter, some adjustment in particulars may be required to suit refinements in planning, but the pattern for use of the major shipyard facilities as produced by Level 1 planning remains reasonably stable during the ship construction period. Building method and overall sequence of major events both play important roles in facilities usage determinations.

#### **Facilities - Level 2**

Block erection/system considerations at Level 2 produce shop loading information with which to refine the usage and occupancy requirements of major facilities, and to define usage of remaining facilities and special shop equipment. Overall shop loading determinations are made to ensure that shop capacity, which is really a facility in this sense, is not exceeded. Later adjustments may be indicated to satisfy level-loading requirements.

#### **Facilities - Level 3**

The principal facilities concern at Level 3 is whether the needs of each WP are accommodated. Facility

requirements that may not have been recognized at other levels must be identified and satisfied through interplay with Level 2. Planning at Level 3 must ensure that the work to accomplish each WP can be carried out when needed, which necessarily involves consideration of all resources. On-site elbow room requirements, as well as special tooling, required for each work package must be accommodated. The facilities aspect, even though it often has a time frame longer than any individual WP, must be examined carefully at the WP level to ensure that it will not be a serious restraint to orderly accomplishment of the work. It is at this point that maintenance and upkeep of the facility must be examined to ensure that the facility will be ready for the planned use.

#### **Facilities - Level 4**

Grouping of fabrication/manufacturing work orders for bulk manufacture, along with manufacturing requirements of individual items produces work center loading information and related facilities usage demands. Planning at Level 4 must ensure that all needs are satisfied, or else take steps to focus the problem at Levels 3 or 2 so that adjustments can be made. One such adjustment is a make/buy determination to ease an overloaded facility or shop if, of course, schedule adjustments cannot accommodate the matter.

### **B.4 Time**

The allocation of time as a resource is done in two related but different ways. The first way is through establishment of durations for accomplishing the work. Usually that work is defined by a Work Package. Planning determines the amount of time, in view of the manpower king applied, that will be required to accomplish the work. The second way that time is allocated is through establishment of the work schedule, which assigns calendar dates to those durations. Again, the work package usually defines the increment of work to be scheduled. Planning may produce the schedule as well as the durations, but more often it is done by a group organizationally separated from planning. In either case, however, the schedule is the eventual result of having done the planning.

#### **Time - Level 1**

Contractual agreements usually set the boundaries for start of construction and delivery of the ship. Within the ship construction period, Level 1 sets the hull erection plan/key events or major milestones to be met by the shipyard, which establishes the basic time frame and goals for construction work. If senior management at Level 1 has accurate information upon which to base their determinations, and business arguments do not distort the picture, then the overall plan will be realistic and within the capability of the shipyard. Setting minor adjustments aside, what remains for planning is to arrange for work accomplishment within the framework of the overall plan.

### **Time - level 2**

Durations for each event on the block erection sequence and plan/outfitting work plan are established at Level 2. Although complete engineering information may not be available for the first iteration, the work can be estimated with sufficient accuracy to warrant manhour budgets on a per-foot or per-item basis. These budgets are then available for use in planning the durations of the block/system events or zone activities, allowing subsequent scheduling of the work. As seen in Appendix C, scheduling is done on the basis of planning inputs and existing schedules for all projects in the shipyard, and must consider the total available manpower, material, facilities, and time with which to satisfy the needs of the entire shipyard.

### **Time - Level 3**

Planning at Level 3 establishes a duration for accomplishing each work package. The work package is the smallest increment of schedule breakdown. The WP is worked to completion once it is started, and the WP duration becomes an increment of the schedule. Planning at Level 3 also establishes the preferred sequence of accomplishing WP'S from a block/system or zone standpoint, with careful regard for the interfaces between adjacent and related WP'S. When tempered by Level 2 durations for block erection/outfitting work plan events, which are made up of several WP's, the sequence of work emerges. Later on, schedulers apply calendar dates to the sequence information; which generates the schedule and meshes this project with the shipyard workload. It is important to recognize here that WP duration should be based on accurate information reflecting the actual work methods involved. Otherwise, accurate performance estimating at this point may affect the usefulness of the schedule.

### **Time- Level 4**

Manufacturing Work Order durations are established at Level 4. This information is used to level-load work centers, facilities, and manpower, and of course to ensure that manufacturing work is completed consistent with the need date for the material.

## **B.5 The Iterative Process**

The first iteration of planning is usually done from Level 1 to Level 2 to Level 3, with each resource being considered independently of the other three. At this point, the whole complement of work packages is identified, blocks/systems are dermed, zones and blocks/systems with the zones are established. This provides a framework within which refinement can take place.

The second iteration unfolds the overlapping requirements of the four resources, and adjusts the planning accordingly. There is much activity going on at each level

across the whole width of the planning pyramid. Those items which will be produced first are planned first. Several iterations within a single level may be required to resolve conflicts and arrive at acceptable solutions. Such intralevel iterations are common, and require no consultation with higher level planning supervision. As the planning at each level becomes more refined and better established, information is exchanged between Levels 3 and 2, mostly, to see whether the latest determinations still agree with earlier resource allocations. The higher level passes its determinations down, and the lower level passes confirming information back up to ensure that one agrees with the other. The presumption in both cases is that the information exchanged is not subject to question by the recipient. In a general sense, of course, it is quite open to question. The Level 3 planner may discover that he lacks sufficient budget to accommodate the work, based on his detailed analysis of the task requirements, and he is forced to request revision to the budget determined at Level 2. Such exchanges between levels are a signal to management that attention may be needed to resolve the matter. Exchanges within the same level, on the other hand, are merely part of the developmental process of arriving at usable planning.

Planning is now sufficiently refined that it can begin to accommodate the problems associated with an industrial undertaking of this size and complexity. The following paragraphs discuss typical situations which affect the plan.

- Items of long lead time material will not be delivered on time, or vendor information upon which to base foundation design will be late arriving, which sets off a chain of late events that impact block erection/systems installation, manpower application in the affected zones, and perhaps special equipment usage. Perturbations of this type are almost a daily occurrence in shipbuilding. Planning must develop the adjustments needed to produce the ship on time anyway. Engineered Standards can aid this planning process.

Since no major U.S. shipyards are currently using engineered work standards but rather rely on historical data for estimating the work content of their projects, estimates of work content (budgets) are often modified as the return costs for earlier portions of the project become available. This is done for work which is similar to past projects, and is needed even more for work which is similar to past projects but was accomplished with different facilities. The assessment of budget requirements is one of the more, important functions of planning where significant advances have been made in other construction industries, but not in shipyards. For example, the

problems associated with reliance on historical data have been emphasized recently by the various contracts for cryogenic ships (LNG's). The shipyards have experienced severe planning and control problems due to the lack of historical planning data for large scale cryogenic work. Planning must be adjusted as improved reliable information becomes available. Engineered Standards can provide such data.

- Feedback from the scheduling and production functions is essential to maintaining the vitality of planning. Any large project is subject to change in external conditions as well as changes in the way the work is actually accomplished compared with the original plan. In order for the plan to remain a useful tool in guiding production throughout the construction period, the plan must be updated to include the effects of these changes. Feedback from accounting is another source of information about the condition of the production process. Planning, along with shipyard management in general, must continuously compare the actual and planned expenditures at various levels to identify potential and actual problems, and to determine the most effective measures for their solution and avoidance in the future. Engineered Standards can provide a norm against which to measure and evaluate performance.
- Responding to constraints is a planning function. Make/buy decisions that affect planning are encountered on a continuing basis and are made by many different shipyard activities. The planner must keep up with these decisions and adjust the plan accordingly. Engineered Standards can assist the planner in making such adjustments.

All of the above situations, and many others that develop as part of the ship construction process, must be accommodated by the plan. Usually three or four reiterations of the total plan will be necessary during the ship construction period of typically two years. Activity within the planning pyramid, both horizontally and vertically, is not an indication of a poorly conceived plan, but rather a reflection of the developmental nature of the iterative planning process.

The functional elements of steel planning and outfit planning are shown in Figures B-4 and B-5, respectively. The previous paragraphs have provided some insight into how the elements are developed and fit together. These two figures should now serve as useful summaries of this information.

### B.6 Review of Budgeting

Resource budgets are determined on the basis of the best available definition of the work content. Ideally this means that higher level budgets (in the sense of the planning pyramid) are determined by summing the budgets of the lower level elements. Since ships are not planned in detail prior to contract signing, or even prior to start of construction, budgets are continually revised as work definition proceeds. At any point in time, the sum of the elemental budgets may not equal the previous budget estimate for that work.

LEVEL I MASTER CONSTRUCTION PLANS OR KEY EVENTS	LEVEL II BLOCK ERECTION PLANS	LEVEL III BLOCK CONSTRUCTION PLANS	LEVEL IV MANUFACTURING OR FABRICATION ORDERS
<b>SHIP/TASK DEFINITION</b>			
-CONTRACT DESIGN AND SPEC -DRAWING LIST -CONSTRUCTION DWGS.	-HULL/STRUCTURAL DESIGN -CLASSIFICATION DWGS & SPECS -DWG. DEVELOPMENT PLAN -STRUCTURAL DWGS.	-WORK PACKAGE DWGS. -OPERATIONS SHEETS	-FAB SKETCHES -OPERATIONS SHEETS
<b>BUILDING METHOD AND SEQUENCE</b>			
<i>[Handwritten notes and diagrams in this section]</i>			
<b>MATERIAL ALLOCATION</b>			
-PRELIM MATERIAL LIST -PROCUREMENT PLAN	-BULK MATERIAL LIST -PROCUREMENT PLAN	-WORK PACKAGE MATERIAL LIST -PROCUREMENT PLAN	-FAB ORDER MATERIAL LIST
<b>MANPOWER ALLOCATION</b>			
PRELIM MAN POWER ALLOCATION -SHIPYARD MANLOADING	-BLOCK ERECTION MANPOWER ALLOCATION -SHOP MANLOADING	WORK PACKAGE MANPOWER ALLOCATION -SHOP MANLOADING	-FAB ORDER MANPOWER ALLOCATION -WORK CENTER MANLOADING
<b>FACILITY ALLOCATION</b>			
FACILITY PLAN -SHIPYARD LOADING	-SHOP LOADING	-SHOP LOADING	-WORK CENTER LOADING
<b>DURATION ALLOCATION</b>			
DURATIONS BETWEEN MILESTONES	-BLOCK ERECTION DURATIONS	-WORK PACKAGE DURATIONS -BLOCK CONSTRUCTION DURATIONS	-FAB ORDER DURATIONS

FIGURE B-4: STEEL PLANNING FUNCTIONAL ELEMENTS

Overall bid values should be accurate for ship construction to be a profitable venture. Bid values, however, are the least accurate of all the estimates of work content because they are based on only gross information about the product. Bid values or the elemental (Work Package) budgets derived by subdividing them are not adequate for the production control function at the Work Package level. Shop performance is not related to bid values, and can be

LEVEL I MASTER CONSTRUCTION PLANS OR KEY EVENTS	LEVEL II AREA OR SYSTEM PLANS	LEVEL III WORK PACKAGES	LEVEL IV MANUFACTURING OR FABRICATION ORDERS
SHIP/TASK DEFINITION			
-CONTRACT DESIGN & SPEC -DRAWING LIST -ARR'GT DRAWINGS	-DETAIL FUNCTIONAL DESIGN -CLASSIFICATION DWGS. & SPECS -DWG. DEVELOPMENT PLAN -SYSTEM DWGS.	-WORKING DESIGN -WORK PACKAGE DRAWINGS	-MANUFACTURING SKETCHES
BUILDING METHOD AND SEQUENCE			
-CONTRACT MILESTONES -PRELIMINARY CONSTRUCTION PLAN	-OUTFITTING WORK PLAN -WORK PACKAGE BREAKDOWN -TEST PLAN -PLAN FOR SUBCONTRACTING	-WORK PACKAGE SCOPES -COMPARTMENT WORK LISTS -TEST MEMOS	-MANUFACTURING WORK ORDERS -MANUFACTURING WORK ORDER ROUTING
MATERIAL ALLOCATION			
PRELIMINARY MATERIAL LIST PROCUREMENT PLAN	-SYSTEM MATERIAL LIST -PROCUREMENT PLAN	-WORK PACKAGE MATERIAL LIST -PROCUREMENT PLAN	-MANUFACTURING WORK ORDER MATERIAL LIST
MANPOWER ALLOCATION			
PRELIMINARY MANPOWER ALLOCATION SHIPYARD MANLOADING	-SYSTEM MANPOWER ALLOCATION -SHOP MANLOADING	-WORK PACKAGE MANPOWER ALLOCATION -SHOP MANLOADING	MANUFACTURING WORK ORDER ALLOCATION WORK CENTER MANLOADING
FACILITY ALLOCATION			
FACILITY PLAN (SHIPYARD) LOADING	SHOP LOADING	SHOP LOADING	WORK CENTER LOADING
DURATION ALLOCATION			
DURATIONS MILESTONES	-OUTFITTING WORK PLAN EVENT DURATIONS	-WORK PACKAGE DURATIONS	-MANUFACTURING WORK ORDER DURATIONS

FIGURE B-5: OUTFIT PLANNING  
FUNCTIONAL ELEMENTS

measured accurately only against budgets resulting from detailed analysis of the content of Work Packages.

The example given in Appendix A (page A-5) illustrates this point. Budgeting has an intense impact on the shipyard, since it is the ruler against which performance is measured. The manner in which budgets are determined takes on added importance if the tendency is toward incrimination for performance mismatches, as that example illustrates. Budgets may become inflated as insulation against punitive measures, which simply misleads the **shipyard and eventually results in an unmanageable mess.** A function as consequential as budgeting deserves the best basis that can be provided and demands careful attention to ensure that realistically accurate determinations are made. As in the earlier example, the actions taken in response to those determinations are not constrained by them, but are enhanced through better knowledge and understanding. A better basis, used extensively in a variety of other U.S. industries, and just beginning to be used in U.S. shipyards, is made up of engineered standards for various types of work. Three categories of engineered standards have been used effectively in shipbuilding; process standards, production standards, and planning standards. These engineered standards offer the most promising hope for substantial improvement in the budgeting process.

## APPENDIX C

### SCHEDULING

Scheduling is an interesting aspect of shipbuilding, perhaps because it has been more an art than a science. In most larger shipyards, scheduling is done by a group organizationally separated from planning. Whereas planning is usually done from the point of view of a single project, scheduling must consider all active projects in the shipyard. Often, scheduling is the point at which these two rather different outlooks converge. Scheduling, generally speaking, is the application of calendar dates to the durations and sequences provided by planning. If the total resources in the shipyard are sufficient to accommodate all of the separately conceived planning demands, and contract dates can be satisfied in the process, scheduling is easy. Most likely, though, all the work will not fit within the contract constraints and adjustments are necessary. Since production will be expected to follow the eventual schedule, and performance will be measured against it, production management is justifiably concerned about keeping the schedule realistic and attainable. If the schedule gets too far afield from the real world, confidence in it will drop and control will diminish, leading eventually to total disorder.

### C.1 Levels of Scheduling

Scheduling is done by levels in much the same manner as planning. It is more of a top-down process with contract dates forming the framework. Herein lies a major dilemma of shipbuilding. Contract dates are set long before the planning is done, and often before the ship design and engineering aspects are defined. These dates, which essentially define the key events listing for the project, are the guidelines for all of the remaining scheduling, planning, and performance effort. They had to be set before the real extent of the contract could be determined. If the project is for a ship similar to those produced by the shipyard in the past, and historical data is used effectively for guidance, then the contract dates should be attainable. If the project involves new technology or a different work mix, however, the possibility of serious misjudgment is very real.

Before looking at how scheduling is carried out, consider the types and purposes of the schedules commonly used in shipbuilding, and the levels at which they are produced.

#### Scheduling - Level 1

- **Key Events Schedule.** This is the basic schedule for the project. It contains about 20 items, like start construction, shift major sections, land main engines, launch, testing period, trials, delivery. It is based on contract commitments, the overall build strategy for the project, and the relationship between this project and other active projects in the shipyard. All other schedules for the projects are expected to conform with the Key Events Schedule.
- **Hull Erection Schedule.** This schedule prescribes the manner in which the blocks and major sections will be landed and connected to form the hull and structure of the ship. This is the principal schedule for steel work. It identifies when each block will be erected, and to what it will be attached. Opportunities for outfitting on the hull before launch are largely determined by this schedule.
- **Systems Schedule.** This is the principal schedule for outfitting work. It defines when and where each major item of outfitting (usually by system) will be accomplished, whether on the hull, on the block before it is erected on the hull, after launch, etc. Outfitting opportunities are identified through use of the Hull Erection Schedule (above) and the Block Assembly Schedules (below), as well as by panel or unit construction schedules (if outfit planning can be refined sufficiently to enable the outfit work to be done at such an early stage of steel construction).

#### Scheduling - Level 2

- **Block Assembly Schedule.** This schedule prescribes when and where the individual blocks are assembled. It must support the Hull Erection Schedule. It is the basis for on-block outfitting work.
- **Sub-System Schedule.** This is an intermediate outfitting schedule that bridges between the larger increments of work on the System schedule and the smaller increments of work on the Outfitting Schedule. It describes outfitting work by shops, and is the basis for the Outfitting Schedule.

#### Scheduling - Level 3

- **Operation Sheets.** Assembly of each Block is prescribed by a set of Operation Sheets, which also cover panels and subassemblies as applicable. These sheets provide work package scheduling for steel. They must support the Block Assembly Schedule. If outfit work is attempted before an individual Block is assembled, these sheets are used to determine opportunities for such early outfitting.
- **Outfitting Schedule.** This schedule assigns calendar accomplishment of outfit work packages. It is based on the Sub-System Schedule and the Outfit Work Plan. It defines outfit work by shop, and is issued perhaps monthly.

#### Scheduling - Level 4

- **Production Schedules.** Further breakdown and support of Level 3 schedules makes up the general category of Production Schedules, which are typically issued once a week, or once every two weeks, to a limited distribution of those who are directly affected by them. These schedules must conform to the higher level schedules from which they are made. Within these higher level constraints, the production schedules can be used to level load shops and facilities, and accommodate actual material deliveries on a daily basis. If the production schedules cannot meet the higher level schedule constraints, little can be done about it except to notify the higher level scheduling people. The rationale is, rather, that production schedules must find a way to get the work done through adjustments (within the constraints), overtime, applying more manpower, etc.

Typical production schedules are:

- Weekly Outfitting Schedule-by shop or work center
- Unit Assembly Schedule- by shop or work center
- Manufacturing/Fabrication Work Order Schedule - by shop or work center

- . Piping Schedule
- . Crane Usage Schedule
- . Transportation Schedule
- . Material Delivery Schedule
- . Testing Schedule

### C.2 Top-Down Scheduling

Figure C-1 illustrates the interrelationships between planning and scheduling, and shows how top-down scheduling is carried out. This method of scheduling is used throughout the shipbuilding industry, domestic and foreign.

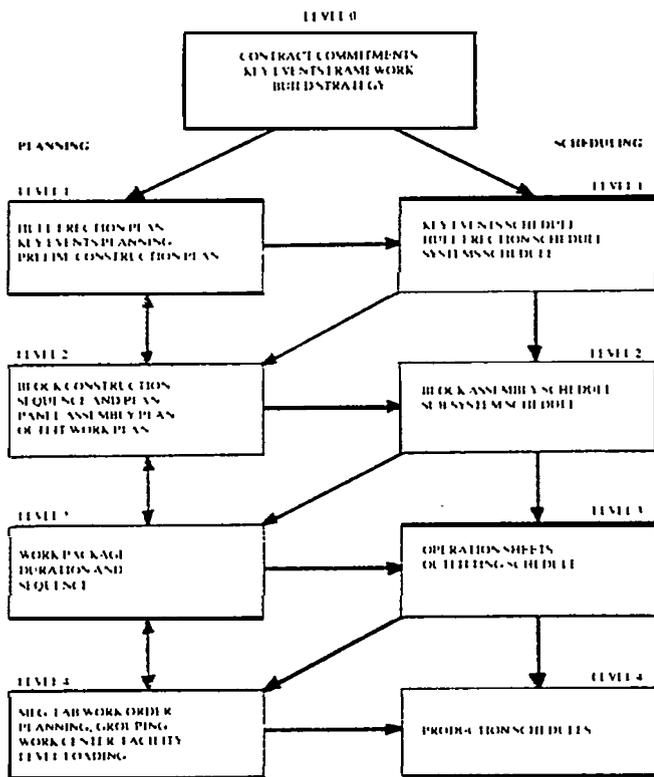


FIGURE C-1 : INTERRELATIONS BETWEEN PLANNING AND SCHEDULING.

A wide variety of schedules are used by a shipyard, some produced by the users themselves. Some schedules cover the entire construction effort and affect everyone. Others contain information of interest only to the user group that produces them. To keep the many schedules from conflicting with each other, even though they may have been produced independently, a system of top-down scheduling is used. This means that a subordinate schedule must conform with the constraints of the parent schedule. A carefully disciplined, one-way system keeps the more detailed but smaller-scoped subordinate schedules in harmony with the rest.

The entire scheduling structure depends, then, on an accurate and realistic Key Events Schedule. Everything must fit within this frame. If it does not, planning must step in and adjust the frame. Scheduling, per se, cannot do anything about it by themselves, as they are constrained to comply with the Key Events Schedule. This interchange between planning and scheduling is carried out during the entire ship construction period in order to keep the pieces inside the frame. Clearly, if the initial Key Events Schedule was off the mark relative to the overall resource capacity of the shipyard, then much planning and scheduling activity is necessary during the construction period to maintain a credible schedule to guide the work. If everything fits on the first try, and no further planning and scheduling activity is needed throughout the construction period, then the initial assessment of shipyard resource capacity was probably too conservative.

For a top-down scheduling system like this to work, there must be latitude available in all of the schedules. It follows, then, that the resulting schedules do not, indeed cannot, reflect the most streamlined and efficient way of doing the work, and the most cost-effective planning possible. Schedule changes are difficult to make, except for those at Level -4 which are really short-term breakdowns and compilations of higher level schedules. The rest of the schedules were issued without any intention of revising them. Maximum effort is needed, with careful planning, to carry out the work according to the lowest level production schedules so that the higher level schedule structure is satisfied. Otherwise, a major scheduling revision will be obligated that may impact other projects in the shipyard along with the one in trouble.

It is usually not necessary, in a typical shipyard, to include all productive effort on some schedule somewhere. It is sufficient to schedule the larger items of work and expect the support effort-like scaffolding, material transfer, lighting, preparation of welding and cutting machines - to follow along. If, however, a particularly tight situation arises where time must be minimized, then more detailed scheduling for that isolated situation may be worthwhile.

The overall capability of the workforce is also germane to scheduling detail. Some shipyards need details scheduled, others do not. The deciding factors are how best to serve production needs. OverScheduling is as bad as underscheduling from the production point of view. A continuing dialogue between schedulers and production people should reveal the optimum mix for a particular shipyard.

Good scheduling depends on several ingredients, some provided by planning and some developed by scheduling, but all of interest to both activities:

Ž Definition of the work involved.

- The level of effort needed to accomplish it.
- Work site considerations, interferences, availability.
- Impact of related resources - drawings, material, manpower, facilities.
- Priority for accomplishment - structure before outfitting, big pipes before small ones, rigid systems before flexible ones, etc.
- Optimum labor force.
- Historical data for similar work.

These and many more pieces of information about the work, and the shipyard capability to do that work, are needed for good scheduling. All of this information must be related to, and carefully meshed with, similar information for all of the other work, active or planned, in the shipyard. A continuing interchange between planning and scheduling is essential.

Good scheduling also demands constant attention and dedication by schedulers. They must know as much about the work as the workers, while keeping the overall perspective needed to project the shipyard capability for doing work in the future under only partially controllable conditions. Planning produces the work procedures, material, sequences, durations, manpower loading, facilities needs, and similar items involved in doing the work on each project. Scheduling considers all of these items for all projects, and establishes when actual work will be done. If these two activities, planning and scheduling, keep the intricate relationships in balance, then a good schedule results.

It is common practice for production management to concur in each schedule before it is published. As mentioned earlier, each schedule is issued with no intention of ever revising it. Should later circumstances require a revision, however, production management concurrence in the revision is commonly obtained before it is issued. This action is necessary because the schedule provides a baseline against which actual production performance will be measured. Prior agreement with the yardstick is certainly appropriate.

It is interesting to consider at this point why top-down scheduling is necessary. It might be possible to schedule from the bottom-up, or perhaps develop a compromise between the two techniques. The immediate complexity of a bottom-up system is a real difficulty. The pieces can be defined, but controlling all of them so that they come together at the proper time and place is a vast undertaking. The next section has been included to provoke a few thoughts in this direction. Although the industry may not be ready for it today, the future may well hold the ability to

handle bottom-up scheduling - on small manageable projects at first, and then on the larger ones,

### C.3 A Look at Bottom-up Scheduling

Scheduling, ultimately, is the application of calendar dates on the durations provided by planning. Since this action will define exactly when the work is done (and the resources are expended), it must consider all active projects in the shipyard (all users of the total complement of resources) and ensure that (1) resources are available when called for, (2) no resources are overloaded or overexpended during any of the work, (3) firm contract boundary dates are satisfied on all projects, and (4) the schedule prescribes the most efficient calendar application of resources, and therefore the lowest expense for the work.

Scheduling is sometimes done by a group organizationally separate from planning. This introduces the first problem, and a formidable one. The planning strategy must be communicated to the scheduler, with all the supporting information on work package size selection, content, manloading, work center level loading, facilities occupancy determinations, timing of actual material needs, process options in case tools and equipment are unavailable or overloaded, and many other considerations used by the planner to arrive at his final product.

The scheduler needs all this information to be sure that the shipyard can accommodate all of the planning demands (which are separately conceived) on all projects within the total resources available in the shipyard, without any discontinuities in the orderly and efficient performance of work. When discontinuities arise, scheduling makes compromises to optimum planning. Soon the carefully conceived plan for a project is in trouble. The scheduler must know the effect of each compromise on the well-being of the shipyard. He must weigh each one against the alternatives available - like delaying another project to suit this one's needs. He must pick the best of the compromise choices available from the standpoint of the least expense to the shipyard. It seems fairly obvious that for him to do these things, he must enjoy the same knowledge of planning, complete with all its nuances, as does the planner.

Suppose for a moment that the scheduler does have all the necessary information. He must handle it, absorb it, keep it sorted out by projects, and retail it accurately. This constitutes the second problem. This time, though, there is help available in the form of computer equipment that can accept, store, sort, and retail all those pieces of information quickly and accurately. The same modest investment in computer equipment can provide much more than automated filing (as discussed in Appendix H).

Now the scheduler must fit all the pieces into the fixed framework. He must manually exercise all the reasonable options or alternatives that are available to see just which combination is the least expensive or has the least impact on the shipyard. If the scheduler has a big piece of paper and a very sharp pencil (with a large eraser) he can try a few alternatives to see which one is the lesser of the evils. Or he can use the computer for assistance. Certain fairly simple precedence relationships can be introduced into the computer program which will exercise all the sensible alternatives in less time than it takes to manually identify the first obstacle. Of course, the computer must be programmed to make certain compromises under certain conditions, or else the possible combinations will be astronomical. Compromises can be altered or manipulated as the circumstances may require, and there is a record of what was conceded in the process. There is visibility of exactly what is going on, which now enables review by those affected. Since the speed with which all this can be done is truly encouraging, there is opportunity for review and adjustment by those who are going to have to produce according to the schedule. Now there is the capability for assessment and adjustment by production management who can see, in advance the ramifications of the schedules and introduce their judgment accordingly. A realistic and practical schedule should emerge in which production can have confidence.

A price must be paid for all this automated advantage. Beyond initial equipment cost, the major requirement is for consistent, high quality input. If the work package can be established as the vehicle for basic information, there are two facets to the problem: (1) ensuring that the work package content truly describes all the work that is involved; and (2) carefully determining the amount of each resource needed to carry out each step of work in the package. The second facet is readily handled with engineered standards, as described in Chapter 7. This leaves the first facet as the real key. Thoughtful assessment of the work in the package, together with feedback from earlier comparable tasks (not necessarily from the same kind of ship) can produce refined contents for the work package, and supply the needed building block. If this can be achieved within reasonable accuracy limits, the rest follows automatically.

That is, except for problem number one - the communications gap between the planner and the scheduler. That gap can be closed by letting the planner do the scheduling. This establishes the rudiments of a totally different, bottom-up scheduling operation. Production can concur in the work package contents - as they do now in at least one U.S. shipyard. Production can influence the trial schedules and concur in the final ones- the latter being common shipyard practice, but without the former there is little latitude for adjustment, and even less time to carry it out.

With this sort of setup, a large amount of information has been captured against which performance can be measured, variances can be determined, adjustments made. The result is vastly improved visibility of what is going on. Exception reports can be used to flag problem areas. From this inexpensive offshoot from the basic body of information needed to produce the schedule originally, it is now possible to reconstruct and evaluate schedule performance.

It seems reasonable that eventually the shipbuilding industry will use bottom-up scheduling as a practical and truly desirable alternative method. The payoff is, predictably, a schedule based on actual ability to produce, rather than a schedule that must contain latitude at all levels and in all places to accommodate essentially unknown subordinate details. A bottom-up schedule could be based on engineered standards and manageable work packages, both of which can be production oriented. Groupings to form higher level schedules could reflect the most desirable and efficient accomplishment of work. Since they would be based on known ability to produce, the schedules would reliably predict what production can actually accomplish. Scheduling would then be more of a science than an art, and as such it would be more predictable and controllable. With a solid base to measure from, a true and accurate picture of shipyard capability could be maintained. Capacity could be adjusted with minimum risk to meet future demands. This is a favorable prospect from "the point of view of management, planning, scheduling, and of course production.

## APPENDIX D

### PERFORMANCE MEASUREMENT

The measurement of resource expenditures is essential to establishing the cost to construct a ship. Additionally, the performance of the shipyard throughout the construction effort can be evaluated by taking measurements of actual resource expenditures and comparing them with the amounts planned to be spent at that point in the construction period. This enables in-process adjustments to be applied to keep the productive effort properly directed.

### **D. 1 Why Measurements Are Necessary**

One November 30th a few years back, the comptroller of a U.S. Shipyard notified corporate headquarters that the profit at the end of the year was estimated at \$10 million. On December 10th, in response to a query from headquarters, the comptroller confirmed the forecast. Again on December 17th, he maintained the number, which pleased the corporate headquarters group because the profit had been low for the past few years.

On December 18th, an accountant brought to the assistant comptroller some figures which had been disturbing him for several days. He had noticed that the work in process account contained an abnormally high number of hours representing about 1/2 million manhours of expenditures which were not included in the profit estimate. On December 21st the comptroller revised the profit estimate to a major loss, which eventually was \$7 million for the year. This surprise caused a great deal of unhappiness at corporate headquarters. The comptroller was dismissed, not for the loss, but because of the surprise. An outside consulting firm was engaged to implement a cost measurement system which would prevent such surprises.

The system implemented by the consultant was simple in concept - break the work down into smaller work packages, budget and schedule these work packages, and then measure the performance on each and every package. Accumulated performance was maintained, and trends were highlighted. The system was satisfactory in concept. The ADP tools which were developed were adequate, but the total results were less than the corporate headquarters had desired. The consulting firm did not solve the problem of how to develop budgets for the work packages. Many years of historical cost records were available, but these were not in the detail needed for the work packages nor did they apply to any new ship types or new shipbuilding methods. If engineered standards had been available, the overall results would have been quite different.

As pointed out above, corporate headquarters insisted on measurement in order to prevent surprises. They wanted to know present cost performance in order to predict future cost performance. Using basic engineered standards, standard costs can be determined for any Part of any ship or for a whole ship, even before the ship is constructed. This ability is of inestimable value to the successful management of a shipyard.

Corporate managers view measurement as a necessary part of the decision making process. A plan implies that a

forecast was made of the conditions to be encountered by the business. Based on this forecast, corporate managers make decisions and plan a course of action which they feel will give the highest probability for successfully meeting their goals. Measurement of actual results compared to planned results is the best way corporate managers have of determining if they will achieve these goals. The better the measuring system, the better chance they have for predicting potential successor failure and for recognizing the need for corrective action early enough to do something about it\*.

Planners need measurement also. Since all major shipyards have more than one ship under construction at one time, the planning of successive ships is constrained by the status of ships already under construction. Build methods are influenced by other shop work, whether planned or already started. Performance to budget and to schedule has a large effect on the planning process.

Measurement is significant to the craftsmen also. He works better if the planner has supplied a logical work plan with reasonable budgets, which come from measurement. Many mechanics are interested in their own job performance and will respond favorably when they are performing measured work. The worker with pride likes to see his efforts recognized. Workers also find that logical measurement frees them from unfair pressures brought about by emotional measurement by a supervisor who judges performance against his own values which are not consistent and do not fairly measure worker effort.

Measurement to a rational standard offers opportunities to a shipyard which provide advantages over an unmeasuring shipyard. Measurement is a vital tool for all levels. The need for measurement increases as:

1. The complexity of the operation increases.
2. The size of the endeavor increases.
3. The time required to complete the work becomes longer.
4. The technology used becomes more sophisticated and more subject to change.
5. The decision-making manager is further removed from the work.

Next, consider what needs to be measured. This will depend on the five points above, and may seem difficult to some levels of the organization.

### **D.2 What Needs Measuring**

During construction of a commercial ship, two general

● Although this addresses the need for measurement from the point of view of top management, measurement is equally important at all levels of management and control.

types of situations exist. The first type exists for about the first half of the construction period, when work is managed by the amount of resources applied. The other type, for about the last half of the construction period, is where work is managed by the attainment of progress goals or key events.

Early in the construction period, few guide posts are available against which to measure progress. Work is spread all around the shipyard, and consists of many small, individual work items that have not yet developed into large, measurable accomplishments. During this period, performance is measured by the amount of resources being applied as compared to the amount of resources that should be applied. The principal resource involved is manpower. It follows, then, that this period is one where manpower is managed.

Somewhere near the middle of the construction period, when the hull is taking shape and major pieces are being landed and assembled, the situation shifts to where actual progress can be measured through attainment of major construction milestones or key events. Now there are plenty of guide posts against which to measure progress. Work is centered on the hull itself, and physical accomplishments can be seen and interpreted. This period is one, then, where progress is managed.

Throughout the construction period, the measurement of resource expenditures and progress attainments is carried out to form the basis for management action. The specific expenditures needing measurement are:

- Manpower
- Material
- Facilities
- Time

Since progress attainments are really a measure of how well the schedule is followed relative to completion of major milestones or key events, attainments are reflected in how much time was expended to reach those goals. Measuring resource expenditures, then, can provide the needed visibility of how things are going. All of the measurements are needed throughout the construction period, although some are more useful than others at certain stages. For example, during early steel erection the manpower measurement is the most important, followed closely by material. Facilities and time take a back seat. Later on during final outfitting, time is the predominant measurement. Analysis of the whole construction period, though, which is needed for long-term improvements and for bidding on subsequent contracts, depends on expenditure measurements of all resources for the entire ship.

The amount of resources needed to do the work is allocated to an individual work package by means of the work package content and the schedule. The actual consumption of each resource needs to be measured in terms that can be related to the original allocation. Two major points apply to the measuring terms or units. First, the initial allocation of the resource was probably based on historical data of some type. This new resource expenditure may be the basis for allocation the next time around. If a continuing basis is used, such as an engineered standard, then this new expenditure may help to refine the data already accrued. Regardless, the measurement needs to be in terms easily applied to the next usage of the data. Second, the expenditure measurement may form the basis of performance evaluation while the work is still being accomplished. If a mid-course correction is being considered, actual expenditure data is needed that can be compared quickly and easily with the allocation. The observation frequency of the actual data may provide some insight into whether the measured performance is a reflection of a well-defined trend which presumably will continue unless acted upon, or whether the measured performance is based on one sighting which could tend to distort the true facts of the matter. The real world is somewhere between these two extremes, and resource expenditure measurements must be governed accordingly. Further, after a course correction is made, measurements are needed to determine whether the desired effect was achieved.

Generally speaking, then, what needs to be measured is everything that was allocated. Measurements need to be in the same terms or units as the original allocation. Measurements need to be taken in such a way that the data can be compared with the original allocation, that is, the same quantity of work is involved in both cases. Fortunately obtaining each piece of information is fairly simple. The difficult part is collecting, sorting, aligning, and interpreting the tremendous number of pieces of information involved. With present day computer equipment, the difficulty is greatly diminished, and the process is readily performed.

Key concepts involved in performance measurement are defined as follows:

Performance is the amount of resources used to accomplish a specific unit of work.

Planned performance is the amount of resources assumed by the plans and schedules, whether manpower budget, material allocation, facility occupancy, or schedule dates.

- Actual performance is the amount of resources actually expended to accomplish production work.
  - Variance is the difference between actual and planned performance.
- Ž Tolerance is the range of acceptable variances, that is, the range of variances which will not pose a problem to the overall project.

Figure D-1 shows these graphically.

Variance is the “control signal” that motivates investigation of production problems and corrective actions. Neither the planned nor the actual performance has such meaning by itself. As a result, an error in either leads to a

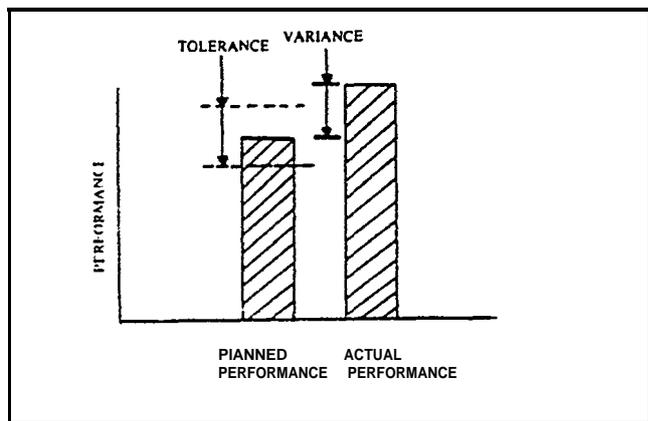


FIGURE D-1: VARIANCE IS THE DIFFERENCE BETWEEN PLANNED AND ACTUAL PERFORMANCE; TOLERANCE IS THE ACCEPTABLE RANGE OF VARIANCES.

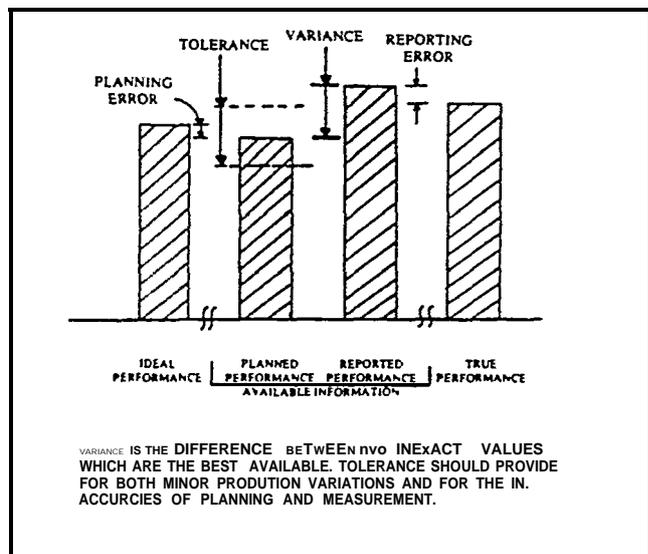


FIGURE D-2: VARIANCE AND TOLERANCE

false indication of variance. Planned values that are too high or too low can cause other than true variance. Reported performance that is higher or lower than the actual case can cause other than true variance. Ideally variance compares plans which accurately reflect the work content with true actual expenditures. In practice, however, variance compares plans which only estimate work content with measurements of performance which are not exact. This is shown in Figure D-2. In order to provide an accurate indication of project status, both planning and measurement errors must be controlled.

### D.3 Measurement of Manpower Expenditures

Manpower expenditures must be measured at the level of the individual worker and individual work package. Manpower budgets are set in man-hours or man-days for some portion of the work. That portion may be the whole ship, a steel zone or outfit group, a steel block or outfit system, or a work package. Manpower budgets are issued to production by work package. Performance should therefore be measured at the work package level. Work package performances can be summed up to reflect performance of larger portions of the work, but if data is collected at those larger portions, the work package performances can never be accurately reconstructed. In U.S. shipyards, the smallest group of production labor is the individual, although in some countries (i.e., Japan) the smallest group is a crew of six to eight workers, who always work together. In that case, a group time card might be in order, with provision for reporting individual absences, etc. However, in U.S. shipyards each individual works independently, and his time expenditure must be collected individually.

Manpower expenditures are recorded for two reasons: to pay the individual and to assign the charge to the work package. Although these appear to be two sides of the same coin, their focus is somewhat different. The individual must be paid for his work, regardless of what work package is assigned that charge and the work package must be charged for work done, regardless of who did it. Payroll is only interested in whether or not an individual was legitimately employed, whereas work package performance evaluation must know exactly which work package was being worked. The basic data for these two functions is different. Pay is based on attendance, as verified by the time clock stamps. Expenditures against a work package are based on the division of the worker's time, as described by this annotation on the time card.

By far the most common means of manpower reporting in U.S. shipyards is with individual daily time cards, such as Figure D-3. Each worker receives a time card each day, on which someone records the time spent on each work

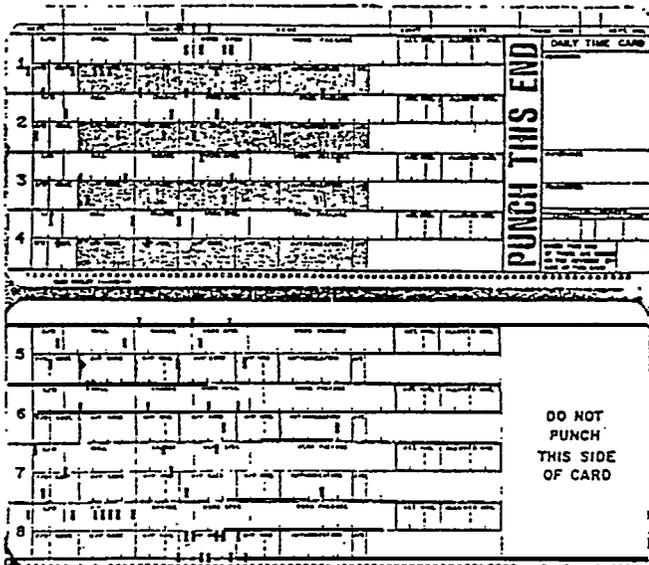


FIGURE D-3: TYPICAL TIME CARD

package he worked on during the day. The cards are collected and processed each day, and sometimes after each shift.

The time card may be filled out by the craftsman, his supervisor, or a shop clerk. Of these, probably the best option is to have the individual fill out his own time card. The individual is the lowest functional level capable of doing the job of reporting, and is therefore the best choice. He is in contact with his supervisor, who should review the card for accuracy, and should sign it to verify attendance. The supervisor may also make note of the daily charges of his people to later check the values reported by the system and thereby provide a periodic audit of it.

Reporting done by other than the individual, for instance by the supervisor or by a time clerk, is more susceptible to errors of communication and intent. The worker knows what he is working on and seldom worries about the budget. The supervisor, and especially the clerk, is more removed from the work and more likely to be swayed by the budget. Whoever makes the report, however, must be made aware of the importance to the shipyard of accurate time reporting. Charging over-budget work to a slack work package is a human tendency, especially where performance is closely monitored to the individual work packages rather than being spread across several. Two other situations do not encourage accurate charging: where good performance is not recognized at least as loudly as poor performance is criticized; and where the planned values are based on estimates that vary significantly from work package to work package. Where planned values vary widely, it is easy to rationalize cross-

charging, because "it doesn't matter anyway the same effort results in good, poor, or average variances depending on the quality of the planning." Planned values based on engineered standards can provide reliable budgets so that variances reflect production effort rather than the vagaries of the planning against which production effort is judged.

A time card system requires management of the time cards themselves. Some shipyards prepare a separate time card each day for each man, rack the cards before each shift, and collect them from the individual slots after each shift. While this makes sense in small business, the sheer number of time cards to be processed at any large shipyard makes this method unnecessarily expensive. As an alternative, each man can have a supply of time cards, prepunched with his name and shipyard identification, but not with the date. A card near the end of the supply carries a special code to request additional cards. At start of work, he takes a card and punches in the time clock stamps both time and date. At shift end, he punches out and deposits the card in a common box. A quick machine sort provides any needed degree of order and preview without requiring manual pickup of several thousand individual cards.

The next step could be to eliminate time cards altogether, and collect the data with a computerized system. At least two U.S. shipyards have implemented some form of computer-based time collection. In each case the individual craftsman is issued a machine readable identification badge. This serves all the usual purposes of the ID badge, but in addition is designed so that some information such as employee number and name can be read by machine. With such a system the payroll and performance measurement functions are clearly divided. Attendance is recorded by the man's inserting his badge into a reader located either at the gate or in the general vicinity of his work station (preferably the latter). The machine reads the identification and records it, together with the applicable time and special code, if any (for sick time, personal pass outs, etc.). Recording manpower expenditures against work packages is the responsibility of the first level supervisor. To do so he goes to a terminal, inserts his badge, and then enters the work packages and hours worked for each of his men. If, by a given time, he hasn't entered charges for any of his workers that have punched in that day, the computer makes a special request that he do so. This system requires the supervisor instead of the workman to record the time charges, but this was chosen as preferable to requiring the worker and supervisor to get together at a terminal every day. Individual logging has been done in a job shop environment, but as yet the cost of the numbers and quality of terminals needed to adequately serve a shipyard without disruption is prohibitive.

An essential element of either manual or machine systems is distribution of the results of the measurement process. The collected information is reported to the various management levels at predetermined time intervals and degrees of summarization. Higher level reporting involves evaluation as well as measurement. The lowest level of distribution is daily reports to the first level supervisors of expenditures for each of his men and work packages. Those reports are primarily used to verify the previous day's charges, although the supervisors also use them to track and evaluate their own progress toward completion.

Usually wages represent the largest controlled variable" in the construction of a ship. It is convenient to classify labor expenditures in three categories: direct, indirect, and overhead. The category selected depends on whether the work accomplished has a direct impact on one ship, or whether the benefits are distributed to several ships or contracts. See Figure D-4. The counting of manhours paid is a simple but voluminous job handled by shipyard accountants. The hours are charged to different accounts usually by distribution recorded on the time cards or by separate time sheets.

WORK IMPACT AREA	PAYROLL CLASSIFICATION	METHOD OF COLLECTING TIME DISTRIBUTION	TYPE OF STANDARD USED FOR VARIOUS COMPARISONS	AUDITING CONTROL
EFFORT DIRECTLY AFFECTS ONE SHIP	DIRECT	CHARGE TIME TO JOB NUMBER ON TIME CARD	WORK PACKAGE BUDGET BASED ON WORK CONTENT AND ENGINEERED STANDARDS	RECONCILE WITH PAYROLL DISBURSEMENTS
SEVERAL SHIPS OR CONTRACTS AFFECTED	INDIRECT	CHARGE TIME TO ACCOUNTS WHICH ARE APPROPRIATE	EARNED HOURS BASED ON DIRECT CONTRIBUTION TO SHIP COMPLETION	RECONCILE WITH PAYROLL DISBURSEMENTS
GENERAL	OVERHEAD	PREDETERMINE AND INCLUDE IN OVERHEAD RATE	BUDGETS PREPARED ANNUALLY AND REVISED SEMI ANNUALLY	RECONCILE WITH PAYROLL DISBURSEMENTS

FIGURE D-4: CLASSIFICATION AND CONTROL OF LABOR CHARGES

In the most elemental measuring of labor efforts, the actual expenditure of hours is compared to the planned expenditure of hours. Planning usually develops "S" curves which show the planned and actual accumulated hours. See Figure D-5. These curves are sometimes drawn for the individual crafts as well as for the whole shipyard.

Usually they apply to direct labor only. Note that the only thing that this method measures is whether the number of manhours paid is the same as the number of manhours planned. It does not offer any measure of how much work was accomplished.

#### D.4 Measurement of Material Usage

Material expenditures fall into two distinct categories. The first is material usage, or how many pieces of an item were used. The second is the material price per unit.

Material usage is relatively easy to measure. Items drawn from the storeroom are charged to the contract and this quantity is recorded. However, the trick is in know how many should have been used. This "standard" quantity is usually taken as the quantity specified on the engineering drawings.

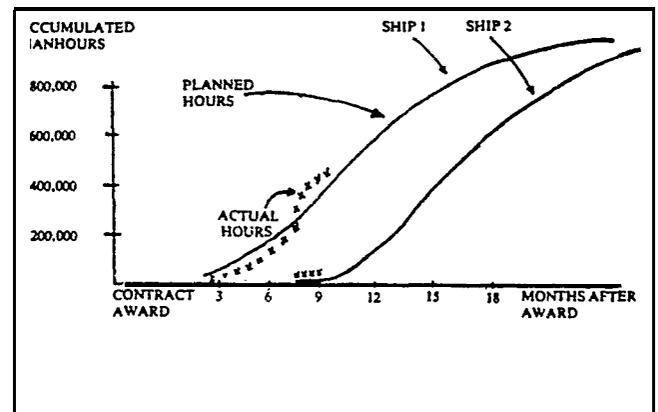


FIGURE D-5: MEASURING MANHOUR EXPENDITURE PERFORMANCE USING CUMULATIVE MANHOUR-CURVES

The unit price variance is the difference between the invoiced price and the standard price. The standard price is carried in the shipyard standard parts catalog, and represents the amount that the item should cost. This standard price is used when making make-buy decisions and when making design trade-off cost analyses. This unit price is also used by the bid preparation people when they are preparing cost estimates.

There are some difficulties in the standard unit and the standard cost figures, especially with a changing inflation rate. The load on the engineering people is increased in that they now have a budgeting obligation with respect to unit quantities. It must be emphasized, though, that imperfect control is better than no control. Variances are indicators that things are different than planned, and therefore

● A controlled variable is one whose magnitude can be influenced or altered to some extent by management decisions, e.g., the amount of oil used. An uncontrolled variable is one beyond the control of management, e.g., the tax rates, or the OPEC price of oil.

should be examined for cause if outside of tolerance. Those variances which remain within tolerance are not in trouble, but all variances need to be examined, if only to guide long-term improvements.

There are several types of variances used in the material area which will be described here for general information. They are not used in this Manual, but are included to complete the terminology typically encountered in dealing with material. These variances are illustrated in Figure D-6 and are defined below.

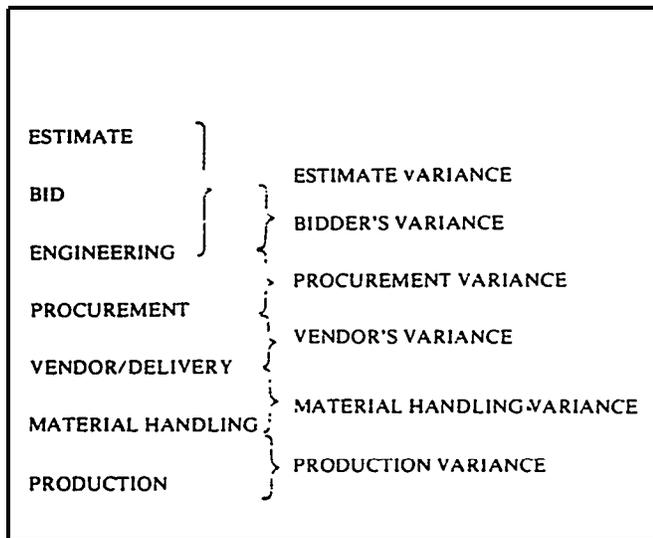


FIGURE D-6: MATERIAL IS SUBJECT TO MANY VARIANCES ON THE PATH FROM ESTIMATE TO PRODUCTION

**Estimate variance** is the difference between estimated material quantity and prices and those developed during detailed engineering analysis. This variance arises because of the lack of definition of the ship when the contract is signed. Engineered standards help to control estimating values.

**Bidder's variance** is the difference between the bid and engineered quantities and prices. This will differ from the estimator's variance to the extent that the bid differs from the estimate. The bidder's variance is the difference between what money is available in the contract price and what will be needed barring other problems to build the ship.

**Procurement variance** is the difference between what Engineering says is needed and what Procurement actually buys. In quantity, Procurement may often buy high to take advantage of bulk orders or price breaks at even lot sizes. This will show up as variance in quantity, but should reduce the total cost of the material. Variance in price will

occur as the buyers are able, or are not able, to better the prices assumed in the bid.

**Vendor's variance** is the difference between what the buyer ordered and what was actually received. The differences are not limited to quantity and price, although these are the most glaring. A vendor's deliveries are his truest representatives, and a shipyard should use all characteristics when choosing among offerors. Delivery compliance, received condition, cooperation in expediting, marking of boxes, and correct addressing of shipments with internal shipyard addresses all affect in some measure the shipyard cost of doing business. While these may not be exactly converted into dollar values, they are still more than adequate for choosing among bidders. Other things being equal, simply advising the vendors of the fact that the shipyard is monitoring this sort of performance is usually sufficient to raise their level of performance. Scoring of performance is easily added to the receipt inspection checklist, and an annual or semi-annual compilation of these reports and ranking of vendors can be prepared, for both internal and vendor distribution. Between this mild feedback and actual litigation is a range of options for dealing with vendor problems, such as removing any vendor with delinquent shipments from consideration in a current procurement until the material is received, possibly with an additional penalty period for chronic offenders.

**Material Handling variance** arises from loss, damage, or deterioration of material between receipt and issue to the production shop. As above, the variance cannot be paid for by the offending shop, but all can be made aware of trouble spots simply by keeping track of what happens and reviewing that record for trends and patterns.

**Production variance** is that loss or damage occurring after material is delivered to Production for assembly or installation and until the ship (or part thereof) is delivered. Usual contributors are outright loss as well as damage due to other trades, or work not related to the item (paint spills, weld splatter dropped loads) and damage due to mistakes having to do with the material (mis-machining, mis-painting, failure during test, excluding vendor liability, of course).

### D.5 Measurement of Facilities Usage

Facilities include machinery (machines, tools, trucks, and cranes), buildings, berths, open space for storage, and similar tangible items which contribute to the ship construction process. Measuring facilities usage involves three considerations:

First - How long the facility was in use.

second - How effectively it was used. (Whether work stayed in the facility too long.)

Third - Whether the facility was used for its intended purpose.

How much of the potential capacity of the facility was utilized is of interest for diverse reasons:

- (a) Whether it gets used enough to provide an adequate Return on Investment (ROI).
- (b) Whether there is spare capacity available which could be used to avoid buying new facilities or could be used to reduce costs.
- (c) Whether maintenance downtime is excessive.

A good way of measuring performance is to keep a log of facility utilization including causes of downtime. In cases where facilities are not under heavy usage, a log may not be necessary except to provide data from which to prepare performance statements.

#### D.6 Measurement of Schedule Performance

Shipyard managers are acutely aware that control of time is the secret to success. It has a direct connection to the profit or loss on a contract. This is true not only because of time penalties which are built into most ship-building contracts, but also because labor expenditures tend to be nearly constant from day to day. Therefore, any delay in delivering the ship means that more labor charges are accrued, because the work expands to meet the time available.

Measurement of schedule performance consists of reporting and recording the actual dates when planned events occur. The first level supervisor who is responsible for a work package is responsible for reporting events associated with the work package. The report is made to the planning group. This should be as simple a matter as possible, preferably no more than a phone call. Planning should take care of the paperwork and data entry to the computer or other data bank. The recording job is usually manageable by a single person, and that person and a back-up are the only ones who need to learn the intricacies of the data entry task. At 2000-4000 work packages per ship the average rate of completion would be 10-20 per working day. Even with four or five simultaneous projects, a data entry and collation job of this size could be handled by a single individual.

Physical progress within work packages is tracked in many shipyards. This requires significant effort on the part of senior planners or production supervisors. The object of checking physical progress is to reduce the uncertainty about the future by comparing progress to expenditures within the work package. This is only necessary when the

aggregate of open work is a large percentage of the total budget for the project. Small and short work packages avoid this problem by providing a smaller "window" of uncertainty, as shown in Figure D-7.

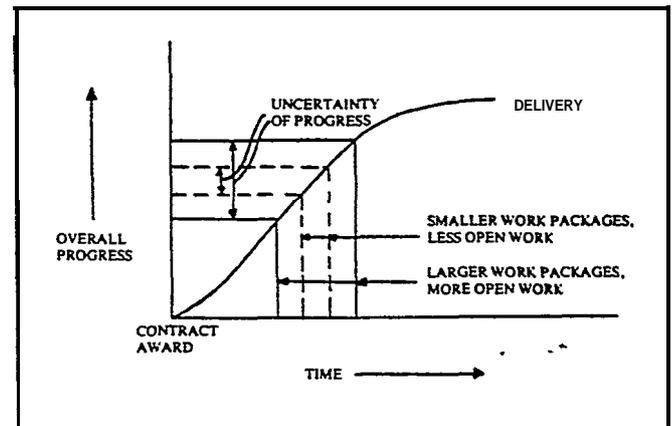


FIGURE D-7: SMALLER WORK PACKAGES MEAN LESS OPEN WORK AND LESS UNCERTAINTY IN OVERALL PROGRESS.

Because a ship is a complex item to build, missing the date on one part of the construction cycle can cause severe cascade effects on other parts. It is also true that being too early, although less of a problem, may cause adverse effects like the expense of storage and retrieval of material, use of facilities that are really needed for more critical jobs, or misapplication of critical trades.

An example of this occurred recently in a shipyard which was building commercial ships and also had subcontracted some submarine work for another shipyard. The shipfitters assembled certain submarine sections ahead of schedule, and in place of the commercial work that they were scheduled to do. This gave them extra tons credit against their tonnage quota. However, the welders' workload was such that they could not weld the submarine section until it was scheduled for welding, which was several days later. This meant that the floor area was tied up, and the scheduled commercial unit could not be worked. To resolve this impact, first class welders needed for the submarine work were pulled off another critical job. The total result of delivering the submarine section ahead of schedule and out of sequence was that valuable floor space was tied up for a long period of time, commercial work that was needed for the follow-on operations was not completed, fitters and assemblers in the follow shop were without work, and welders had to be put on overtime at a premium pay rate to break the bottleneck, even though there were enough welders to have performed the work if it had been done in the right sequence according to the schedule.

What should be measured in schedule performance to prevent such costly mistakes? Basically, the scheduled completion date of each scheduled unit should be compared to the actual completion date. If a network is developed in the planning process and if the dates assigned on that network allow the ship to be completed on time, then each event should be completed as scheduled and the total ship will complete on time.

However, since knowledge of late completions may not allow enough time for recovery, work starts must be tracked. Actual dates, both start and completion, are measured against planned dates to develop performance.

$$\text{Start Performance} = \frac{\text{Number of units which were planned to start which were actually started}}{\text{Number of units which were planned to start}}$$

$$\text{Completion Performance} = \frac{\text{Number of units which were planned to complete which were actually completed}}{\text{Number of units which were planned to complete}}$$

In figuring the actual starts and actual completions, only those work packages which were scheduled are counted. If a work package is started before it is scheduled to start, no improvement in performance is allowed.

Figure D-8 considers a further possibility. Some shipyards have such skill at networking that they are able

to determine earliest and latest start and stop dates, and then report these and actual dates to the appropriate level in the organization.

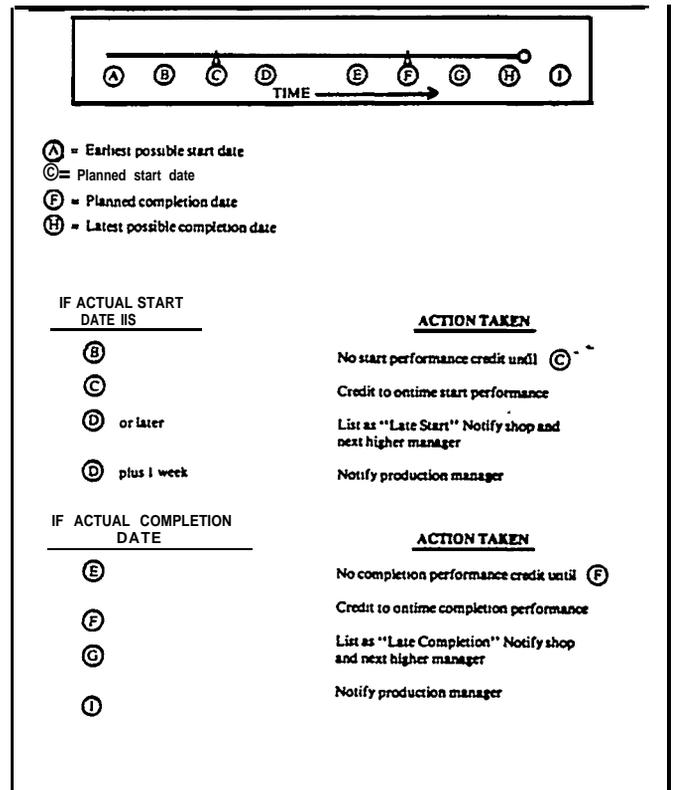


FIGURE D-8: START AND COMPLETION DATES

## PPENDIX E

### EVALUATION OF PRODUCTION PERFORMANCE

Appendix D discussed the measurement of performance for each of the four major shipyard resources. Evaluation of performance based on those measurements is discussed here. The variance between planned and actual performance of a shipyard is used to evaluate both production and planning. On one hand, it is a warning signal to tell when and where current nearterm problems lie. On the other hand, actual performance of the shipyard is necessary feedback and historical data for evaluation of the planning and estimating functions.

The same variance may mean that production has a problem, or planning has a problem, or both. In fact, the shipyard has a problem whenever significant variances exist. Short term fixes to that problem are production's headache. Only they can do the work, help the shipyard out of the immediate problem, and deliver the ship. Long term fixes are planning's problem. Only they can produce more accurate plans, better schedules, and help the shipyard avoid a similar problem in the future. One way to do this is to improve the reliability of the planning.

Variances in performance occur for two main reasons. First, planning cannot analyze every work package perfectly. Budgets have some degree of uncertainty in them. Second, production is subject to the vagaries of the real world. Material is late or damaged, mistakes are made, paperwork is incomplete or inaccurate. Even if these are planned for in the broad scope, they cannot be predicted in detail. The basic production processes are far more uniform than either of the previous two factors. Burners burn, welders weld, and fitters fit at quite uniform rates when they are not disrupted.

Although variance is a measure of both production and planning, it is difficult to discuss both at the same time. This Appendix discusses the evaluation of production. Evaluating the planning function is covered by Part IV of the Manual.

### E.1 Evaluation of Production

Performance is evaluated to show the status of a project to those people in a position to do something about it. In many respects, performance evaluation is like a quality control problem: some characteristic is measured, and the measurements are compared with a range of acceptable values. Some action is taken, which depends on the results of the evaluation. In the physical world, this may be acceptance or rejection of the part. In the case of rejection, a decision is made whether the part should be reworked or discarded. Actions are similar in the performance world. Evaluation may show that the project is proceeding within the plans, in which case operations and planning should proceed as before. If the evaluation shows serious differences between planned and actual performance, then something must be done to avoid future problems. Corrective action may involve planning, production, or both, depending on the location of the problem.

Evaluating and interpreting performance is a staff job, and a demanding and responsible one. Line management is generally very busy, and cannot take time to do extensive chart-making and trend-watching; this can be done by specially trained analysts. But the analysts are responsible for prompt and accurate reporting at the very least, and hopefully also for suggestions of ways to resolve problems. The analyst's broader range of view may help him supply good suggestions. It is important that production be able to rely on him; if not, the entire planning and evaluation effort will fall quickly into disrepute and disuse.

Measurement of individual pieces is less important for their own sake than for the sake of the overall process. It is important to know if a given part is satisfactory, but it is more important to know if the machine or process producing that part is satisfactory, or if it needs adjustment. Similarly, each work package should show satisfactory performance, but it is more important that the overall project be satisfactorily completed, and that future work be accurately planned.

Evaluation is based on comparing actual characteristics with desired ones. In the physical world, these characteristics may be size, weight, hardness, color, chemical composition, etc. Performance characteristics, on the other hand, are schedule dates, manhour expenditures, material usage, and facility occupancy. All are important, but manpower and schedule tend to dominate. Production and planning generally have little control over the material requirements for a project; they are essentially fixed by ship design and specifications. Of course material can be lost, damaged, and misused, and material performance should be monitored, but it is a secondary characteristic. Similarly, facility occupancy is secondary to schedule performance. Once facility occupancy has been planned,

facility performance depends heavily on schedule performance.

Figure E-1 shows the measurement and evaluation relationships schematically. Variance - the difference between planned and actual performance - is the obvious "control signal". In fact, though, the simple difference is not sufficient. Going back to the physical world, no dimension is ever specified for manufacture of an item without a tolerance range, for without the tolerance range there is no way to tell whether or not the finished item is acceptable. Small deviations are expected in any process; a guideline is needed to tell when the deviation represents a problem condition.

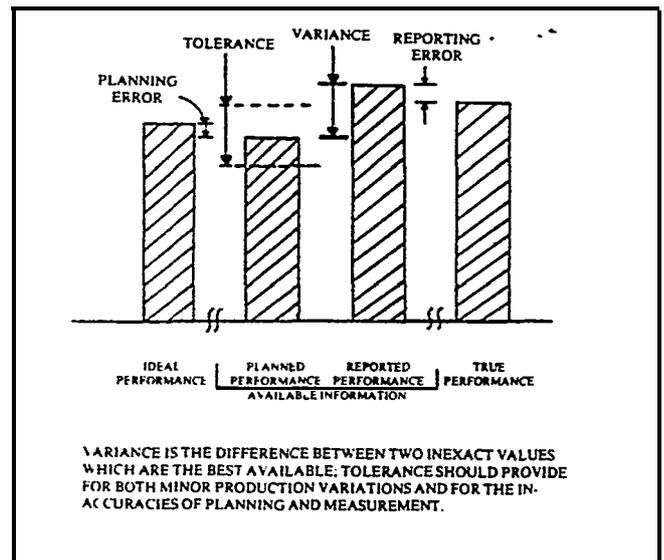


FIGURE E-1 : VARIANCE AND TOLERANCE

The width of the tolerance range is subject to conflicting influences. Functional requirements of the item tend to narrow the tolerance range. Manufactured pieces have to fit somewhere, or the dimension would not be specified in the first place, and the tighter the tolerance, the more easily it will fit. On the other hand, production cost considerations tend to widen the tolerance range. The proper setting of tolerances requires a broad perspective. Assembly costs tend to go down with tighter tolerances, but the cost of making the individual pieces tends to go up. The best solution is a balance between the two.

Similarly, the setting of tolerances on performance measurements requires a broad perspective. Looser tolerances are easier to plan and execute, but increase the risk of not meeting the overall project goals. Tighter tolerances are harder to plan and execute, and in the extreme may allow too little margin for the normal variation of real world production. Here again, the best solution is a

good balance, which can be knowingly found only by considering both extremes.

### E.2 Manpower Performance

Manpower expenditures must be measured at the level of the individual worker and individual work package, but this is not the best level for the evaluation, for several reasons. First, planning budgets are least accurate at this level. Budgets for a whole system, zone, or group of work packages are likely to be more accurate, being based on historical and broad performance measures. The individual work package budget, by comparison, is usually based on a comparatively small amount of analysis. Second, the individual work package is more susceptible to the random problems of production life. A missing piece of material or paperwork, a broken tool, or absence of a key man can easily put a single work package in budget trouble. This is not cause for concern, unless a pattern develops. Third, both of these reflect the fact that any work package is a small portion of the overall project. The deviations of a large number of small measurements tend to average out, unless a persistent problem is present.

A rule of thumb for manpower variance tolerances is 5 % for individual work packages, 3 % for whole system or shop-level groups of work packages, and 1 to 2 % for a steel zone or outfit group. This means that if an individual work package shows a variance of less than  $\pm 5\%$ , there is absolutely no cause for control action. Obviously, however, if many work packages all show a  $-5\%$  variance, the project can be headed for trouble.

The tighter tolerances at high levels reflect the smoothing effects of wider averages, and show broader performance trends. Much of this information is also available at the work package level. Tolerance is a useful tool for telling when an individual value is out of the satisfactory range, such as when the variance is probably due to more than random variations in planning accuracy, or more than random variations in production operations. The pattern of variances can also give advance warning of problem conditions. In Figure E-2 the top picture shows a generally satisfactory situation. One work package was out of tolerance, and the reason for it should be investigated. The trend, though, is one of tolerable random variation about the budgets. The lower pictures are obviously quite another matter. Although no variance has yet exceeded the tolerance limit, no one could call the situation shown in the middle picture healthy! Similarly, the lower picture represents a situation which shows why tolerances decrease as the groups of work packages get bigger. Here no single work package is out of tolerance, but the pattern certainly shows a problem which will be seen as definitely out of tolerance at the next higher level of review.

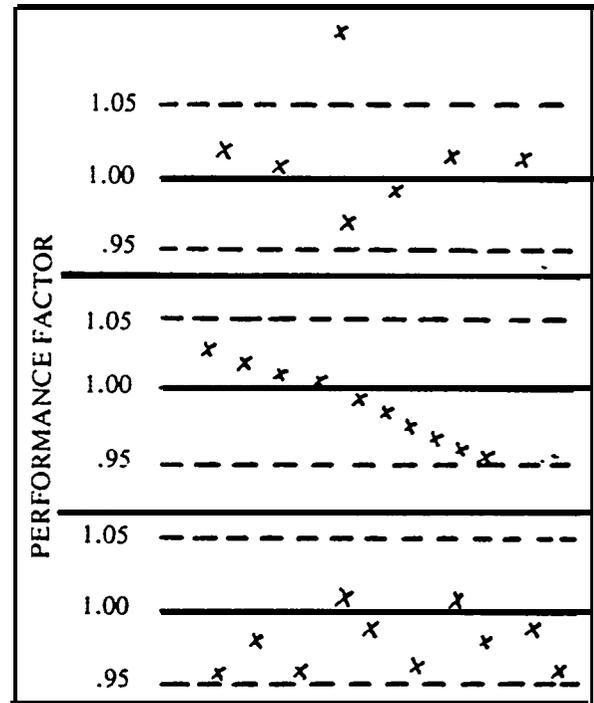


FIGURE E-2: TOLERANCE RANGES DESCRIBE THE SAFE LIMITS OF "RANDOM" ERRORS. PATTERNS OF ERROR ALSO CONVEY INFORMATION.

Scattered data is common in the real world, as in the top picture in Figure E-2. To smooth these numbers out, and show patterns as soon as possible (without waiting for higher level groupings of the work to be completed), a useful arithmetic technique is the moving average. A moving average is the average of the most recent values, for instance, the last four values. As new values become available, old ones are dropped from consideration. Figure E-3 demonstrates the smoothing effect of a four-value moving average, showing how it both smooths local disturbances and shows short term trends

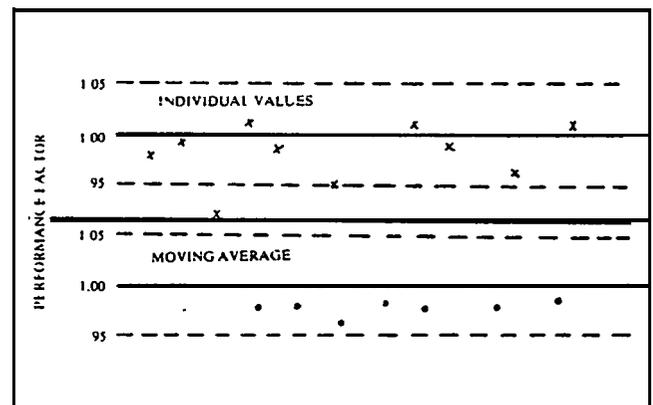


FIGURE E-3: USE OF A MOVING AVERAGE SMOOTHS RANDOM VARIATION AND SHOWS SHORT TERM TRENDS.

This discussion of tolerances was based on manpower budgets, but applies to other resources as well. The discussion will not be repeated for each resource. However, tolerances are important in evaluating performance with respect to every shipbuilding resource. Scheduling, though, deserves additional consideration.

### E.3 Schedule Performance

Evaluation of performance in regard to manpower, material, and facilities is comparatively straightforward because performance on each work package generally affects the total only by its own weight. Being over the manpower budget of one work package generally does not affect the performance of other work packages. This is not the case for schedule performance. Delay of any work package often directly affects the progress of others, and the impact of a given work package being late has little or nothing to do with the size of that particular work package. Also, being early does not necessarily contribute to overall schedule performance. Evaluating the true effects of schedule performance is therefore quite difficult.

The simplest evaluation, of course, is a record or chart of days late or early. The next level of complexity is to weight the schedule variance by the number, or the work content, of following work packages. This can get very

complicated to manage by hand, but the necessary arithmetic is trivial to a computer. This weighting should take into account any buffer time between the scheduled completion of a given work package and the beginning of its successors\*. For instance, in Figure E-4 lateness of work package "A" has no impact until the scheduled start of work package "B"; and the impact increases as the start of work package "C" is passed.

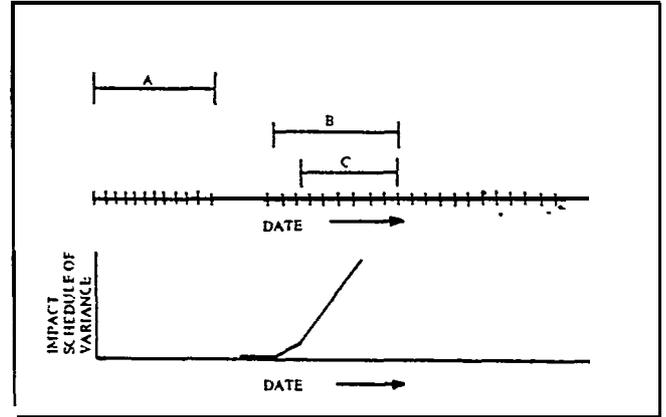


FIGURE E-4: SCHEDULE VARIANCE HAS WEIGHT AS IT IMPACTS OTHER WORK

\*The size of the buffer between successive work packages is quite important. Shorter buffers lead to more disruption when work packages are late for any reason, and longer buffers lead to unnecessarily long overall schedules. Chapter 5 discusses this problem in more detail.

## APPENDIX F

### PLANNING GROUP ORGANIZATION AND COMPOSITION

The planning group in a shipyard has a heavy influence on the success of operations. Several points affect the output of a planning group.

- Location - both organizationally and geographically
- Composition - in terms of skills, numbers, and interrelationships
- Authority - consistent with the amount of planning involvement desired by shipyard management

Scheduling is often performed by planners within the planning group. In some shipyards, planning and scheduling are synonymous terms. No attempt has been made in this description to treat scheduling as a separate entity.

### F. 1 Why Some Plans Are Failures

The success of a planner is measured by how much money is saved because of his work. Largest actual savings generally occur on the waterfront, because planning work is so leveraged. Why do some planning groups have less than a satisfactory score? To some extent this is a foregone conclusion. The organizational structure within the planning group and the relationships that are established between the planning group and the rest of the shipyard are such that it is extremely difficult for the planner to generate all the savings for the shipyard that he is capable of generating.

### F.2 Conditions Promoting Successful Planning

Most planning functions evolved in response to a need for assistance by the waterfront. Management responded with a budget, a personnel authorization and an announcement soliciting cooperation and support for the new central planning group. However, the group had no clear-cut authority. Quite obviously this does not represent the best way to plan. A good organizational structure is needed. Management must do the difficult work of defining the responsibilities, authority, and accountability of the planning group in relation to all the other organizational units in the shipyard.

In the United States, almost all major manufacturing firms (with the exception of the new electronic firms)† initiated centralized planning as a result of demands by production for assistance. The planning function simply grew to fill the need to schedule production. No clearly defined and integrated charter was developed for all the groups involved.

To increase the effectiveness of the planning function, shipyard management should review the role of the planning group and issue a charter for the organization. It must define the relationships that are desired between planning and the rest of the shipyard. It is the job of management to determine relationships and explain them to the positions involved.

Management should:

- Establish objectives for the planning group

• Responsibility is the work that is assigned to a position (or department for later reallocation within that department). Work is generally defined in terms of the functions performed and may include statements of output from the position based on the given information.

•• Authority is the power or rights assigned to a position. Authority is characterized by action verbs such as “decides”, “recommends”, “selects”, etc.

••• Accountability is obligation of the position to perform the work assigned (responsibility) and exercise the authority given to the position. Performance evaluation of the position's accountability requires known goals and rational methods of measuring results against those goals.

† The reason that these new firms are the exception is a logical one. Usually the founders of these firms were engineers who decided that they could successfully apply their scientific knowledge to develop needed products. They concluded that just as their engineering skills would give them a competitive advantage technically, so also would professional managers give them a competitive advantage organizationally. Thus the professional managers were hired before the firm developed, and they were able to establish organizational relationships rationally. The responsibilities, authority and accountability were determined at the same time for planning, production, marketing and finance.

- Determine what work planners are to do and what work planners are not to do
- Define what decisions planning is empowered to make and what action is permitted by others when they are affected by planning decisions

### F.3 Who Owns The Planners

The executive vice-president of a major U.S. shipyard had a strong personal conviction that people charging to overhead accounts were much less productive than people charging directly to shipwork. He regularly directed programs to eliminate overhead people. The planning group was one of his favorite targets, and he would decree that there would be only X number of planners for the whole shipyard. This meant that the work descriptions, budgets, and all other necessary plans went out to the production people without any detail. In order to operate at all, the various production groups had to invent shop planners. Since there was no budget for shop planners, these people were usually craftsmen who continued to charge their time to the jobs on which they had worked in the past. But they did not work these jobs they worked on overall planning for the shop. The planner reported directly to the Shop Superintendent. In this way the superintendent arranged planning so that it was most convenient for him. He thus had much better control, and was able to make his shop look good. From the overall shipyard point of view, however, this was not a satisfactory arrangement. The Shop Superintendent might choose to operate in a particular frame or window, and his decision could jeopardize the ability of some other shop to do their work. The net effect could be detrimental to the total shipyard. Since planning must take into account the impact on all trades in the same area, shop planners who have allegiance only to their own shop may not provide planning which will have the most benefits to the total shipyard. Figure F-1 illustrates such a potential planning conflict.

Because of the potential conflicts of interest generated when too little coordination takes place among shop planners, another way of organizing the reporting relationship of planners is necessary. It is possible to have all the planners (central and shop) belong to the central planning group. This keeps all the planning under the control of the planning superintendent, and does not look after

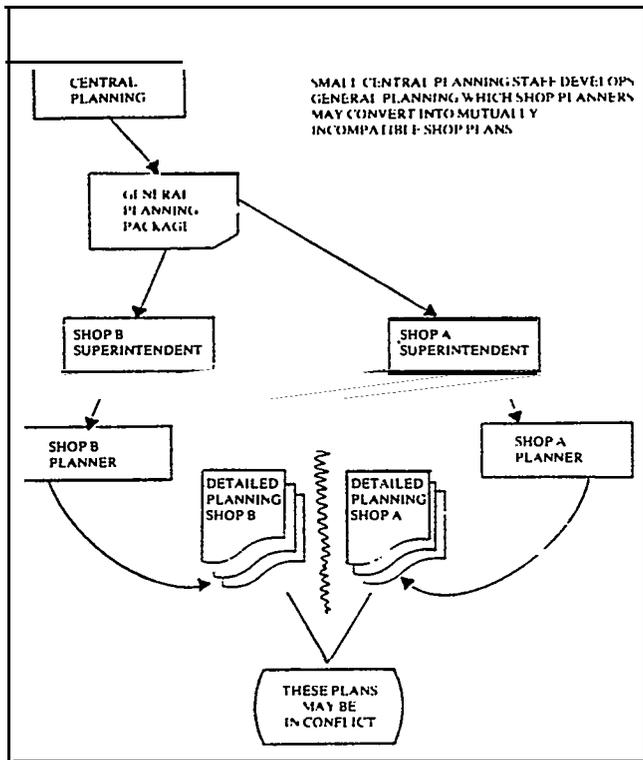


FIGURE F-1 : INCOMPATIBLE PLANNING

the best interest of the total shipyard. This situation eventually tends to deteriorate in two respects, however. First, the planners are so far removed from the real world of putting the ship together that their skill and knowledge levels tend to drop. Second, the shops not wishing to work to the plan simply ignore it. The Shop Superintendent can go about doing whatever it is in whatever manner he wishes. This leaves the planner unaware that his careful planning has not been followed.

A solution to this problem that has been tried successfully in several shipyards is to differentiate between reporting relationships and geographical proximity. The organizational arrangement with the best combination has had the top level planners in the central planning office area, with the shop planners physically located in the shops (in a position to be aware of things that are happening in the shop) and reporting through the planning group. In this arrangement the planner's work is evaluated by his planning boss. However, he cannot ignore the shop because he is right there in the middle of it. Shop people can come in and say, "Hey, we've got this situation. Did you know that such and such happened?" Because of his location, the planner can see first hand the status of the job. He can look at the work and see whether it is being performed in the manner prescribed. His closeness to the

real world will improve the rational planning process. However, his organizational position within the planning group protects him from undue pressure from the Shop Superintendent to plan to the disadvantage of other areas. Figure F-2 shows this arrangement.

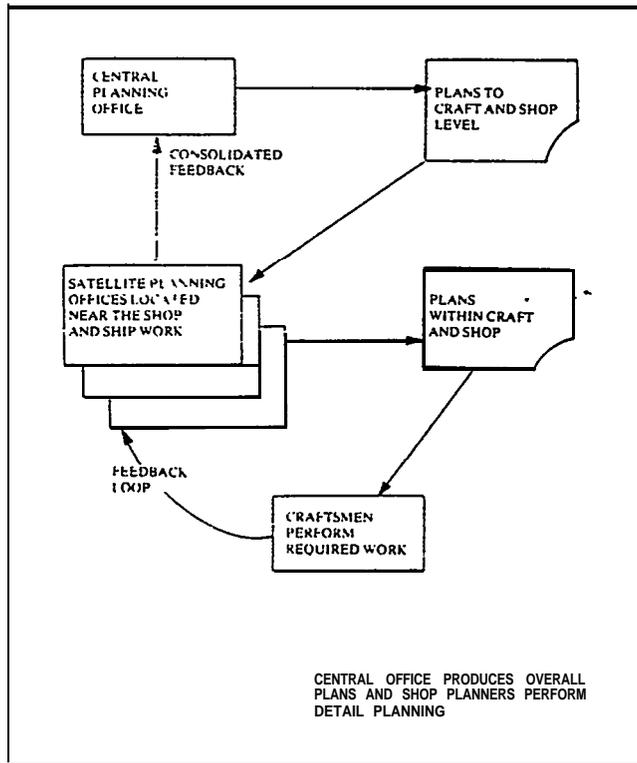


FIGURE F-2: IMPROVED PLANNING ARRANGEMENT

Another advantage of this particular system is that the shop planner has vertical access in the planning group to get quick resolution of difficulties which he cannot resolve

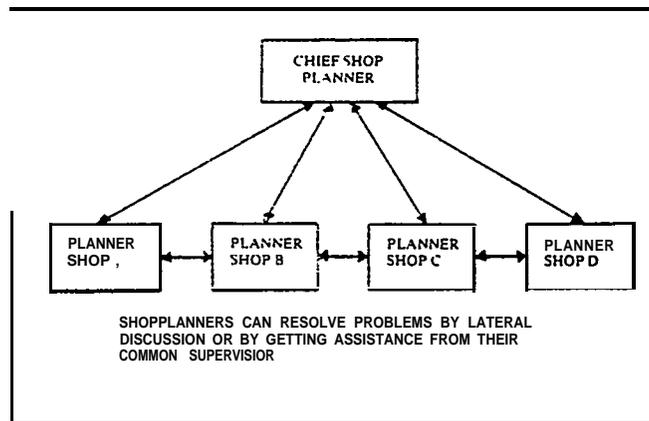


FIGURE F-3: ACCESS FOR RESOLVING PLANNING PROBLEMS

through discussions with a counterpart planner in another part of the shipyard. The supervisor of these two planners is the same person, so that resolution of planning problems can be made at a minimum organizational level. This situation is shown schematically in Figure F-3.

The check and balance to ensure that the planner is responsive to production needs is provided by the chief shop planner. When trying to evaluate the performance of his subordinates, he can check with the shop superintendent of the area being served by each subordinate planner, and ask the superintendent whether the planner is performing the intended service as well as possible, or whether there are improvements that should be made. In this way the organization is kept in line, and produces as economically as possible.

Figure F-4 is included to illustrate the difference between "span" and "level". Figure F-5 shows the extra cost incurred in an organization by adding extra levels or extra span. This figure is significant because it shows that increasing span is more effective than increasing levels. The

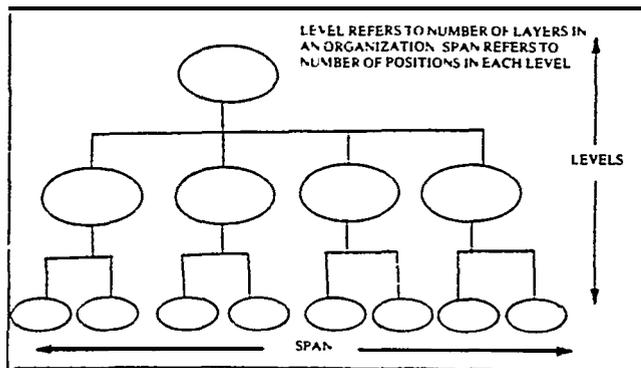


FIGURE F-4: LEVELS AND SPAN

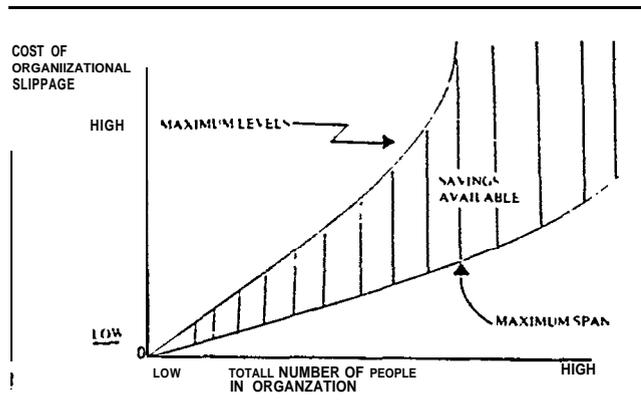


FIGURE F-5: EFFECT ON ORGANIZATIONAL SLIPPAGE OF INCREASING ORGANIZATION SPAN VS. INCREASING ORGANIZATIONAL LEVELS

cost of organizational slippage is not the salary costs associated with the additional planning people, but is the cost associated with the non-planning work generated by increasing the size of the planning group.

#### F.4 How Big Should The Planning Group Be

Another way to ask this question is, "How many people does it take to do the work?" This section of the Manual will deal with this question. Figure F-6 represents what is typical in American Business. First, a person is in a job "O", and he performs the work so well that the Company expands. Now the work exceeds the amount of time that he has available. So he hires one or more people to assist him

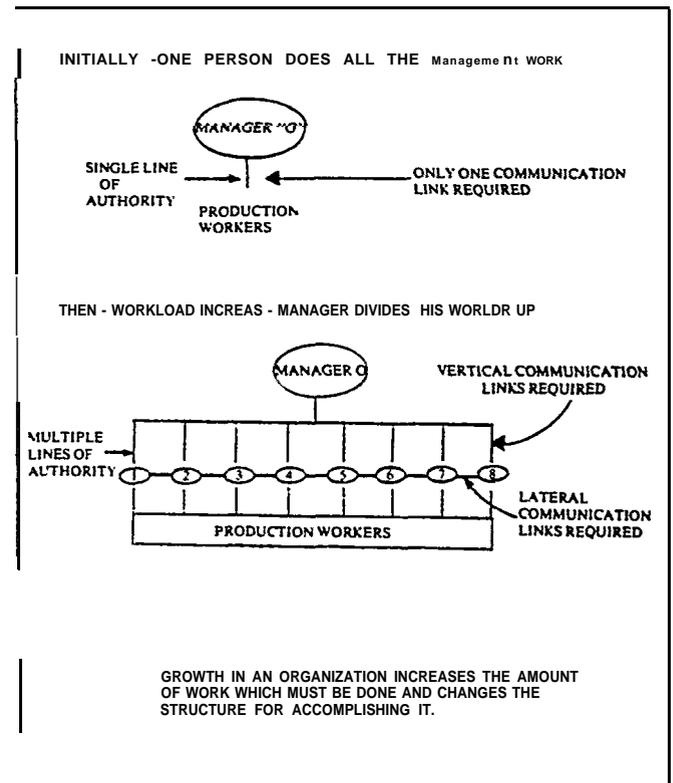


FIGURE F-6: ORGANIZATIONAL GROWTH

in the work that he was doing, and that creates job numbers 1, 2, 3, 4, 5, 6, 7, 8. Now, when he created these jobs, he created more work. When he did the job all by himself, he had all the material there with him. He knew what decisions he had made. He knew what communications he had made. When he did it all by himself the process was more efficient than it can be with 8 new people doing it. Now what one decides must be communicated to others. This creates paperwork. In addition to the paperwork of communication, there is the paperwork necessary for authorization. When Mr. O was the only one involved, authorizations were not a problem because he was the only one who did the work. Now there are more

people involved, and there must be some system to the authorizations. It is easy to see that adding people does, in fact, add work. The well known Parkinson's third law states that if you have enough people, they will generate so much work communicating with each other that they will all be busy all of the time. This extra work has been called organizational slippage. It is more sensitive to the number of levels in the organization than it is to the number of people. When the 8 new people become fully occupied, each one asks for assistance. This creates a third level in the organizational structure. It is interesting how quickly the number of people that can be supervised goes up as the number of levels rises. For instance, if each person who supervises has only 8 subordinates, three levels would provide organizational slots for 73 people that report to him, making 1 plus 8, and each of these 8 have 8 reporting to them, which makes the grand total 9 plus 64. This is quite a large planning group. If the next layer is added, again arbitrarily picking an 8 to 1 ratio, then the fourth layer involves 512 people with a cumulative number of 585 people to be supervised in four levels. See Figure F-7 for the possibilities involved.

SPAN LEVELS	1	2	3	4	5	6
1	1	1	1	1	1	1
2	2	5	9	13	17	21
3	3	21	73	157	273	421
4	4	85	585	1885	4369	8421
5	5	341	4681	22621	69905	168421

FIGURE F-7: POTENTIAL NUMBER OF PEOPLE SUPERVISED FOR VARIOUS COMBINATIONS OF SPANS AND LEVELS.

It may be interesting to determine how many levels actually exist in a planning group. During a shipyard survey\* cases were found in which the organizational structure was far in excess of four levels, yet with far fewer than 585 people, resulting in a high cost for organizational slippage. One over one, one over two, one over three reporting relationships were observed in some planning groups, which generates low organizational efficiency. It is clear that to minimize the levels, the span must be minimized. This means that each supervisor should supervise as many people as possible without causing inefficiency in the group.

\*in connection with preparation of a manual on outfit planning under MarAd Task SP-IV-D.

When Mr. O started delegating some of his work he had a fairly firm handle on how much he had been doing, and therefore knew how much his subordinates must do. As time went on the work changed, and he got farther and farther away from it. He also became more and more involved with other duties, and before he knew it, he was having a tough time assessing whether the work level was too high or too low, or if some of his people were working harder than others. The solution to this problem has eluded planning management for years. Some industrial engineers have advocated measurement of the amount of work being done. Although some people argue that creative work cannot be measured, planners can indeed have some rulers applied to measure their output. However, a large benefit is also possible if an analysis is made of work being done to see if it is really necessary. An accountant had been a long time employee of a certain shipyard. One day the new employees asked him what he did. The accountant said, "I put these figures together for the vice-president." The new man asked, "How often does he come and get the figures from you?" The old-timer looked at him and said, "He hasn't asked for them in several years." The point of the anecdote, of course, is if the work isn't needed, don't waste time on it. Apply the effort to something worthwhile.

The size of the planning group then should be controlled by keeping the number of levels to a minimum while maximizing the span. A regular audit should be made to evaluate whether the planning work contributes meaningfully to production of the ship.

#### F.5 How Many Planners Are Needed

Several attempts have been made to develop a formula which will tell exactly how many planners are needed. When the results of these attempts are tried and compared, the numbers of planners vary. Management eventually has to make a "best guess" decision. Although there is disagreement on the needed size of a planning group, there seems to be some agreement on the factors which cause the number of planners to be higher or lower.

There are four areas which need to be weighed in determining whether a large or small number of planners is needed. These will be examined individually:

- Work Factors
- Organizational Factors
- Worker Factors
- Working Conditions

Consider Work Factors first. These depend on the physical nature of the planning resources available.

Obviously a complicated ship will require more planners than a ship with simple requirements. Not only is the planning work more complex, but the production workers will want planning performed for more items. Similarly, if work is covered by standards for methods and time, the planner will have a much lighter load than if he must develop the work method and budgets without standard data.

WORK FACTORS	PLANNING GROUP WORK METHOD		WORK COVERED BY PUBLISHED STANDARDS		
	ORGANIZED AND SYSTEMATIC		OVER 75%	25% to 75%	UNDER 25%
FACTORS PRODUCTION WORK	YES	NO			
SIMPLE WORK	1	2	1	2	3
COMPLEX WORK	3	④*	3	4	⑤
OLD DESIGN	1	②	1	2	③
NEW DESIGN	2	3	2	4	5
EXPERIENCED WORKERS	1	②	1	2	③
NEW WORKERS	1	2	2	4	5
LARGE WINDOWS	1	②	1	2	③
SMALL WINDOWS	2	3	1	3	5

FIGURE F-8: PLANNING WORK FORCE SIZE INDICATORS: WORK FACTORS

Figure F-8 shows the relative weight to these factors. The planning group work factors are listed across the top. These include: (1) whether the planning group is organized and systematic; and (2) the percentage of the planning work which is covered by standard methods and standard budgets. Later in this Appendix the internal and external organization of the planning group will be discussed. The degree of skill with which that organizational work is performed affects the efficiency with which a planner can execute his work.

A low number (1 for example) indicates a lower work load than a high number (5 for example). The numbers are Load Indicators and do not tell in absolute terms the number of planners needed, but do show that more planners are needed for complex work without standards than for the same work with standards.

These factors reflect the organizational position of the planning group and its internal and external relationships. A low score (for example, because of the predominance of “usually” answers) indicates fewer planners will be needed than a high score (for example, by several “seldom” answers).

Organizational Factors are considered in Figure F-9.

ORGANIZATIONAL FACTORS	INDICATOR VALUE		
	1	2	3
Does position which performs the planning work make : Dont decisions about the work?	usually	① Sometimes*	seldom
Arc decisions referred to higher authority by the planner, made expeditiously and wisely?	usually	sometimes	① Seldom
ARC PLANNING COMMUNICATIONS SYSTEMATIC AND ORGANISED?	usually	① Sometimes	① Seldom
Does planning get all the feed back needed from pro duction workers?	usually	① Sometimes	seldom
Where does the planning group report in the shipyard?	To the president	① To a Vice President	below vice president

FIGURE F-9: PLANNING WORK FORCE SIZE INDICATORS: ORGANIZATIONAL FACTORS

Worker Factors are next. Figure F-10 indicates the degree to which individual attitudes and skills affect the number of planners required.

WORKER FACTORS	RATING AND INDICATOR VALUE		
	HIGH	AVERAGE	LOW
Natural ability for this type of work	①*	3	4
Expence and Training	1	②	3
Motivation	1	③	5
Sense of accomplishment and realization of personal con- tribution to shipbuilding	1	③	4
Rational performance measurement and recognition for good work	1	3	⑤
Turnover or attrition rate among planners	1	③	5

FIGURE F-10: PLANNING WORK FORCE SIZE INDICATORS WORKER FACTORS

\*Disregard the circles for now: they will be explained later in the next section.

**Work Conditions** affect the number of planners required. Figure F-11 deals with the impact of work conditions.

WORKING CONDITIONS	RATING AND INDICATOR VALUE		
	u s u a	SOMETIMES	SELDOM
Necessary information readily available and close by	1	2*	1
Required information indexed or systematically arranged	1	2	3
Planners work area close to production work area	1	2	3
Planners work area reasonably quiet, lighted, ventilated, etc.	1	2	3

FIGURE F-11: PLANNING WORK FORCE SIZE INDICATORS: WORK CONDITIONS FACTORS.

### F.6 How to Use Planning Work Force Size Indicators

Figures F-8 through F-11, can be marked up to reflect the condition in a particular shipyard. The circled values on those figures are scores from one U.S. Shipyard.

SCORE SUMMARY							
	TOTALS	ENGINEERING	METHODIZING	ALLOCATING			
FIG. 10-8 WORK FACTORS	14	0.21	3	0.53	7	0.43	6
FIG. 10-9 ORGANIZATIONAL FACTORS	12	0.25	3	0.83	10	0.76	9
FIG. 10-10 WORKER FACTORS	17	0.82	14	0.93	16	1.17	20
FIG. 10-11 WORK CONDITIONS	9	0.33	3	0.22	2	0.22	2
PLANNERS BY CATEGORY		23		35			37
		TOTAL PLANNERS					95

FIGURE F-12: EVALUATION SHEET - PLANNING GROUP SIZE ESTIMATE

The scores can be entered on the evaluation sheet shown in Figure F-12. This sheet adjusts the indicators for the type of planning work, and provides an estimate of planning group size and composition. The numbers used in this chart have not been developed to the point where they are totally supportable for sizing a planning group. The research data does not yet exist which will permit this method to be used with enough accuracy to be fully reliable. The research needed for such determination is outside the scope of this Manual. The size and composition estimate should be useful, however, for a gross deter-

• Disregard the circles for now; they will be explained later in the next section.

• This information came from shipyard visits and first hand knowledge of the researchers involved in this and other related MARAD tasks.

mination which can be refined through application of the techniques explained in Chapter 9 of the Manual.

The ratio of planners to craftsmen is shown in Figure F-13 for several shipyards\*\*.

SHIPYARD	A	B	C	D	E	F	G	H
TOTAL SHIPYARD EMPLOYEES	4000	1200	25000	5000	4500	4500	4500	6000
PRODUCTION WORKERS	3000	1000	15000	4500	3900	3200	3800	5000
PLANNERS	86	37	200	45	25	62	52	73
PLANNERS AS PERCENTAGE OF PRODUCTION WORKERS	2.9	3.7	1.3	1.0	0.6	1.9	1.4	1.5

FIGURE F-13: TYPICAL SIZES OF PLANNING GROUPS

### F.7 Planning Skills Vary With Construction Method

The correlation between the number of planners and the number of production workers depends on the way the ship is constructed.

This can be seen more clearly if three shipbuilding situations are compared. An evolution in shipbuilding technology has taken place over the years. At first all materials were brought to the building location where they were cut and fitted into position as the hull was erected

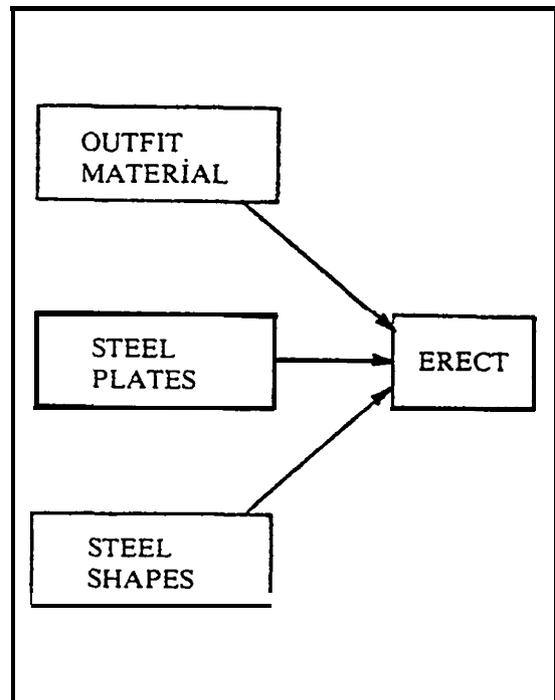


FIGURE F-14: ALL FITTING OF MATERIAL DONE AT SAME LOCATION

(Figure F-14). The next evolutionary step was to make some of the parts of the hull ahead of time; for example, panels and assemblies into which were fitted some foundations and some outfit material (Figure F-15). The final evolutionary step was to determine at the time of design that the ship was going to be built by zones, and to plan accordingly. The steel was assembled into blocks and the outfit material was installed (Figure F-16). The block was then moved to the hull location to be joined to other blocks. European shipyards launch six large ships a year from one basin using this method. Newport News recently made a most noteworthy achievement when they erected a completely assembled outfitted deckhouse.

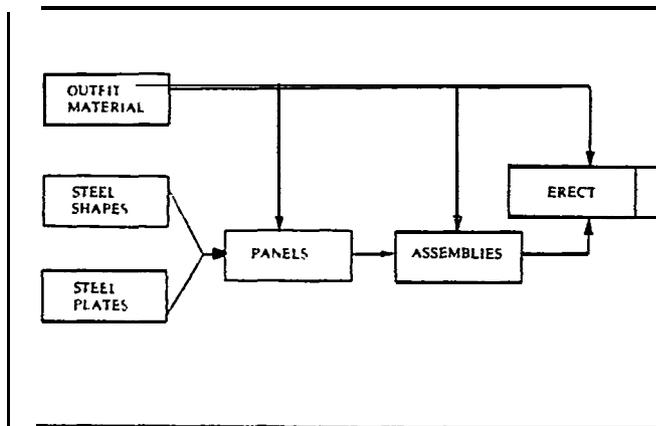


FIGURE F-15: SOME MATERIAL FITTED AND PREASSEMBLED BEFORE GOING TO ERECTION LOCATION.

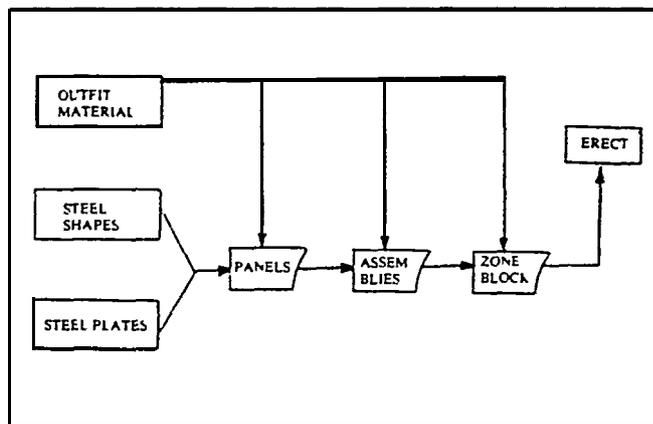


FIGURE F-16: INCREASING QUANTITIES OF MATERIAL PREASSEMBLED AND OUTFITTED BEFORE BEING MOVED TO ERECTION SITE.

What effect has this change in shipbuilding methods had on the planners? In the early methods of shipbuilding, the production craftsman had to possess many varied skills. He had to plan his work to match other people's work. Planners needed minimal skills because most of the planning work was done on the waterfront by the mechanics themselves. However, as shipbuilding methods changed, so did the work required of the planners. The production worker was given more specific jobs which required less planning by him. More work was coordinated by the planners and the planning had to be done sooner.

Today the planner must know more than ever before about the shipbuilding process. His impact is greater and greater. More work means more planners are required. But more significantly, more impact means better planners are a necessity. Today the production worker specializes more than he was able to in the past. He benefits from improved production aids such as jigs, fixtures and tools. His learning curve potential is increased. But now the planner has increased work to make all this possible. He has to plan so that production improvements can reduce costs on every contract. He has to translate ship design into ship producibility. The result of the evolutionary improvement in shipbuilding methods is to demand more and better planners, and closer ties between planning and production.

#### F.8 Review of Planning

- The organizational structure of the planning group and its organizational relationship with the rest of the shipyard is critical to successful planning.
- Management must establish those organizational relationships clearly, and ensure that they are maintained.
- Standard methods can benefit the shipyard.
- Planning workload and skill requirements increase with an increase in early outfitting, which requires careful meshing of steel and outfit plans.
- More sophisticated construction procedures and requirements mean that planning and production must get together and stay together throughout the ship building effort.

APPENDIX G  
GENERATION OF  
SAMPLE ENGINEERED STANDARDS

A standard is a yardstick or norm which is selected for purposes of measurement. Engineered standards are a more tightly defined subset of standards with the following characteristics:

- The examination of work content and assignment of values for resources required follow recognized industrial engineering practices.
- The research results are reproducible. Any qualified and trained observer could obtain the same standard values.
- The results are documented with an audit trail which includes a description of methods, product quality, and resources used.

Normally in heavy industry applications industrial engineering practice includes use of time study with pace rating for labor measurement. Allowances are made for time earned to compensate for fatigue, authorized personal time and delays which are beyond the control of management or worker.

The following material describes in detail the steps necessary to produce high quality engineered standards. Also included are cost and benefit numbers for establishing and using engineered standards in the steel fabrication plant described in Chapter 1, where the family of standards developed and used included:

- ž Process Standards
- Production Standards
- Scheduling Standards\*

• Although called scheduling Standards, these standards were used for planning and budgeting as well.

### G. 1 Developing Engineered Standards

There are two major parts to developing engineered standards for production processes. First, measure process rates for various controllable parameters, e.g., weld disposition rate as a function of process, current, rod size, composition. Second, on the basis of the rate measurements, select the optimum rate considering such factors as quality, cost, etc. Input settings for the optimum rate then becomes the standard method and the associated process rate the standard rate which is used in synthesizing the higher level production and scheduling standards. See Figure G-1.

TYPE OF ACTION	EXAMPLE
(a) Establish the objective	(a) Cut a plate to plan dimension
(b) Define the work which is required to achieve this objective (standard method)	(b) Work elements Position plate Measure and mark Ignite torch, adjust Burn cycle, including Pierce Bevel (if specified) Aside scrap Aside parts
(c) Define quality	(c) Dimensional tolerance $\pm 1/16''$ Edge Quality to Mil Spec Bevel to $\pm 5$ degrees.
(d) Measure resource requirements (standard rate)	(d) Elemental times - manhours, machine hours, material required, material produced
(e) Determine allowances	(e) Fatigue by work element from standard data. Time for personal needs according to company policy Other

FIGURE G-1 : GENERAL APPROACH TO SETTING AN ENGINEERED STANDARD WITH EXAMPLES.

Figure G-2 illustrates the steps involved in establishing engineered standards. The example Used is a Telerex flame cutting machine. Steps 1-3 are critically important in establishing the proper management and labor frame-of-mind which is absolutely essential to the success of the project.

- ① Management must understand what is to be done, and what they will have to do with the results.
- ② A memo should be distributed by management stating the objectives and establishing organizational responsibilities involved. Program management controls over schedule and budget should be settled.
- ③ A study team should be commissioned and introduced to the people they will contact during development of necessary data, including anyone who may be involved in the time study phase. Questions about the program should be answered.

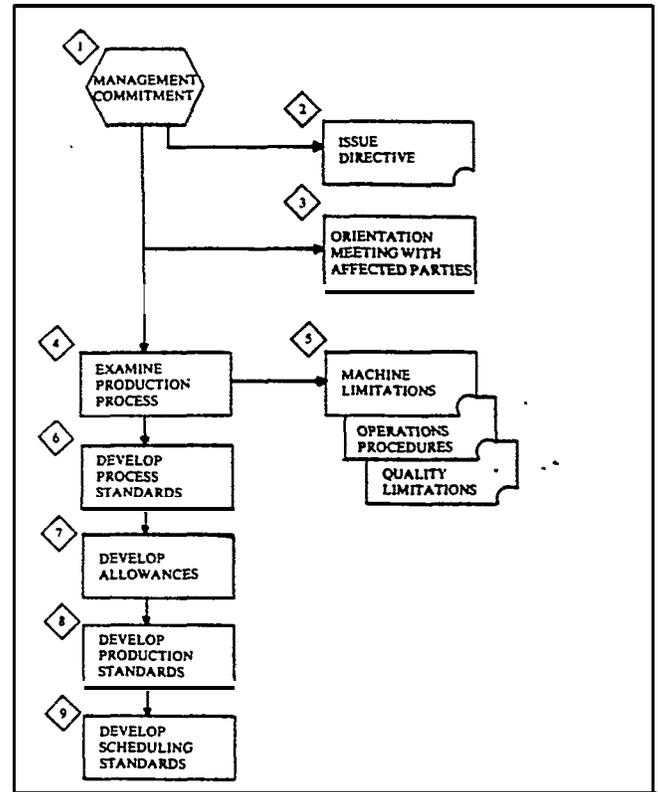


FIGURE G-2: STEPS INVOLVED IN THE DEVELOPMENT OF ENGINEERED STANDARDS.

- ④ The existing production process should be examined and understood. Steps should be examined and the **best method selected**.
- ⑤ The capabilities of the production center should be published to show dimensions, etc., but not production rates. Safe operating procedures should be recorded. Quality limitations of the machinery and the process should be published. When establishing production rates, these three documents will serve as the limitations envelope within which standard operating speeds are valid.
- ⑥ The time required to perform the necessary work to complete the manufacturing process is determined. Resources to convert the incoming material into the specified part are established within the operating limits. Operating procedures, and quality envelope are established.
- ⑦ Allowances for fatigue, personal time, delays and occurrences are determined from observation and standard data.

- ⑧ The production standard is developed from the standard process times and the allowances.
- ⑨ A scheduling standard is developed where required. It incorporates production standard data into a form more compatible with information used by the scheduler.

## G.2 Illustrated Example

The steps involved in establishing engineered standards for machine burning steel plates into parts are as follows:

### Step ①

The Shipyard president and the industrial engineering manager meet to establish the goals and work plan. The industrial engineering manager has prepared an outline of the method to be used, the schedule to be followed, and the budget required. The burning machines are selected as a **demonstration operation**. Exhibit (1) (exhibits are at the end of this Appendix) summarizes this meeting and also illustrates the material covered by the President at his next staff meeting.

### Step ②

Exhibit (2) describes the organization of the study effort, along with implementing memoranda.

### Step ③

Exhibit (3) is an outline of the information meeting held in each department to prepare for the study effort.

### Step ④

Good industrial engineering practice calls for an examination of the production process being studied with the intention of answering these questions about the work:

- Why is this work step being done?
- Can it be eliminated?
- Can it be simplified?
- Can it be combined?

Also questions should be asked about how the work is being done, such as:

- Is the method consistent with company safety guidelines?
- Is the machine (if any is involved) being operated within the manufacturer's specifications?
- Is the quality of the material coming to the work station consistently within published quality guidelines?
- Is the end product within published quality guidelines, or is it too good or too poor?

From this examination a list applicable to that production center can be developed. Next the work processes involved in developing the standard are cataloged and a study method determined. These study methods usually are:

Labor studies—Direct time study for a predetermined time using data from work sampling.

Machine studies—Direct team study of data from work sampling with an analytical survey of the total process.

The direct time study should be used in all cases where significant time elements are involved. Pace rating should be applied to elemental measured times. Rest factors should be applied directly to normal times for jobs in which the man is controlling. Rest times should be subtracted from man ideal times during machine controlled cycles.

Analytical studies, historical data, ratio delay studies, or sampling may be used to determine occurrences of events which are not fully observed during direct study, for example, infrequent production delays, or seldom run products. Exhibit 4 is the result of this examination. This is a **description of how the work should be done, that is, the method upon which the standard is set.**

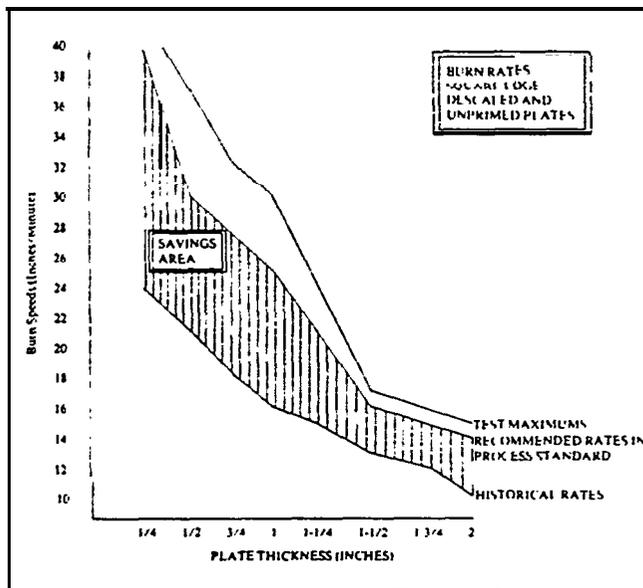
### Step ⑤

The practical operating limitation, operating procedures, and quality limitations of the equipment should be published. These limits should represent the maximum and minimum dimensions that apply when the machine is operated at the production rates used in the process standard. Any processing beyond these limits may require special allowances. For example, normally 70' is the maximum length of a finished part of a certain exactograph flame planer installation. However, by extra work plus 2 crane moves, instead of the normal 1, it is possible to remove a 89' plate. This is outside the machine design limitations, and would require additional standard hours since this unusual occurrence is not included in the standard. The industrial engineer assigned to that area will have to determine if additional standard hours have been earned and thereby avoid all non-standard work. Exhibit (5) is such a machine limitation. Note that machine limitations do not contain any process speeds which are set by the process standard. The speeds shown are those of which the machine is capable, not the standard speeds at which the burning process will take place.

**Step 6**

Development of the standard reflects the resources\* that are required to operate the process successfully. For plate cutting on the machine selected for this example, it is necessary to determine what torch travel speeds will be used so that the cutting times required can be determined.

Initial data taken during the experiment described in Chapter 2 revealed that the cutting speeds being used were significantly below those recommended by the tip manufacturers for the plate thickness and bevels. It was therefore decided to experiment with cutting speeds to see if they could be optimized. At this point, an experienced burning machine operator, who was also a part-time supervisor, was assigned to the task team. For several weeks he worked with an industrial engineer and they developed an optimum speed, tip size, fuel pressure and volume, oxygen pressure and volume setting for each thickness of plate, each bevel and each surface condition (blasted, blasted and primed with paint, blasted and primed with inorganic zinc primer). Torch travel speeds were increased until the quality of the burned edge was declared unacceptable, and then the speed was reduced so that a consistently acceptable edge was produced with no "flame outs" resulting from the speed. This speed was then the maximum operating speed. Standard times were set, however, using a number that was 80 % of the



**FIGURE G-3: BURNING SPEEDS AS A FUNCTION OF PLATE THICKNESS. HISTORICAL, STANDARD AND TEST RESULTS.**

\*The resources under shipyard control have been identified previously as manpower, material, facilities, and time (duration). Standards should be developed for all four. However this Appendix deals directly with manpower and time duration. Production standards typically are expressed in manhours and machine hours, thereby permitting measurement of manpower, time (duration) and facility requirements.

maximum operating speed to take into account atmospheric conditions, changes in gas conditions, and to set the level for a second class burner rather than the first class man who had run the tests. See Figure G-3 and Exhibit (6).

All the work that was associated with the burning process was incorporated into the process standard. Work which was different for a machine in another location in the shipyard was not included. Thus this process standard was relatively "universal" in that it applied to the machine in any shop. However, the process standard is not a usable end product in itself. It is necessary to take into account the effect of machine location on the output (different crane service delays for example) so a production standard must be developed.

**Step 7**

The various people factors which change from location to location are collected in the form of allowances. When these are combined with the process standard, a usable production standard results. See Exhibit (7).

**Step 8**

A production standard is assembled from the process data and allowances. Much of the data needed is collected during observations taken from the process standards. In addition to establishing the optimum burning speeds, stop watch measurements are made of the other work done by the operators. For example, the load and unload cycles are measured. So are the times to replace tips and adjust torches. In addition to the times established by direct observation and stop watch timing, standard times from standard time data from commercial sources can be used for some elements.

The miscellaneous work which has a low occurrence factor, and is not individually reported as work accomplished, is handled differently. An estimate of the amount of low occurrence work is made for each operation. A standard time is estimated for that work, and the resultant extra hours "earned" are added as an extra percentage to the reported earned hours. See Exhibit (8).

**Step 9**

Although production standards can be used for budgeting and consequently scheduling, their application is sometimes time consuming. Most often this is because the scheduler does not have available to him enough information about the ship to apply the production standard. Consequently, production standards are in some cases condensed so that standard hours (man, machine and

duration) can be determined from the information normally used by the schedulers. In some cases, added information can be made available, such as routines which generate machine instructions for burning parts from the plate using calculated standard machine hours. Some variables and some occurrences may have to be set at average values and the averaging error accepted if it does not increase the statistical deviation above an acceptable value\*.

Scheduling standards are, in fact, approximations of production standards. Where the cost of using the production standards for scheduling purposes exceeds reasonable limits (in this case 5 % or more of the standard hours) it is of experimental interest to measure the error introduced by the approximations. Results of this comparison for a representative set of work packages are summarized in Figure G-4. See Exhibit(9).

FUNCTION	PRODUCTION	SCHEDULE	ERROR INTRODUCED
WELDING	8%	5-6%	1-2%
BURNING	7%	4%	1-2%
FIT UP AND TACK	5%	N. A."	N. A."
SHAPE LAYOUT	12%	1-2%	1-2%

\*N.A. = Not Applicable

FIGURE G-4: COST TO APPLY STANDARDS TO FABRICATION SHOP FUNCTIONS.

EXHIBIT(1)

OUTLINE OF ITEMS COVERED AT MEETING WITH PRESIDENT AND WITH SHIPYARD MANAGEMENT

SUBJECT: ENGINEERED PLANNING AND SCHEDULING STANDARDS

L Goal

To improve management control over schedule performance and labor costs through improvements to the data used for scheduling and productivity measurement.

\*Although deviation may be increased, scheduling standards usually are applied multiple times so that the plus and minus errors tend to cancel each other. The total error reduces in direct proportion to the square root of the number of times that it is applied.

$$\text{ERROR} = \frac{\text{STANDARD DEVIATION OF TOTAL POPULATION}}{\sqrt{\quad}}$$

- II. Method - Proposal
  - A. Improve accuracy of planning forecasts by using engineered standards to schedule load at all work stations.
  - B. Measure work station schedule performance.
  - C. Determine man-hour content of required work and develop engineered standards for performance measurement.
  - D. Develop necessary reporting system and measure labor productivity at the lowest level of accountability.
  - E. Select and use best manufacturing method.
- III. Expected improvement in Schedule Performance
  - A. Present level of schedule compliance,
  - B. Anticipated level of schedule compliance.
  - C. Benefits from Achieving B.
- IV. Expected Improvements in Productivity
  - A. Present levels of labor productivity.
  - B. Potential levels of labor productivity.
  - C. Savings in labor costs.
  - D. Benefits from improved control over methods.
- V. Proposed Organizational Responsibilities and Accountabilities
  - A. During study period.
  - B. After study period.
- VI. Schedule of Action Steps for Conducting Study and Implementary Results
  - A. Getting the support of supervision.
  - B. Assemble necessary team of skilled people.
  - C. Cost and schedule milestones.
- VII. Discussion of Potential Problems and Their Mitigation
- VIII. Action Which Will Be Undertaken by President
  - A. Charter letter to Division Managers
  - B. Progress review meetings.
  - C. Visible support.

EXHIBIT(2)

ORGANIZATION OF THE STUDY EFFORT

Successful industrial engineered standards setting operations have been accomplished by a team of industrial

engineers and production supervisors working together. This method saves a lot of time normally lost while the engineers become knowledgeable in the work methods used in the production process. The production supervisors learn new skills from the engineers and when the project is completed, they return to their production assignments supporting the effort because of their involvement in it.

The team members must all have analytical skills (latent or developed), must be able to communicate, and must have impeccable integrity. Clean statements of the authority and accountability of the team members must be made. Team budgets and schedules must be established and monitored.

Sample memoranda are attached.

Communications are a key element to any innovations. Consequently careful attention is paid to letting people know what is going to happen and why. "U and A" Understand and Accept - is the password.

**MEMORANDUM**

FROM: James A. Burns, President  
 TO: Division Heads  
 SUBJECT: improved Scheduling Data  
 DATE:

This memo establishes a task force to improve the data which we use to operate our business. Increasing competitive pressures mean that we must bid more aggressively, and that requires improved data. Once we have a construction contract, we must meet our schedule and cost commitments. Again, one of the tools which we need is improved data on the time required to perform the work.

Therefore, we are commissioning a task force to use industrial engineering techniques to build us a set of numbers which will meet our needs for improved control. Industrial engineering will contact you to arrange a briefing in your division during the next 10 days to explain the program, to answer questions and to receive your suggestions.

J. R. Harris, Chief I. E., will manage this project for the President's Office. Organizational memo is attached.

**MEMORANDUM**

FROM: J. R. Harris, Chief, I.E.  
 TO: Division Heads  
 SUBJECT: Scheduling Data Task Force  
 DATE:

The task force will combine the forces of industrial engineering, planning and production departments.

AREAS TEAM ASSIGNMENTS	FABRI- CATION							
	ASSY	WAYS	OUTFIT	SHOPS	PAINT	MAT'L HAND	WARE- HOUSE	
K. P. Giles (IE)	L	L						
C. L. Mays (Steel Dept.)	X	X		X			X	
R. E. South (Steel Dept.)		X	L				X	
R. G. Frost (Steel Dept.)	X				X	X	L	
R. W. Thomas (IE)	X	X	X					
S. J. Lovelace (Planning)			X	L	X			
J. M. Brown (Planning)			X	X	L		X	
J. E. Lewis (IE)			X	X	X	L	L	
P. A. Cline (Outfit Dept.)			X	X	X	X	X	
J. E. Pardeaux (IE)			X	X	X		X	
Scheduled Start	2/1	4/1	6/1	6/1	9/1	9/30	10/15	12/1
Scheduled Finish	3/30	1/15	7/30	9/30	12/30	12/1	12/15	1/30

L = Leadership Responsibility

Results will be reviewed with department heads regularly. Standards will be published as soon as production area is completed.

**EXHIBIT (3)**

**OUTLINE OF INFORMATION MEETING WITH SUPERVISION AND WITH HOURLY WORKERS ON IMPROVEMENTS IN PLANNING AND SCHEDULING**

**SUBJECT IMPROVEMENTS**

- I Brief introduction of each person on team-quick positive biographical comment.
- II. Outline Objectives-Be positive about benefits to the audience. Mention the obvious features.
- III. Explain how objectives are to be achieved. Listen for feedback which might contain helpful information. Answer questions and encourage discussion.
- IV. Explain team conduct below.
- V. Explain to audience what their role is going to be in this effort.
- VI. Ask for their assistance and cooperation. Without it you will fail.
- VII. Answer questions.

**GUIDELINES FOR TEAM CONDUCT**

Do not interfere with in-process work.

Observe present conditions.

Stand out in the open. Do not study people unless you tell them first that you are going to do so, and what you are going to observe. If you do not know the operator be sure that his supervisor introduces you and tells the man why you are there.

Show your study sheets and explain them to the operator and supervisor involved, whether they ask to see them or not.

Document how the work was done.

Pace rate each element.

Share results first with the supervision involved.

## EXHIBIT(4)

### EXAMINE PRODUCTION PROCESSES

(Instructions given to operator so that operations follow a repeatable sequence for observing/measuring operations.)

#### OPERATING DESCRIPTION

Of Work Covered By Standard On  
Exactograph Flame Planer  
PC418

As Used In Establishing  
Production And Scheduling Standards

#### MACHINE

Exactograph Flame Cutting Machine

#### PARTS COVERED

Steel Plates

#### OPERATION

Set Up  
Burning  
Plate Handling

#### ALLOWED TIME AND DIMENSIONS

All times are in minutes and hundredths of a minute.

Distance in feet and inches.

#### ANALYSIS

Variables: Plate Thickness, length of plate, amount of slag to be removed, speed of cuts, paint thickness, tips, paint composition, desired edge cut, angle or square cut, number of passes per side.

#### TOOLS REQUIRED

Spare tips, cleaning brush and tip cleaners, combination square, tip wrench, soap stone, hand strikers, paint and brush.

#### PLATE HANDLING

Plates are loaded and unloaded with a 16-ton magnetic crane.

#### MACHINE CAPABILITIES

The flame planer machines are capable of burning and double beveling sides and ends of one 14' x 90' plate internally. The main bridge for side cutting is equipped with two torch carnages with free floating heads and triple torches. The two auxiliaries are each equipped with one torch carriage with free floating heads and triple torches for bevel cutting.

#### BEGINNING AND END POINTS

1. Set-Up Main begins with "position main bridge" and ends with "start of edge cut."
2. Set-Up Auxiliary begins with "position auxiliary bridges" and ends with "start of end cut."
3. Hand Bum Scrap begins with "obtain torch" and ends with "aside scrap. "
4. Chip Slag begins with "obtain scraper" and ends with "visual inspection. "
5. Mark Plate For Identification starts with "obtain paint and brush" and ends with "aside paint and brush."

#### PROCEDURES

When the plate length is not adequate to allow auxiliary 1 and 2 to cut internally to the main bridge, the first cut will be with auxiliary 2 and will be external time. Main bridge set-up will be done internally to auxiliary 2 burn. Following auxiliary 2, start main, set-up and start auxiliary 1. Perform scrap functions internally as time permits.

If one end requires two passes (i.e., to obtain a bevel and 60° chamfer undercut) and the other end requires only one pass, the single pass end will be burned first by auxiliary 2 to minimize the interference between the main bridge and auxiliary 2.

EXHIBIT(5)

MACHINE LIMITATION

APPROVED \_\_\_\_\_

NO. \_\_\_\_\_

DTD. \_\_\_\_\_

ASSET NO. \_\_\_\_\_

MACHINE CAPABILITIES

HARDINGS PLANT

Exactograph Flame Planer

	Length	Width	Thickness
Max. incoming plate size:	90'	14'	4"
Min. incoming plate size:	9'	2'	1/8"
Max. size of finished part:	70'	13'-9-3/4"	4"
Min. size of finished part:	4'	6"	1/8"

Min. edge trim: 1/4" per side on cut plate

Max. edge trim: 137-3/8"

Number of heads:	Main bridge 2 triple torches	Each of two aux. bridges 1 triple torch
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Machine speeds:	High Speed Travel Drive System	40-980 IPM 4-65 IPM
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Rail length: 101'

Parking Space:	East Aux. 7' West Aux. 7' Main Bridge -15'-6"
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Tolerances

Width ± 1/16 in 40'

Length ± 1/8 in 40'

Edge preparation single pass:

square, bevel over up to 45°, bevel under up to 45°,  
double bevel up to 45° each X or K cut.

Separate pass needed for bevel under 60° and/or 4:1 chamfer.

- Notes: (1) Minimum distance between main torches for square or bevel under is 16".  
(2) Torches in one head can adjust to strip from 7" to 11½" wide. Can burn one, two, or three at one time.

EXHIBIT(6)

INDUSTRIAL GAS

PLT. THK. INCHES	TIP SIZE No.	CUTTING SPEED IN/MIN	OXYGEN CUTTING PRESS. P. S.I.G.	PREHEAT PRESS. P. S.I.G.	MAPP GAS PRESS. P. S.I.G.
1/4	68	24-31	60-70	5-10	2-10
3/8	65	23-30	70-80	5-10	2-10
1/2	60	22-29	80-90	5-10	2-10
3/4	56	20-26	80-90	5-10	<b>2-10</b>
1	56	18-24	80-90	5-10	2-10
1-1/4	54	16-22	70-80	10-20	2-10
1-1/2	54	15-20	80-90	10-20	2-10
2	52	14-19	80-90	10-20	2-10
2-1/2	52	12-17	80-90	10-20	4-10
3	49	10-14	80-90	10-20	6-10
4	44	9-13	80-90	10-20	6-10
6	44	7-11	80-90	10-20	10-15
8	38	6-9	<b>80-90</b>	<b>5-30</b>	10-15

Performance Data for HS ( 1 piece) and FH (2 piece)  
High Pressure Cutting Tips

Cutting oxygen pressures at the torch. All recommendations are for straight line cutting with 3 hose torch perpendicular to plate.

Preheat pressures measured at regulator based on 25' maximum of 5/16" I.D. Hose. Preheat oxygen 10-30 P. S.I.G. (injector torch).

Information from MAPP ADG-MAPP 1026

4-73 -50M-1327

## EXHIBIT ⑦

### ALLOWANCES

Personal Allowance based on 480 minute shift:

- 2 % = 10 Minute Morning Break
- 5% = 24 Minute Personal
- 5 % = 24 Minute Miscellaneous And Interferences
- 12 % TOTAL

## EXHIBIT ⑧

### STUDY SHEETS FOR DEVELOPMENT OF STANDARDS

Includes:

1. Work Steps - pages G-11 through G-13
2. Sample Job Method Ticket - page G-13

### WORK STEPS

Ref.

1. Check paper work.  
Compare daily sequence sheet to daily write-up sheet for plate size and job number. Job number identifies B/M summary sheet for cutting instructions and dimensions.
2. Load and position plates.  
Crane lowers plate on skid and slides against plate guides. Plate guides are operated from control panel on main bridge.
3. Measure length (stl. tape).  
Operator measures length of plate with 100' steel tape and small hand magnet. Stl. tape is secured on one end of the plate and walked the length of the plate to verify adequate stock.
4. Position main bridge (30')\*\*, set torches for parallel check.  
The main bridge is moved to the finish end of the plate. Torches are set to approximate width dimension.

• Bill of material

● "Distance talc. 10' required west skid, 50" required east skid. Ave. distance = 30'.

5. Check parallel (main bridge).  
Bridge is motor driven at 65 F.P.M. the full length of plate, at the same time the operator walks backwards and visually checks runout to verify adequate stock for required width for burn.
6. Set-up for straight and/or angle cuts.  
For straight cutting, the set-up consists of checking center torch for vertical level and set for correct width cut. Angle set-up 60° and less for over bevels can be obtained by positioning bevel torches into slots of pre-set guides of 22 1/2°, 30°, 45°, and 60°. Angles of greater than 45° or chamfers of 4 to 1 for under cutting must be done by removing burning tip and adding pre-set extended torch head. Under cutting must be done after a straight cut for desired width has been done (i.e. a second pass).
7. Ignite Torch(es) and pre-heat.  
The torches are ignited by hand switches. Bridge is moved into start position allowing for pre-heat prior to cutting.
8. Preliminary cut, check measurement and set-up.  
Cut into scrap part of plate, aside bridge, measure with steel tape for accuracy and adjust if necessary.
9. Start main cut.  
Start bridge and dial speed.
10. Walk and obtain Aux #2 (approx. 55').  
Walk from the start end of plate to west end of skid for auxiliary bridge #2 (see note #1).
11. Position Aux #2 (15').  
I-land push Aux. #2 (15') at 65 F.P.M. to the finish end of plate (see note #1).
12. Ignite torch(es) Aux #2. "  
See reference #7.
13. Set-up (Straight and/or Angle).  
See reference #6.
14. Preliminary cut and check.  
For straight cuts and over bevels or under bevels of less than 45° checking can be visual. For preliminary cuts of over 45° and chamfers of 4 to 1 check by cutting into scrap part of plate, aside bridge, check, adjust if necessary.
15. Start final cut.  
See reference #9.

16. Walk and obtain AUX #1 (approx. 115').  
Walk from finish end of plate to Auxiliary # 1 (see note #1).
17. Position Aux #1 (60').  
Hand push AUX #1 to start end of plate approx. 60' at the rate of 65 F.P. M. (see note #1).
18. Ignite torch(es) Aux #1.  
See reference #12.
19. Set-up (Straight and/or Angle).  
See reference #13.
20. Preliminary cut and check.  
See reference #14.
21. Start final cut.  
See reference #15.
22. obtain hand torch (15").  
Climb on plate and walk to main bridge for hand torch. Ignite from main torch.
23. Hand burn scrap.  
Cut edge scrap, both sides, into 4' lengths and let rest on railroad irons.
24. Aside Torch (6").  
Turn off torch and return it to main bridge.
25. Aside Scrap.  
Lengths of scrap on right side of plate are put into scrap trays located an average of 3' on right side under skids. Scrap on left side is did across plate and put into trays. Average distance of 13'.
26. Hand chip slag (straight).  
Operator removes slag with hand scraper.
27. Hand chip slag (angle).  
Same procedure as straight removal except amount is greater and more time is required.
28. Return to AUX #2 (40').  
Walk 40' to AUX #2 at finish end of plate (see note #1).
29. Stop and aside Aux #2 (approx. 15').  
Lock floating head to prevent dropping over end of plate. Shut down machine. Hand push bridge to west end of skid (see note # 1)
30. Return to Aux #1 (60').  
Walk approximately 60' to Aux #1 at start end of plate (see note #1).
31. Stop and aside Aux #1 (approx 60').  
see reference #29.
32. Obtain hand torch (85').  
See reference #22
33. Hand burn scrap.  
See reference #23.
34. Aside torch (6').  
See reference #24.
35. Aside scrap.  
See reference #25.
36. Hand chip slag (straight).  
See reference #26.
37. Hand chip slag (angle).  
See reference #27.
38. Return to main (15').  
Walk approximately 15' to main bridge at finish end of plate.
39. Stop and aside main (60').  
Lock floating burning heads to prevent dropping over end of plate. Stop all functions of main by pushing stop all button of control panel. Turn on high head travel at 65 FPM and walk 115' to position main for next plate (see note #2).
40. Aside scrap.  
See reference #25.
41. Hand chip slag (straight).  
See reference #26.
42. Hand chip slag (angle).  
See reference #27
43. Hand paint piece marks.  
Walk to main bridge for paint and brush approximately 60'. Return to start end of plate (60'). Paint job number and next location and repeat for finish end. Return to main bridge (115').
44. Aside Plate.  
The magnetic crane removes finished plate from skid.



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**Section B - Application of Occurrence Allowances**

Add .31 hours for loading and main bridge set-up.

Add .09 hours for each 60° under or 4:1.

Based on plate thickness and burn length, add the longitudinal burn time from the attached table.

Add the burn time for external butt passes if required as determined by the instruction in "Internal Burning of Ends."

Add 12% to this total for allowances.

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**Section C - Allowances**

Allowances for shift start up and clean up, fatigue, personal relief, and miscellaneous delay totaling 10% are included.

**Section D - Direct Crew**

This standard is based (1) Machine Operator

**Section E - Material Handling**

Time is included for load and aside plates and for scrap tub removal, but the crane operator's time is not included.

418-S	Oct. 7, 1975		1/8" incre.	1	2	3	4	5	6	7	8	9	10	11	12			
				IPM	17	14	10	9	8	7	6	5	4	3	2	1		
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TIPS																		

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EXHIBIT 9 (Cont'd)

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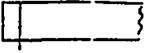
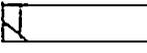
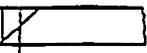
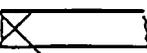
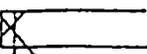
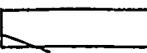
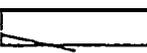
Plate IPM	Hours Per Bum Length Shown In Feet														
	5	6	7	8	9	10	20	30	40	50	60	70	80	90	100
8	.138	.165	.192	.220	.248	.275	.55	.825	1.10	1.37	1.65	1.93	2.20	2.48	2.75
10	.110	.132	.154	.176	.198	.220	.440	.660	.880	1.10	1.32	1.54	1.76	1.98	2.20
12	.092	.110	.128	.147	.165	.183	.367	.550	.733	.917	1.10	1.28	1.46	1.65	1.83
14	.079	.094	.110	.126	.141	.157	.314	.471	.629	.786	.94	1.10	1.26	1.41	1.57
16	.069	.082	.096	.110	.124	.138	.275	.412	.550	.687	.83	.97	1.10	1.24	1.38
18	.061	.073	.086	.098	.110	.122	.244	.367	.489	.611	.73	.85	.98	1.10	1.22
20	.055	.066	.077	.088	.099	.110	.220	.330	.440	.550	.66	.77	.88	.99	1.10
22	.050	.060	.070	.080	.090	.100	.200	.300	.400	.500	.60	.70	.80	.90	1.00
24	.046	.055	.064	.073	.082	.092	.183	.275	.367	.458	.55	.64	.74	.83	.92
26	.042	.051	.059	.068	.076	.085	.169	.254	.338	.423	.51	.60	.68	.77	.85
28	.039	.047	.055	.063	.071	.079	.157	.236	.314	.393	.47	.55	.63	.71	.79
30	.037	.044	.051	.059	.066	.073	.147	.220	.293	.367	.44	.51	.58	.66	.73
32	.034	.041	.048	.055	.062	.069	.138	.206	.275	.344	.41	.48	.55	.62	.69
34	.032	.039	.045	.052	.058	.065	.129	.194	.259	.324	.39	.46	.52	.59	.65
36	.031	.037	.043	.049	.055	.061	.122	.183	.244	.305	.37	.43	.49	.55	.61
38	.029	.035	.041	.046	.052	.058	.116	.174	.232	.290	.35	.41	.46	.52	.58
40	.028	.033	.038	.044	.050	.055	.110	.165	.220	.275	.33	.39	.44	.50	.55

ABOVE HOURS INCLUDE 10% ALLOWANCES

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### Edge Preparations

	Sq.
	Bevel Under (Also with square)
	Bevel Over (Also with square)
	Double Bevel "X"
	Double Bevel w/land "K"
	Bevel Under 60°
	4:1 chamfer

Each of the above edges requires one pass.

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### Calculation of Standard Time

1. Determine quantity of pieces to cut from the plate.
2. Select time for length pass from table that corresponds to [the length of burn, thickness of plate and edge preparation. Use the slower burn rate if the edges vary in preparations.
3. Select the appropriate set-up times for the specified edge preparations.
4. Repeat (1) and (2) if more than one length pass is needed.
5. Determine the end passes that cannot be performed internal to the main burn: see Internal Burn of Ends. Select time for each external pass. Common line burn is used for adjacent square butts of two pieces.
6. Select the appropriate set-up times for each external pass.
7. Add together the time to check paper work, set-up, burn plus allowances.

### Section F - Procedure Description

#### Internal Burning of Ends

At least one butt pass is performed internal to the main bridge longitudinal burn. To determine how many other butt passes can be performed internal to the main add 12 feet to the length of each butt pass plus 4 feet. Accumulate one at a time, the length plus 4 feet for each pass. Each new total that does not exceed the overall length of the plate is another pass that can be done internally. Each pass that exceeds the length will be performed external to the main burn, therefore adding to the overall time to burn the plate. The functions of burning scrap, aside scrap and chip slag are considered internal to the burning also. There is usually enough idle time during burning to perform these tasks since the time per foot of burn averages .23 minutes. For a 10' x 40' plate the time needed to take care of scrap and slag is 23 minutes.

The reason butt passes can be burned internal when plate length is greater than 12 feet plus butt pass length plus 4 feet is:

1. 12' 1/2" minimum distance between Aux 1 and main bridge torches
2. the length of the butt pass is offset by the comparable distance traveled by the main bridge
3. adding four feet offsets the distance traveled by the main bridge during the set-up and preheat for the width burn.
4. one butt can always be burned internal by Aux 1 because the butt can be burned without any chance of interference with the main bridge since the main bridge is moving away.

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### Section G

#### APPROVALS:

Prepared By: \_\_\_\_\_

Reviewed By: \_\_\_\_\_

Dept. Supv.: \_\_\_\_\_

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## APPENDIX H

### AUTOMATIC DATA PROCESSING

The computer can be a valuable asset to a shipyard if used effectively. The proper role of a computer in shipyard operations depends on the particular systems being used, the size and complexity of the processes involved, and many other details unique to each situation. Some general considerations of what to automate are presented here, along with the evolution of computer usage over the past several years.

## H-1 The Proper Role of a Computer in Shipyard Operations

What functions should be put on the computer? Before answering this question, consider what the historical trend has been.

ADP technology first began to impact business in a serious way only about twenty-five years ago when accounting functions were transferred from punched card tabulators to the early IBM machines (the Model 701 system for example). Accounts receivable was one of the first applications computerized because business depended on the flow of cash as the human body depends on blood. Next was payroll because business also depends on its people.

Inventory control followed shortly thereafter, because by this time most companies had arrived at a hand-shaking agreement with the computer and inventory control was a nice neat problem to attack.

Next came order processing and work-in-process tracking because customers always wanted to know how their orders were progressing before making progress payments, and the banks required the value of work-in-process before making loans.

In considering this progression which typically took place over a period of say ten to fifteen years depending on the industry, three facts become clear. First the progression was from the well-known and orderly functions like accounting and payroll to the less well-known (in those days, that is) like inventory. Accounting functions were, in fact, already being run on electrical/mechanical tab equipment.

Second, it was typically the financially oriented applications that were treated first rather than the manufacturing operations. Accordingly computers were placed under the custody of the comptrollers, and the focus remained financial.

Third, as pressures to apply computers to less well understood functions grew, there tended to be a flurry of research activity directed toward establishing the logic and principles of the application. Research in network processing flourished as more and more companies turned to PERT/CPM for scheduling. For a while the job-shop scheduling and sequencing problem received a lot of attention as operations researchers attacked the chaotic conditions of the typical job-shop.

Still the financially oriented motive was dominant. And where pioneers attempted to apply computers to unknown areas, the areas were seldom considered as parts of a larger whole, but rather as separate and individual problems.

Accordingly, other than in the financial area, there emerged a motley collection of semi- or fully-independent applications which typically overlapped each other; were not consistent; and demanded excessive clerical input for rather meager output.

Why hasn't the computer performed as well as it should after all these years? It is simply that the financial focus is the wrong focus. Financial data is historical data; it tells you how well the company has performed in a prior accounting period; it does not tell how well the company is performing now nor does it forecast how well it will be performing in the future.

A moment's thought will show why this is so. Financial data is obtained by converting units of physical resource (facilities, labor, material) into dollars. But it is the applications of physical resources that drives production. Although dollars are needed to acquire the resources, it is still the skill with which the resources are planned, applied, and monitored that determines whether the operation will be financially successful or not. The financial statement itself is only an accounting of performance in units of dollars after the fact. It is the production planning function that is central to the financial health of the shipyard, not the accounting function.

The effective harnessing of the computer to production needs demands a complete reorientation in thinking to emphasize planning and scheduling as central to the successful operation of the shipyard: all other functions are then seen to be derivative and will fill into their proper places within the system. The reason that separate independent systems like work-in-process tracking, inventory control, material requirements planning, etc, etc, have developed—each with their separate sets of reports—is that there was no framework to hold them all together. The focus on production oriented planning will solve this problem if it is always remembered that planning is not an end in itself; rather it is the means for effective production.

## H.2 What Functions to Automate

Automation should be considered only when: (1) a manual system does not provide the response needed to maintain the efficient flow of production work, or (2) when automating the system (really portions thereof) will reduce the cost by more than enough to recover the cost of automating within a period of at most two years or so. If either (or both) of these conditions exist, then automation should be seriously considered.

The next step is to identify which functions to automate. Here the natural tendency is to focus on the production of better management reports. But this is the wrong focus.

The focus should be on corrections of problems, and on providing necessary and relevant information to management—no more, no less. Another is to clean out congestion in the feedback control system. The improvement in information to management then becomes automatic. Even more important, the problems—and there are many more than one might suspect—which derive from faulty or obsolete information will vanish.

So what are the basic elements of feedback control? They are:

- (1) The budget—material, manpower, facilities and time allotted for a job.
- (2) The schedule—the calendar dates between which specific jobs are to be accomplished.
- (3) The cost\* collector—the vehicle for collecting resource expenditures and physical progress.
- (4) The monitor—the mechanism for measuring expenditure against budget and progress against schedule and detecting out-of-tolerance conditions.
- (5) The regulator—the corrective action to be taken when out-of-tolerance conditions exist.

Note that the financial dimension is not included as a separate item on the list. The reason is that if expenditures and progress measured in terms of physical resources tracks budget and schedule, then the dollar costs will fall into line. If the resource expenditures don't track budget and schedule, then there is nothing that can be done on the financial end to correct the situation. Items (1) and (2) are central to the system since without these, there are no yardsticks to measure performance. Cost collection has no control value unless the yardsticks exist. Item (5) represents the basic management function which should never be automated.

Two major changes in ADP technology have occurred over the past decade that significantly increased the utility of computers in planning and control systems. First was the introduction of the disk as a large, random access storage device. This device allows a large amount of data such as that required for maintaining budget information (material lists, work package labor allowances, etc.) in an immediately accessible form.

Second, is the development of low cost communications and data equipment which makes access to a central data base from remote locations economically acceptable to an average company.

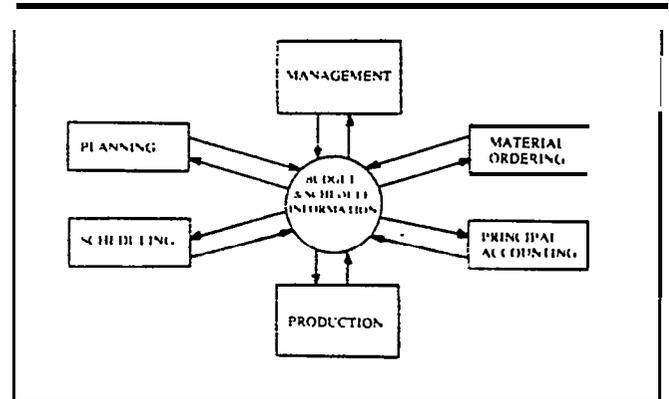


FIGURE H-1: PLANNING AND PRODUCTION CONTROL SYSTEM STRUCTURES

“ These two developments together make it quite feasible to set up a centralized file of directly accessible planning information (Figure H-1) that all authorized users have immediate access to via communications links and terminals. They also make it possible to collect expenditures and progress information with minimum manual effort, and store it with the associated work packages so that management has immediate access to information on performance to budget and schedule. Even more important, this system can produce exception reports to spotlight pending out-of-tolerance situations before they become chronic.

For industries like shipyards which have typically a few large projects (and perhaps some smaller ones) information within the system should be organized in terms of the work break down structure used for planning and managing the project. The basic grouping of data will then correspond to work packages which will have associated with them budget (material lists, labor allowances) and schedule information. As expenditure and progress information is collected, it is accumulated by work packages alongside budget and schedule information (Figure H-2) so that variances are immediately detectable.

with such a system all of the basic information is there for effective control of production. And it can be sorted and grouped into a variety of different reports or display screen formats to satisfy a number of different user needs. For example, a shop superintendent may want to know what his scheduled work load is four weeks in the future. The computer scans work packages assigned to his shop. Because schedule information and the allowances are

● cost is used here in the broad sense of physical resource expenditure, not dollars.

stored there, the projection is made by adding labor allowances together by week for each of the four weeks and outputting the results\*.

WORK PACKAGE NO _____		SCHED ISSUE _____	
WORK PACKAGE NAME _____		SCHED COMPLETION _____	
SCHED COMPLETION _____		ACTUAL COMPLETION _____	
<b>MATERIAL</b>			
PLANNED		ACTUAL	
_____		_____	
_____		_____	
<b>LABOR</b>			
PLANNED		ACTUAL	
_____		_____	
_____		_____	
<b>FACILITIES</b>			
PLANNED		ACTUAL	
_____		_____	
_____		_____	

FIGURE H-2: BASIC INFORMATION GROUPING WITHIN A PLANNING AND CONTROL SYSTEM

Complexity of the system can be increased to accommodate practically any additional function desired. it can be turned into a printing press for production of operations sheets, or job instructions, etc., etc.

But the real pay-off will come when the simplest possible structure is implemented consistent with planning and production needs. And again the key to the success of this system is reliability and consistency of the budget data it contains.

One final comment should be made before closing this subject. The collection of the data for measuring system and production performance required to identify improvement needs and opportunities is an automatic by-product of the system. it therefore satisfies the requirement stressed in Part III for self-regulation.

\* There are much more effective ways of implementing this function; the example is only used to illustrate the fact that answers to many different function are Possible with this relatively simple system.

## APPENDIX I

### BASIC STATISTICAL CONCEPTS

Understanding Part III of this Manual presupposes a general familiarity with several basic statistical concepts. This Appendix is provided for those readers who do not have this familiarity. It presents in layman's terms these concepts:

- Performance Factor
- Distribution
- Average
- Dispersion (or scatter)

More thorough and rigorous treatment can be found in any standard text on statistics.

### 1. 1 Performance Factor

If an operation or process is to be controlled, there must be a method or mechanism available to measure performance. For example, in order to control the speed of an automobile there must be some instrument for measuring how fast it is going. This is the function of the speedometer. The speed limit acts as a standard. If the speedometer registers speed greater than the limit, speed is excessive.

Sometimes on major highways two limits are posted - a minimum of say 40 miles per hour and a maximum of 55 miles per hour. If the speedometer registers between these two standards, then speed is within tolerance. If it registers either above maximum or below minimum limits, speed is out of tolerance and an adjustment should be made to bring it back within tolerance.

Controlling production operations is similar to controlling the speed of an automobile. Units for measuring production operations are usually expressed in terms of resource expenditures - manhours, machine hours, material usage, or time as appropriate. The standards against which performance of production operations are measured are the resource allowances set during the planning process. Expenditures in excess of allowance indicate poor performance, while expenditures less than allowance indicate good performance\*.

To avoid using two numbers to indicate performance (that is, one for resource expenditures and one for the allowance or standard), differences and/ or ratios may be used so that performance can be indicated by a single number. For example, performance-to-schedule for a job can be measured as the difference between the scheduled completion date and the actual completion date for the job. The units of measurement may be days or weeks depending on the precision desired - the performance indicator then becomes days (weeks) early or late. If the job is completed on time, time early (and late) is zero.

The same method may be used for measuring labor or machine performance where actual performance is measured as the arithmetic difference between man (machine) hour allowance and man (or machine) hour expenditure. On the other hand, it is sometimes more convenient (and in fact more appropriate) to measure labor performance as a ratio. This is usually the case when jobs vary widely in labor content. An overrun of 100 manhours on a 10,000 manhour job is far less significant than an overrun of 100 manhours on a 200 manhour job. In the first case the overrun is only 1% of the total: in the second

case 50%. Unless ratios are used there is no way of comparing performance on different jobs of different sizes.

In using ratios to measure performance, there is a choice of which number - the allowance or the actual expenditure - to use as the numerator. If the allowance is used as the numerator, then ratios greater than 1 mean that actual expenditures were less than allowances so that performance is above standard, whereas ratios less than 1 indicate expenditures greater than allowances so that performance is below standard. The converse is true when expenditures are used as the numerator and allowances as the denominator. Under this convention, superior performance is reflected by numbers smaller than 1 and inferior performance by numbers larger than 1.

In this Manual we have preferred to indicate performance superior to standard by numbers larger than one and hence use this formula:

$$P = \frac{A}{E}$$

for measuring performance. Here A is the manhour allowance for a job (i.e., work package); E is the actual labor hours expended; and P is the resultant performance factor.

### 1.2 Distributions

Shipyards managers are seldom interested in performance on single work packages only. Rather they will be concerned with performance on many work packages which collectively reflect trends in the construction of a ship) or the performance of a shop.

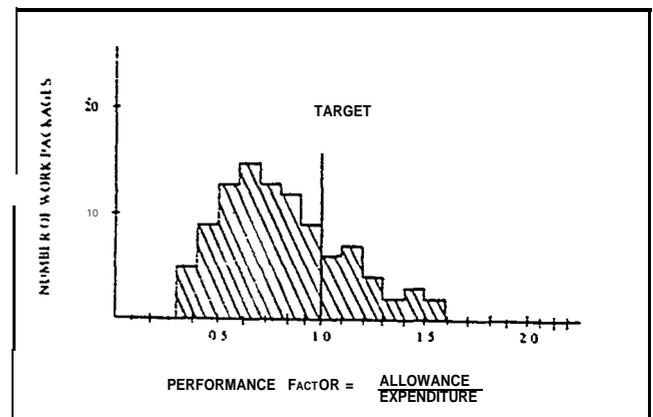


FIGURE 1-1: HISTOGRAM OF LABOR PERFORMANCE

\*Assuming, of course, that the allowances are realistic and reliable guides for action.

One effective method of presenting performance information for many work packages is to plot the data in the form of a histogram as shown in Figure I-1 which portrays the distribution of labor performance about the allowance or target - the vertical line in the Figure which intercepts the horizontal axis at the point equaling 1.0. The horizontal axis represents performance defined in terms of  $P = A/E$  as discussed in the preceding section. If expended hours equal allowed hours, the  $P = 1$  and the job is on target. If A is greater than E, the performance is better than target and will fall to the right of the point 1.0 in the Figure. Similarly, if E is greater than A, P will be less than 1.0 and performance will fall to the left of the point 1.0 in the chart.

The horizontal axis is divided into units equal to 0.1 about the 1.0 line so that the first marker to the left of the 1.0 line represents performance equal to 0.9; the second mark equal to 0.8, etc. To the right of the 1.0 line, graduations of performance are respectively 1.1, 1.2, 1.3, etc.

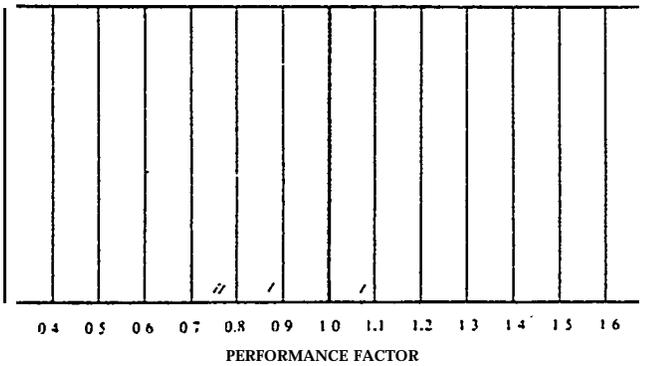


FIGURE I-2: WORK SHEET FOR CONSTRUCTING HISTOGRAM

To construct the histogram, proceed as follows. First, construct a table as shown in Figure 1-2. Second, compute the performance factor for each work package in the sample, using the formula  $P = \frac{A}{E}$ . When a performance factor has been computed, a tally is made in appropriate column on the work sheet. Four such tally marks have been entered in Figure I-2 as examples. The two marks in the column bounded by lines labeled 0.7 and 0.8 indicate that two work packages had performance factors with values between 0.7 and 0.8. Similarly, one work package had a performance factor with a value between 0.8 and 0.9; another 1.0 and 1.1.

For values that fall on the lines exactly (e.g., equal to 0.8, 0.9, etc.) they should consistently be placed either to the right or left of a column boundary line.

When all the performance factors for all of the work packages have been tallied on the worksheet, it will look something like that shown in Figure I-3. Each column then contains a count of the number of work packages having performance factors falling between the column boundaries, as shown in the Figure.

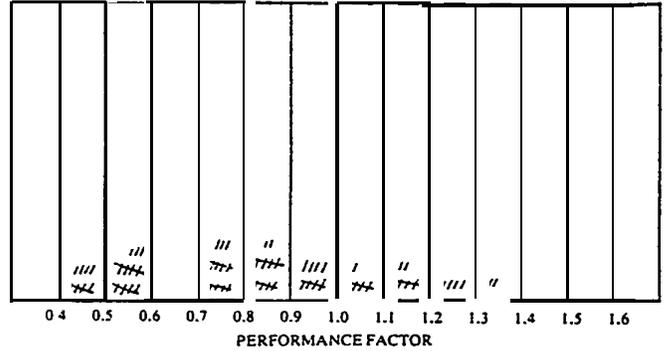


FIGURE I-3: EXAMPLE OF COMPLETED WORK SHEET

The final step is to construct the histogram from the completed work sheet. The horizontal axis in the histogram will be graduated in the same fashion as the work sheet. The vertical axis, however, will be marked off in units corresponding to numbers of work packages, as shown in Figure 1-4.

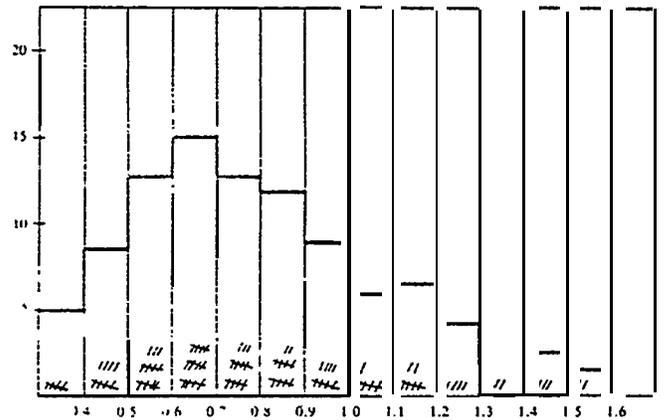


FIGURE I-4: COMPLETED HISTOGRAM

Figure 1-4 is the same Figure as I-1 except that the tallies have been included to illustrate the relationship between counts and heights of the bars in the histogram. For example, the tally shows that 15 work packages had performance factors with values between 0.6 and 0.7. The height of the corresponding column is, therefore, equivalent to 15 work packages in accordance with the

units specified on the vertical axis at the left of the figure. A histogram contains no more information than the work sheet, but presents that information in a more readily intelligible form. A histogram is also a representation of what is known as a distribution.

### 1.3 Averages

The histogram shows rather nicely the spread of performance about the standard. A simple inspection shows whether performance centers around target or whether it is biased in the superior or inferior direction. If a bias does exist, its quantitative value can be found by computing the average of the distribution represented by a histogram. For histograms having the typical form shown in Figure 1-4, the average is the value of the point which has an equal number of work packages on either side of it. Equivalently it is represented by the vertical line dividing the histogram into two parts of equal area, as shown in Figure I-5. Here the average performance factor for the distribution is 0.8 or 20070 below target which represents a significant departure from plans. As discussed in Part III of the main text, departure of average actual performance from target may be due to either poor performance or improperly set targets.

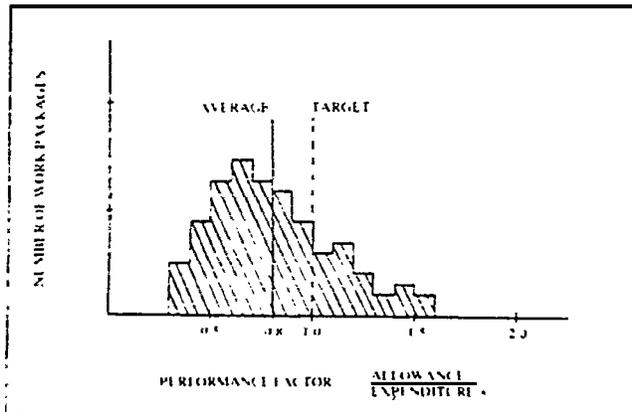


FIGURE I-5: AVERAGE OF A DISTRIBUTION

The average is computed by taking the value of the center point in each column, multiplying these center point values by the height of the column above it and adding all of the products together. This sum is then divided by the sum of all the column heights.

The arithmetic for computing the average in the sample histograms shown above is summarized in Table 1-1. The number of work packages in the sample is 100, and the sum of the products 80.70. Thus the average performance is  $P = 80.70 / 100 = 0.80$  as shown in Figure I-5.

COLUMN BOUNDARIES	MIDPOINT	NO. OF WORK PACKAGES	PRODUCT
0.3-0.4	0.35	8	1.75
0.4-0.5	0.45	9	4.05
0.5-0.6	0.55	13	7.15
0.6-0.7	0.65	15	9.75
0.7-0.8	0.75	13	9.75
0.8-0.9	0.95	9	10.20
1.0-1.1	1.5	6	6.30
1.1-1.2	1.15	7	8.05
1.2-1.3	1.25	4	5.00
1.3-1.4	1.35	2	2.70
1.4-1.5	1.45	3	4.35
1.5-1.6	1.55	2	3.10
TOTALS	N.A.	100	80.70

TABLE I-1 : COMPUTING THE AVERAGE OF A DISTRIBUTION

Histograms are cumbersome to manipulate mathematically. Frequently it is more convenient\* to represent them by continuous curves as in Figure I-6. We have done so in many of the illustrations in Part III of the main text.

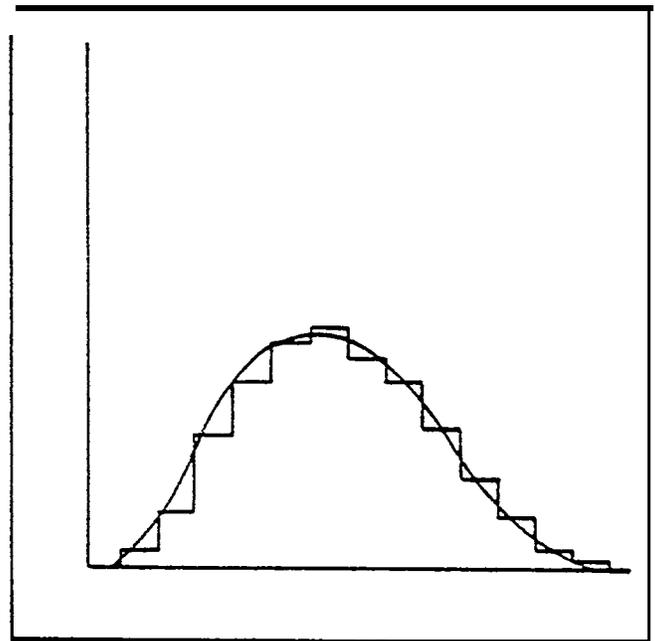


FIGURE I-6: SMOOTH CURVE REPRESENTATION OF A HISTOGRAM

\* There are also round theoretical reasons for doing so which are well discussed in most statistical textbooks.

### 1.4 Dispersion

Distributions of physical processes have an infinite variety of shapes. They can be symmetrical about their averages; or highly skewed. Even attributions with the same averages may reflect different degrees of "spread", as shown in Figure 1-7. Both distributions in this Figure consist of samples of 100 work packages; and both have the same average of 0.8. But A is clearly more peaked and has less spread than B. This means that work package Performance clusters more closely around the distribution average. The average for distribution A is a more reliable indicator of expected performance than the average for distribution B. Put another way, when production operations exhibit the amount of variability in performance shown in distribution B, then work packages with surprisingly poor performance will occur with disturbing frequency. As argued in the main text, it is more important to reduce the variability than to bring the average closer to the standard.

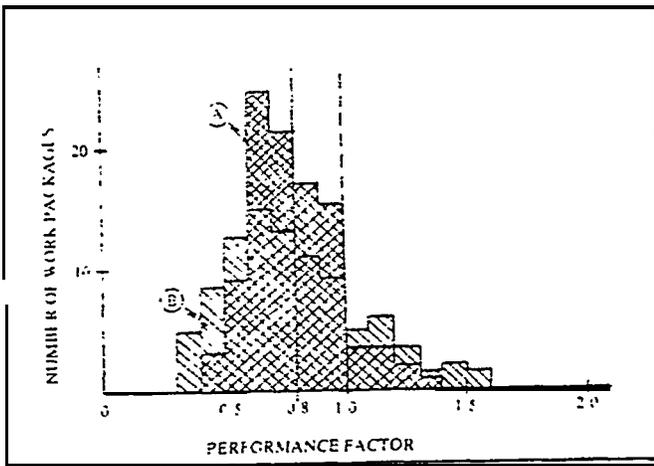


FIGURE 1-7: DISTRIBUTIONS WITH THE SAME AVERAGE BUT DIFFERENT SPREADS

Another more graphic way of portraying dispersion in performance is by means of scatter diagrams. Figure 1-8 is such a scatter diagram for the same 100 work packages used to construct the illustrative histogram shown earlier in Figure 1-4. The vertical axis represents manhour allowances; the horizontal axis represents actual manhour expenditures. Each work package in the sample is plotted in this diagram. Each work package has an assigned manhour allowance. Assume that work package A has an allowance of 750 manhours. First, the point on the vertical axis corresponding to 750 manhours is located. Next, the point corresponding to the manhour expenditure is located on the horizontal axis, which in the sample work package is, say, 1500 manhours. A line parallel to the horizontal axis but at a height of 750 manhours above it, and a

vertical line passing through 1500 manhours on the horizontal axis, will intersect at the point A within the diagram.

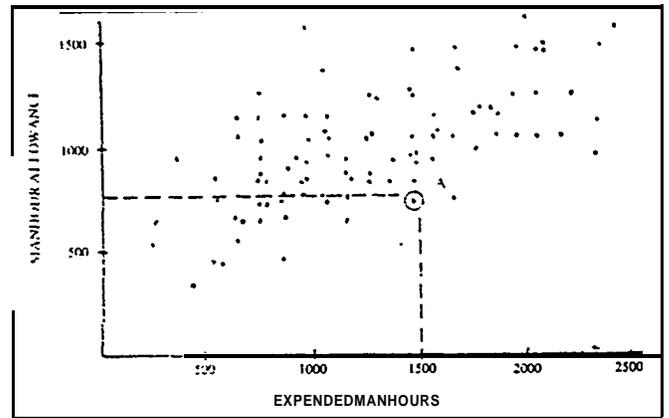


FIGURE 1-8: SCATTER DIAGRAM OF ALLOWED VS. ACTUAL EXPENDITURES

Following the same procedure for each of the remaining ninety-nine work packages in the sample will produce the scatter plot shown in Figure I-8. If actual expenditures were always equal to the allowance, all points in the diagram would fall in a straight line as shown in Figure I-9.

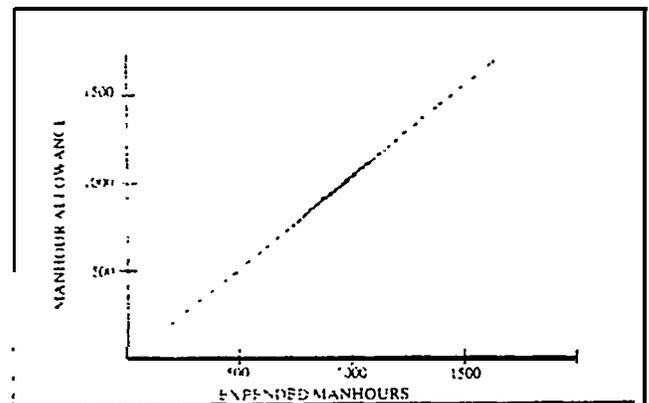


FIGURE 1-9: SCATTER DIAGRAM REFLECTING PERFECT PERFORMANCE

The density of the dots increases toward the center of the line because (in our illustrative sample) average work package size was about 1000 manhours.

A line of perfect performance superimposed on the scatter diagram of Figure 1-8 will provide a reference from which actual scatter can be analyzed (Figure 1-10). Dots above the line represent performance better than standard

while dots below the line represent performance poorer than standard.

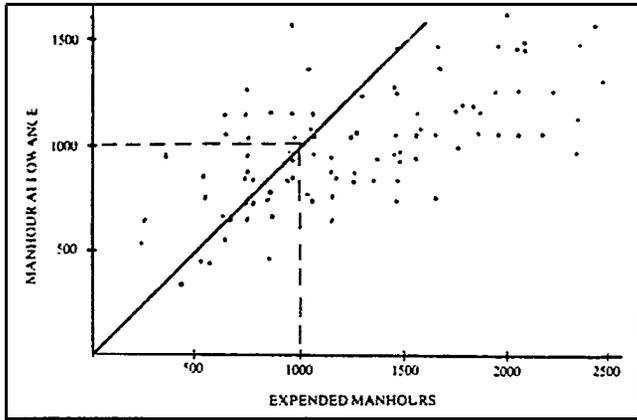


FIGURE I-10: SCATTER DIAGRAM WITH REFERENCE LINE

Two facts become obvious from Figure I-10. First, the points scatter widely about the reference line indicating unpredictable performance\*. Second, many more dots occur below the reference line, showing a strong bias toward substandard performance.

This Appendix has discussed several statistical concepts in a very basic way. For more detailed information in these areas, consult the references in the Bibliography or any standard text or Statistical Analysis.

● Perfectly predictable performance would have a plot like that shown in Figure I-9.

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## GLOSSARY

- Accountability**—the obligation of a position to perform the work assigned and exercise the authority given to the position.
- Assembly**—two or more structural panels joined together in a shop area, attached to a supporting framework or to themselves. Also the term given to larger and more elaborate panels. One or more assemblies may comprise a block (unit).
- Authority**—the power or rights assigned to a position.
- Block**—the largest assembly of steel that will be handled as one piece and lifted into position for attachment to other assemblies. (Sometimes called a unit.)
- Budgeting**—the process of determining what resources should be committed to a given task; an itemized inventory of probable expenditures for a given period. It provides a criterion for judging performance during that period.
- Erection**—the process of lifting an assembly of steel (block or unit) into position for attachment to other assemblies, usually done on the hull.
- Forecasting**—the work of predicting the future, to estimate the conditions, problems, and opportunities that lie ahead: includes assessment of direction, timing, and magnitude of changes.
- Goal Setting**—the process of determining and stating objectives to be achieved.
- Outfit**—that portion of a commercial ship that comprises the propulsion and auxiliary machinery, operating equipment, doors, hatches, ladders, accommodations, electrical equipment, deck machinery, cargo handling equipment, and similar movable [not necessarily portable] items. (Non-structural items.)
- Pallet**—a platform on which material is placed for storage or transportation.
- Panel**—several steel plates joined together in a shop area, attached to a supporting framework or to themselves. One or more panels may comprise a block (unit).
- Performance**—the amount of resources used to accomplish a specific unit of work.
- Actual Performance**—the amount of resources actually expended to accomplish production work.
- Planned Performance**—the amount of resources assumed by the plans and schedules, whether manpower budget, material allocation, facility occupancy, or schedule dates.
- Performance Measurement**—the process of determining the actual expenditures of resources and the actual accomplishment of authorized work.
- Performance Evaluation**—the process of determining the difference between planned and actual accomplishment and expenditures, including assessment of which variances are outside the tolerance band.
- Performance Correction**—the process of taking the action necessary to achieve the desired objective or goal when the actual results are not the same as the planned results.
- Planning**—the process of selecting the course of action to be taken in order to achieve the objectives (in light of the forecasted opportunities and obstacles).
- Production Control**—systematic planning, coordinating, and directing of manufacturing activities and influences to ensure having goods made on time, of adequate quality, and at reasonable cost.
- Responsibility**—the function, duty, or work assigned to a position (or to a department for later reallocation within that department).
- Scheduling**—the process of assigning calendar dates to a sequence of events.
- Steel**—that portion of a commercial ship that comprises the hull, structure, framework, heavy foundations, shell, decking, and similar fixed non-operating items.
- Tolerance**—the range of acceptable variances, that is, the range of variances that will not pose a problem to the overall project.
- Unit**—the largest assembly of steel that will be handled as one piece and lifted into position for attachment to other assemblies. (Sometimes called a block.)
- Variance**—the difference between planned and actual values.
- Work Package**—a collection of information that identifies the drawings, specifications, operation sheets, resource budgets, work sequences, relationship with

adjacent effort, material lists and requirements, cost and progress reporting arrangements, and similar items needed to tell the producer what to do and how to do it. A work package usually covers work described on a single drawing (or portion of it) to be

done by a single trade in a single geographical area of the ship or shop, typically requiring about 500 manhours and 3 months duration.

Zone—a *major* planning *subdivision* of the structural portion of a ship.

OCT 29 1984

