

THE APPLICATION OF COMPUTER-AIDED PROCESS PLANNING  
TO SHIP MODERNIZATION, OVERHAUL AND REPAIR

SHIP PRODUCTION COMMITTEE

PANEL SP-4

DESIGN/PRODUCTION INTEGRATION

Report Documentation Page				Form Approved OMB No. 0704-0188	
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1. REPORT DATE <b>MAY 1991</b>		2. REPORT TYPE <b>N/A</b>		3. DATES COVERED <b>-</b>	
4. TITLE AND SUBTITLE <b>The Application of Computer-Aided Process Planning to Ship Modernization, Overhaul and Repair</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>Naval Surface Warfare Center CD Code 2230 - Design Integration Tools Bldg 192 Room 128 9500 MacArthur Blvd Bethesda, MD 20817-5700</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release, distribution unlimited</b>					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>SAR</b>	18. NUMBER OF PAGES <b>73</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

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## FOREWORD

This report is the product of the National Shipbuilding and Research Program (NSRP) project "The Application of Computer-Aided Process Planning to Ship Modernization, Overhaul and Repair", MARAD contract DTMA 91-84-C-41043, conducted under the auspices of the Ship Production Committee's Design and Production Integration Panel (SP-4) of the Society of Naval Architects and Marine Engineers. The purpose of this study is to investigate and evaluate the use of Computer Aided Process Planning in the extension of Group Technology concepts to ship repair and modernization.

Conducted by CDI Marine Company, this study was performed by RADM H.L. Young, USN (Ret), former Chief Engineer of the Navy and CAPT M.R. Gluse, USN (Ret), former Commander, Norfolk Naval Shipyard.

Appreciation is expressed to Mr. Frank J. Barbarito, Chief Design Engineer, Philadelphia Naval Shipyard, for his unfailing support and review of portions of the manuscript. Mr. Barbarito's pioneering work in Zone Technology relative to the repair and modernization of surface ships undergirds much of this study effort.

Appreciation is also expressed to CDR Larry D. Burrill, Zone Technology Project Officer, Philadelphia Naval Shipyard, for his insight relative to the fine points of Zone Technology and how they relate to the ship repair and modernization process, and to RADM W.C. Wyatt, USN (Ret) for his review of a portion of the manuscript.

## ABSTRACT

To be truly competitive, the U.S. ship repair industry must divorce itself from the entranced, archaic practices that impede the productive work effort and stymie personal initiative. The industry is married to a 50 year old systems-oriented work culture that has failed to reap the benefits of a product-oriented work structure. The application of new construction experience to repair work, specifically, group technology and zone logic, has been limited. Pockets of excellence do exist in the repair industry but, overall, progress has been excruciatingly slow. Where change is taking place, it is more a testimony to individual leadership and initiative than stated Government policy.

Industry experience has demonstrated that when computer-aided process planning (CAPP) is applied to a zone-based, product-oriented work structure, significant cost savings can be realized. CAPP exploits the principles espoused by Dr. W.E. Deming that improvement in any industrial operation is achieved by the constant, bit-by-bit refinement of the process by which work is accomplished. A system or functional approach to work execution does not provide that opportunity. Nor does it allow the creative talents of the work force to be synergistically joined.

Repair yards are captive customers of a depressed market that is essentially Government-sponsored. In a repair industry that is heavily controlled by Navy-induced, systems-oriented policies and practices, there is little stimulus for change. Initiatives are underway by the Navy to optimize work execution at the component level, but solid linkage with zone technology and computer-aided process planning is required if meaningful, cost-effective results are to be realized. Effective change can only come by joint government and industry involvement, a conclusion emphasized in the 1988 report by the Presidential Commission on Merchant Marine and Defense. The time is ripe to develop and execute a truly integrated build and repair strategy. The re-assessment of our sealift capabilities, a necessary fallout of Operation Desert Shield and Operation Desert Storm, can provide the catalyst for change.

## THE PLIGHT OF U.S. SHIPBUILDING/SHIP REPAIR

Hidden within the appendices of the comprehensive 1988 "Report of the Commission on Merchant Marine and Defense" are some very prophetic words, which, to date, have gone largely unheeded:

. ..Although U.S. shipyard management is well aware of the modern production organization methods of process lane work flow and zone/area/stage outfitting, actual conversion of the management process to take advantage of the productivity enhancing concepts has been very elow...if an infusion of federal capital is employed to fund a renewed commercial cargo vessel construction effort... as recommended.. .the opportunity to revolutionize U.S. shipbuilding operational management should be an integral part of the program.. . [1]

In very direct terms, the Commission's statement addresses much of what plagues the U.S. shipbuilding and repair industry today. Without a swift reversal in our thinking, led by strong Maritime Administration and Navy Department policy direction at the corporate level, U.S. shipbuilding will continue its downward spiral. Just as world events serve to shape the fabric of society, those same forces can change the way we do business. The Iraqi invasion of Kuwait, followed by the build-up of U.S. Forces in Saudi Arabia and the ensuing conflict, can be that window of opportunity. Virtually concurrent with the announcement by General H. N. Schwarzkopf III, Chief of the U.S. Central Command, that Operation Desert Shield was being impacted by an inadequate sealift capability, Transportation Secretary S.K. Skinner advised that he was considering asking for a revival of government subsidies to the

u.s. Maritime industry to meet future mobilization needs. The time is ripe for change. [2]

What is being advocated in that statement is a transformation of the U.S. shipbuilding and ship repair base from one that polarizes around the systems of the ship (functional orientation) to one that concentrates on the products indigenous to those systems. The principles of Group Technology (GT) and Zone Technology (ZT) provide a vehicle for such a transformation.

The principles of GT are not new to the U.S., and were described as far back as 1925 by an American, R.E. Flanders. The productivity benefits of the technology have been emphatically demonstrated by foreign shipbuilders, but it has not been widely accepted in this country. In general terms, GT is the operational alignment of production resources, including people, equipment and work products, into self-contained groups, each of which share common characteristics in the manufacture of components, either at the final or interim product level. Zone technology and zone logic - the terms are used interchangeably - refers to the geographic or area control of work when GT principles are applied to a shipboard environment. While a general lack of understanding of GT does prevail, when all is said and done, a leadership vacuum has thwarted the recognition of its merits.

Admiral Frank B. Kelso II, Chief of Naval Operations, in his remarks to Shipyard Commanders at the 31 July 1990 NAVSEA conference on industrial management, addressed the challenges that must be met if our Navy is to maintain its preeminent role as a viable instrument of U.S. foreign policy. Unlike many speeches, the gloves were taken off when he singled out the areas that need immediate attention if the trends of the past years are to be reversed: (1) the need for a competitive environment; (2) the importance of finding new ways to manage in detail; (3) that total improvement can only be realized by constant improvement of the process by which work is accomplished, with a direct reference to Dr. W. Edwards Deming and his principles of statistical quality control; and (4) that leadership, not the worker, is at the root of much of what is wrong in U.S. shipyards.

The salvos directed by Admiral Kelso could not have been more on-target, but they fell short in one vital area: his remarks were directed at an audience whose primary concerns were that of ship repair. Shipyard leadership by itself will not achieve the results required, particularly in ship repair. In a very fundamental sense, a product-oriented work culture demands a change in both the style and structure of operational management. Herein lies the problem. Change requires a recognition that the systems-oriented work structure that has been cultivated over the years has run its course, and that it is time to adapt to more innovative approaches to work execution. That can happen only within an atmosphere



conducive to change. To many leaders in the ship repair industry, today's challenge is one of sustaining employment levels in an era of diminishing workload. When survival is at stake, there is little time to experiment with "new ideas" when quick returns are not in the offing. To others, there is no need for change, when repair work that is predominately government-sponsored is routinely allocated under the guise of mobilization base requirements, and new ship awards are competitively limited to a select few. In a repair industry that is heavily controlled by government-induced, systems-oriented policies and practices, the impetus for effective change can only come by joint government and industry involvement. The seeds for change can be sown at the working levels, but a full harvest requires direction from the top. The Commission foresaw this need for joint action in its Finding No. 22:

In the past, many government programs have addressed only parts of the maritime problem. Coordinated action is now even more essential. To avoid wasting private and public funds, and to address the situation effectively, government leadership (underscoring added) is required to ensure active and constructive cooperation among government, business and labor to make the U.S. maritime industries more productive and cost-competitive in world trade. [3]

In a recent report on the U.S. shipbuilding industry, the Naval Sea System command reported that the capability of shipyards to build large ships was now about 50% of what it was in the early 1980's. [4] Tables 1 and 2, which follow, are derived from data available in the Commission's report and graphically illustrate the precipitous decline in our maritime capability.

Table 1. Core<sup>1</sup> Shipyards in the United States.

	1982		1988	
	Shipyards	Production Workers	Shipyards	Production Workers
Largest Private	5	57,500	5	57,600
Naval	8	39,500	8 <sup>2</sup>	33,000
Remaining Core	67	46,800	44	23,900
Total	80	143,800	57 <sup>3</sup>	114,500

<sup>1</sup>Core shipyard defined as full service", with ability to build or drydock a ship 400 ft. long and 68 ft. in beam.

<sup>2</sup>As of Sept. 1990, under review was the closing of one or more Naval Shipyards, with the downsizing of all eight Naval Shipyards another option under consideration.

<sup>3</sup>As of Aug. 1988, four core shipyards were operating under Chapter 11 bankruptcy protection.

Table 2. Comparison of U.S. Ship Operating Companies, 1970 and 1980

	1970	1987	% Change
Liner Companies	21	14	-33%
Number of Ships	458	137	-70%
Tanker Companies	68	48	-29%
Number of Ships	299	238	-20%
Dry-bulk Companies	21	16	-24%
Number of Ships	32	26	-18%

Comments: (1) 69 commercial ships were on order in 1980. One ship, the first commercial ship ordered since 1984, is now on order.

(2) U.S. shipbuilding is oriented almost entirely to government work, mostly Navy, with 95% of that new construction concentrated in five private shipyards. [4]

## THE FORCES OF COMPETITION

The devastating impact of foreign competition on U.S. shipyards has been well-documented over the past decade. And while out-dated arguments are still being put forth that lower labor rates in foreign shipyards have been the true cause of the demise of U.S. shipbuilding and repair work, those same arguments fly in the face of the productivity gains being realized by shipyards actively pursuing a product-oriented management philosophy. Where changes have taken place, competitive pressures have been a central forcing function. Increasingly, new construction shipyards in the U.S., particularly those involved in major Navy shipbuilding programs, are shifting to zone construction and outfitting. In the process, they have also come to realize that Group Technology can ameliorate the impact of skills shortfalls in many areas. But the full embrace of a product-oriented work structure has been painstakingly slow. In a limited sense, the Navy has given tacit endorsement to group technology by its incorporation of modular drawings into the deliverables package of some shipbuilding contracts. However, this is little more than a short-term step on the part of the Navy, with the expectation that final construction costs will be lower. Furthermore, there has been no tangible spillover of these actions onto the ship repair side of the house.

These same forces of competition do not come into play for repair work. Private repair shipyards find themselves being

captive to a depressed market, and one that is heavily - dependent on government sponsored work. And over the years, Navy policies and practices associated with a systems-oriented maintenance strategy have steadily, but consistently, influenced the operational management structure in place at each of those shipyards. This is not an unusual situation. When a company has one primary customer, the administrative practices that evolve frequently tend to parallel or mirror those of the customer, if only to facilitate the work flow process. With many of the shipyards already operating on the margin, there is little stimulus for change, particularly when those changes represent an upfront investment that cannot be quickly recouped when executed by individual yards. This point comes home in dramatic fashion in situations where there is minimal rollover in work package commonalities applicable to follow-on availabilities. Competition is not a forcing function for change in the public sector either. With the preponderance of available Navy repair work allocated to the eight Naval Shipyards based on mobilization requirements, true competition does not exist in the public sector. Competition sheds the insulation that surrounds the inefficiencies of an industry, and the costs of operations - true costs - are basic to that principle. The Navy Industrial Fund provides little support for that axiom in the public sector.

The Navy Industrial Fund, in excess of \$14 billion, is a revolving fund designed to free more than 50 Navy designated

industrial and commercial activities from annual appropriations. Established in 1977, it functions in a "buyer-seller" environment, and is directly comparable to the corporate profit center concept that prevails in the private sector. But the parallel stops there. Stabilized manday rates (SMDRs) were developed principally to ease the budget preparation process so that the customer could plan, budget, and execute without worrying about cost escalation. This allows the seller, the shipyard, to recover losses or return prior year gains at the end of the fiscal year periods by virtue of an activity group payback feature in the corpus. But SMDRs, set approximately two years prior to execution, do little to strengthen fiscal accountability. And where is the incentive for improvement by an individual activity when losses from poor performance are routinely recovered from the corpus and gains for good performance are paid into that corpus for subsequent distribution to other activities operating on the margin or in a loss mode? The creation of the SMDR, in sum, has removed all vestiges of any competitive influence on performance.

In his efforts to streamline the management of Naval Shipyards, Secretary of the Navy John Lehman, in 1985, directed a series of actions designed to incrementally dismantle the SMDR at the activity level, but leaving intact the stabilized rate concept at the NAVCOMPT/DOD interface and at the fleet level. It was a forceful action designed to give visibility to the true costs of

industrial operations in the public sector. But with his departure in April 1987, full implementation of the initiatives was stymied.

Interestingly, this same issue of accurate cost accounting was raised in 1984 by the National Research Council's Committee on U.S. Shipbuilding Technology, when it concluded that the Navy's performance measurement requirements did not lend themselves to modern shipbuilding methods. While the basic problem was patently different from the problems inherent in the SMDR structure imposed on public shipyards, the underlying issue of conformance to DODINSTR 7000.2 was the same. At issue was the Navy's instructions associated with the Ship Work Breakdown Structure (SWBS) for weight and cost programs to account for product-oriented work and management methods. That Committee also concluded that an expanded work breakdown structure could be developed to accommodate system-related cost and progress reporting (such as functional design and system testing), as well as interim product and product zone-oriented reporting. An extended system would allow efficient use of current computerized product-oriented management systems and, more importantly, it would bring current cost, schedule and progress reporting requirements into closer compliance with the intent and purpose of DODINSTR 7000.2. This point appears to have been lost on the financial community, for meaningful progress in this direction is not in evidence.

The fact that public shipyards polarize around the people aspects of the organizational structure, rather than the institutional process itself, helps explain why the transition to a product or zone-oriented management base has been so slow in ship repair. There are a few pilot programs in existence but, with the exception of Philadelphia Naval Shipyard, the public shipyards have merely nibbled at the fringes of a product-oriented work culture. And where progress has been demonstrated, it has been more a testimony to that shipyard's leadership and initiative, rather than any stated Navy policy so necessary to nurture it to full maturity. It is the nature of bureaucracy that sharp or sudden moves be minimized. When change is in the wind, the risk-free option of a pilot program is always an avenue that creates the illusion of action. But where is the risk in a management concept that has been time-proven by such shipbuilding giants as Ishikawa Jima-Harima Heavy Industry Co., Ltd. (IHI), in Japan, and to use a non-shipyard example, our own IBM? The proof is in performance, and that has been demonstrated by IHI's construction and overhaul of more than 3000 ships and other major end products using ZT principles. IBM needs no introduction.

To gain a fuller appreciation of the benefits of a product-oriented work structure, there must be a recognition at the outset that you win or lose the performance battle on the waterfront, not in the recesses of any hierarchical structure remote from the day-to-day fray. All of that becomes mere window-dressing to the more

exacting toll of what is going on at the deckplate level. Even the presence of a learning curve as a demonstration of achievement is insufficient. As Dr. W. E. Deming's principles of statistical control have so aptly demonstrated - principles embraced and revered by Japanese shipbuilders - examination of processes at the macro-level, i.e., system or functional level, obscure product and process similarities that exist at the micro level. Complacency is but a short step to failure, and any organization that views its current performance as "good enough" is doomed to fail. Dr. Deming is the enemy of the status quo. Central to his 14 principles of management is that improvement in the production process comes by constant, bit-by-bit refinement of the individual pieces or products that constitute the whole. Only by a constant, iterative effort that concentrates on improving each product, whether the basic process by which the product is achieved or the design of the product itself, can productivity be improved, costs lowered and the overall learning curve be pressed further downward.



## TRADITIONAL WORK PACKAGE PREPARATION

The quality of traditional, systems-oriented process planning in public shipyards is weighted heavily by the experience level of the lead planner. In the main, planners are ex-tradesmen. Regardless of how well-intentioned, they are products of their background, with new methods and new processes essentially limited to those that have been gleaned from their waterfront experience. It is also a fact that some managers resist the use of new time and labor-saving technologies, such as computers, due partly to the fear of the technology, but mostly to the fear that technology can replace people. As with all work, personal motivation also enters into the picture. Without a direct and genuine interest by the planner as to what really is happening at the shop floor or deckplate levels, the quality of planning will suffer. The dynamics of change are real in ship repair, and the planner must be intimately familiar with the job's constraints and the problems being encountered by the trades. All too frequently, however, planners are satisfied with solely a desktop planning effort, rather than verifying the adequacy of their software product at the worksite itself.

In this discussion, it is important to understand that planning is not the responsibility of any one functional code. A lead planner may have overall responsibility and final sign-off authority on a job order, but that work document should be viewed

as the coordinated actions of engineering, planning and estimating (P&E), scheduling and material procurement. This required interaction is vividly illustrated in the series of action steps leading to material procurement. Direct material accounts for 25% or more of the final repair costs in any availability. Based on working drawings developed by engineering (design), generalized bills of material are provided to P&E. Planning and estimating translates those material requirements into material specifications, including National Stock Numbers (NSNs), manufacturer's part numbers for purchase specifications, and job order material listings that allow material codes to do their job within a specified timeframe. But when each functional area acts in series, based on the information it has been provided, the potential for error is high. Buyers should not be consulting engineering codes solely in response to vendor inquiries concerning non-conformance to specifications, nor should engineering be assisting P&E on an "as-called" basis. Rather, all parties need to work in concert from the outset since inadequate technical data is the leading cause of incorrect repair parts and components being delivered to the waterfront, a fact borne out by the large number of job material listings (JMLs) that are returned for additional information. A systems-oriented approach to job order preparation, moreover, treats each of these issues in isolation, negating a standard solution to what is really a common problem.

Planners are also victims of the management policies that have been imposed. The fact that some shipyards strive to meet the artificial goal of having all known work issued to the trades at the start of an availability further detracts from the quality of the planning. Once used as one of many management indicators to evaluate the readiness to start an availability, this rush to put paper in the hands of the waterfront trades, frequently months in advance of actual need, now only leads to sloppy planning and poor work execution. (The 1985-86 Coopers & Lybrand Naval Industrial Fund review of the eight public shipyards found that, on the average, some 20% of the material ordered for overhauls and repair work was not used [51]. Against a Direct Material Inventory (DMI) and shop stores inventory of in excess of \$500 million, this is certainly not an insignificant figure. Unfortunately, some shipyards view excess material as merely the price of doing business in a line of work beset with unknowns. But the impact of excess material transcends the simple dollar value of the material held. The tasks of ordering, expediting, inspecting and warehousing material that is not needed ultimately equates to more people being required to do the work.)

Once issued, moreover, job orders tend to remain as written, unless the work scope is changed by the customer, or the work content is challenged by the trades as being either impractical, ambiguous or technically incompatible with the work at hand. And it would not be unusual to find three variations of the same job

if written by three different planners. The degree to which similar work on follow ships is refined and improved is frequently dependent on the extent to which job order history files - the "lessons learned" - are utilized. As a simple check of how golden promises can turn to dross, shipyards need only to check the number of job order revisions issued and the number/frequency of design liaison action requests. And as that planning experience base is diluted, the learning process starts all over again. Job order reserves, including the application of contingency allowances or J-factors to allotted hours, are a function of planner experience and operating style, with shop performance factors swinging in the balance. (In public shipyards, "J-factor" come in various forms and can include allowances for in-scope growth, contingency factors to cover potential shipyard errors and performance inefficiencies by non-production direct labor. In some shipyards, contingency factors even cover situations for design and planning and estimating errors, as well as rework. Those practices lend little to a credible estimating system.)

The paper empire that has resulted from this scenario defies description. The two to three page job order of the 1950's - early 1970's timeframe has been supplanted by all-encompassing documents that can reach thirty or more pages in length, with an equal number of references, as the originator seeks to cover all bases and to anticipate all circumstances that might arise at the worksite. More, rather than less, becomes the rule of the day. A recently-

completed review of one highly-specialized area of ship repair work, for example, revealed that work requirements had undergone a three-fold increase in the 1955-1990 timeframe. Given the tight controls placed on this work and the stringent review that it receives, it is highly likely that other ship repair areas have realized a substantially higher increase in the paper demands associated with their work. Environmental and safety requirements generated over this past decade, by themselves, do not account for this avalanche of paper. And when in doubt as to who should receive a copy of the work instructions, all too often the solution is to simply expand the distribution.

If the Navy runs the risk of being over-whelmed by its own paper, the need for accurate technical documentation is even more pressing. The existing Navy technical data repository is based on film or copy data with little automation. The manual steps of indexing, storage, retrieval, cross-referencing, updating, and refiling, by themselves, are highly error-prone and frequently culminate with the mechanic, responsible for the work, being the recipient of drawing packages that are incomplete, outdated or unreadable. It goes without saying that the costs' associated with this manual process are staggering. The fact that in excess of 6 million drawings are maintained in the central files of Norfolk Naval Shipyard alone illustrates the size of the problem. And Norfolk Naval Shipyard, like all shipyards, is not classified as one of the Navy's eight primary engineering drawing repositories.

The issue is so acute that more than one shipyard shop has attempted to establish its own data files, in the shortsighted belief that it would solve their compelling need for accurate technical documentation.

For repair yards, help, hopefully, is on the way in the form of EDMICS (Engineering Data Management Information and Control System). EDMICS, a subset of the Computer-aided Acquisition and Logistics Support (CALS) initiative, is moving to automate the Navy's engineering drawing repositories using optical disk storage technology. As of February 1991, Operational Test and Evaluation (OT&E) of the first site (Naval Ordnance Station, Louisville) was essentially complete, with Major Automated Information System Review Council (MAISRC) scheduled for the near future. When implemented, it portends a quantum leap in the ability of shipyard operations to support the productive effort. Funding remains a major obstacle. For the present, however, plan vault operations remain virtually on the same plateau as has existed over the past 40 years - labor intensive, slow response to system needs and prone to inaccuracies and lost data.

But the fortunes of any shipyard are ultimately determined by what transpires at the production worksites. At this point in the discussion, it is important to gain an insight into the environment in which the waterfront supervisor is expected to do his job when operating within this systems-oriented management structure.

## THE WATERFRONT SUPERVISOR

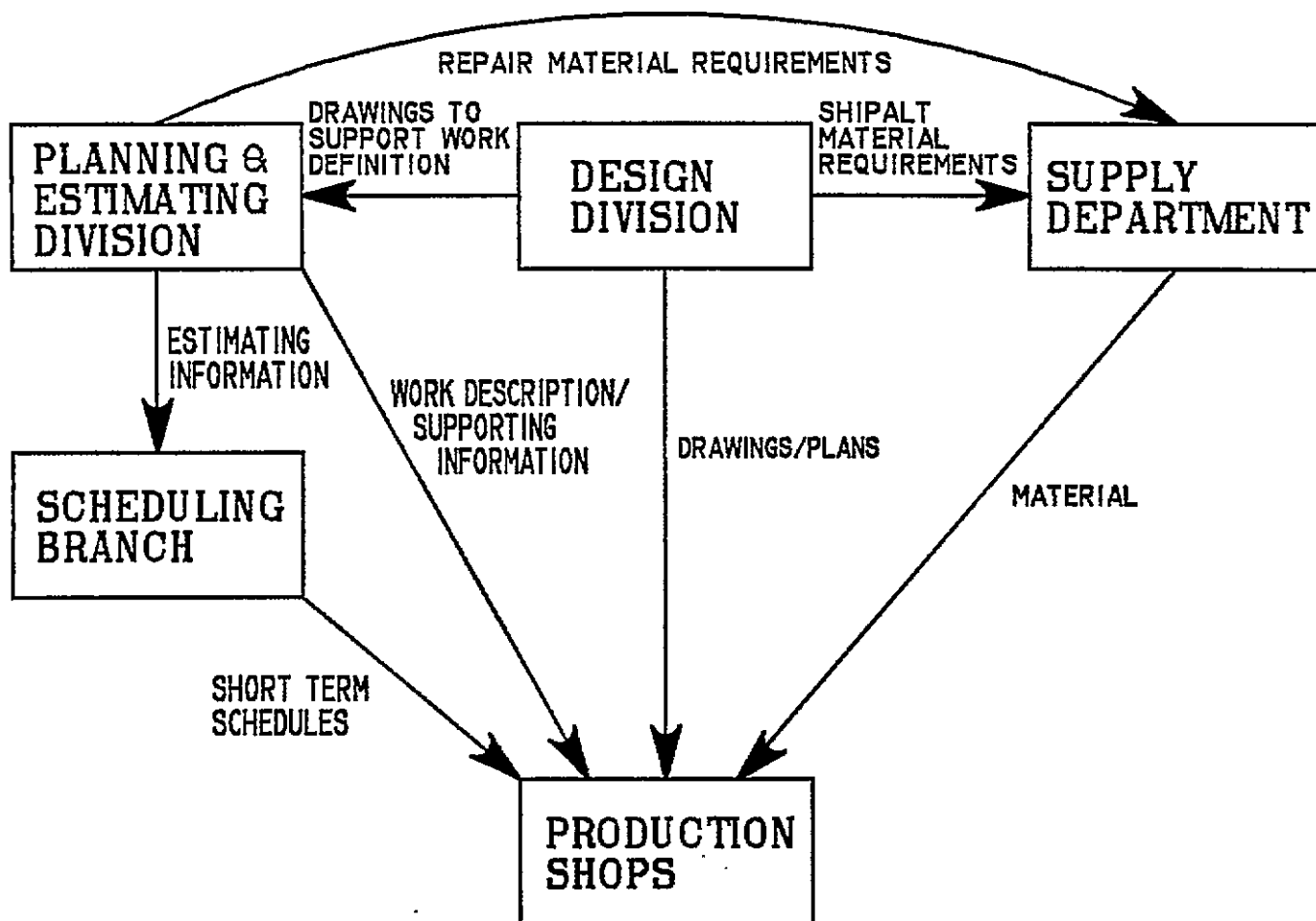
In any complex endeavor involving disparate disciplines, there is the real and constant potential for a mismatch between the job assigned and the resources required to accomplish the objective. Ship repair is no exception. The sheer magnitude and complexity of blending the efforts of 8,000 or more people into a cohesive structure, one that synchronizes the accomplishment of work detailed frequently at the 8-10 manhour level, can defy comprehension by even those intimately familiar with the process. Like new construction, the repair of ships is characterized by an overlap of functional responsibilities, with each shipyard department susceptible to the pressures of its own internal priorities, work constraints and imperfections.

And when those disparate work efforts finally come into congruence at the job site itself, any bottleneck can create disruption and even chaos, particularly when pressures mount to meet key events. Mismatches between work assigned and the resources provided come in a variety of forms, whether it be required material not in hand, inadequate or confusing technical instructions, a skills shortfall for the process described, or the basic challenge of work space competition with other tradework that is in progress. Up until this point, each organizational entity believes it has done its job, at least within the constraints under which it functions. For them, it is time to move on to the next

problem. Placing order into the process - aggregating the pieces provided, managing the exceptions and integrating those elements into some orderly semblance of work progression - becomes the responsibility of the lead shop assigned the work. And in the center of this vortex stands the first line supervisor, the individual charged with actually doing the work. Jockeying multiple revisions of a drawing, frequently laden with inconsistent data baselines, along with multiple copies of the same data, can be a thankless job. In public shipyards, as well as many private yards, drawings are not routinely issued by the Planning Department with the job order that references it. It is not unusual to have drawings, applicable technical manuals, and other documentation acquired separately by the mechanic doing the work. Figure 1 is representative of the traditional planning process used in most repair yards. It is, in effect, a series operation with the final product reflecting all the shortcomings of the process that produced it.

The first line supervisor is expected to resolve those shortfalls and merge them into a doable work package. Blindly expecting that the sanctity of the job order will transcend all problems, that the aforementioned "mismatches" will magically dissolve, ignores reality. As a minimum, the traditional system-oriented documents must be broken down by the physical location of where the work is to be accomplished, material must be segregated by location and manpower allocated for the work areas available.





**FIGURE I.**  
**TRADITIONAL WORK PLANNING PROCESS**

The fact that this same supervisor must coordinate system line-ups, establish work boundaries, schedule support services, and may be required to resolve ships force interface issues, is of secondary consideration. At this juncture, then, the supervisor must function as both traffic cop and referee, with success determined by his personal ingenuity, initiative and experience.

Over time, solutions to each perceived symptom have been put in place, each equipped with its own charter of authority, each addressing its own discrete portion of the overall problem and, in the process, each making its own contribution to the paper morass that ultimately masks personal responsibility. Material expeditors, shop planners and design liaison engineers are the immediate examples that come to mind. This should not be construed as a reflection on those who have valiantly labored long and hard within those organizations. Rather, it is an indictment of the system that fostered the need for this degree of specialization. The authors themselves were reared in an era when exhortations such as "think shipyard" and "work smarter, not harder" were but some of the common terms in the repertoire of shipyard folklore, along with "put production on the windy corner" and "put the engineers on the deckplates". Each such pronouncement had its purpose and, backed up by policy decrees and strategy sessions, they undoubtedly served a useful purpose for the circumstances that prevailed at the time. But the sporadic performance of both public and private shipyards over the past 30 years suggests that the successes

achieved were more the product of leadership and personal charisma than any other factor. And to that same supervisor on the waterfront, they had a hollow ring, for nothing was drastically changed - at least not with any degree of permanency. Planning the job, in a fashion that met the needs of the production trades, still required that a disproportionate amount of the details be worked out on the waterfront before the start of work.

But isn't planning defined as the detailed formulation of an action program to achieve a given objective? Shouldn't the basic purpose of planning be one of simplifying work execution to increase productivity? And shouldn't the planning process be engineered to the extent that facilities and shipboard producibility and procedural constraints are routinely weighed and work shifted to earlier manufacturing stages for ease of fabrication and off-hull outfitting? And when all is said and done, doesn't it really mean that the waterfront supervisor can minimize the downtime of his work group, and exit the starting blocks, at the scheduled time, knowing that he is playing with a full deck? A serendipitous attitude by the functional codes will not achieve that objective. The extent to which these questions are satisfactorily answered rests with how well design engineers, planners, production engineers and the trades have worked in concert before the job is released for execution. In an interview concerning the challenges that U.S. industry faces in the 1990's, Mr. J. Welch, CEO, General Electric Corporation, summarized the

interaction that will be required when he stated that ". . . we no longer have the time to climb over barriers, such as engineering, or between people; that geographic barriers must evaporate." [6] Explicit in this interview was the need to move faster, communicate more clearly, and to involve everyone in an effort to serve ever-demanding customers in an era of technological change and intense competition. Management cannot package and distribute self-confidence, but it can foster it by removing institutional barriers and giving people a chance to win. Achieving that interaction, on a sustained basis, is a fundamental characteristic inherent to the zone technology management process. computer-aided process planning (CAPP) is the management tool that forces this horizontal integration of work effort.

## PROCESS PLANNING

Process planning, the determination of how the authorized work is to be accomplished, can be the single-most dominating factor influencing the cost of production work. In a macroscopic sense, shipyards are similar to any industrial operation that produces a product, whether it be automobiles, airplanes or television sets. In totality, each final product is the summation of the pieces, parts and components that make up the delivered product. The repair of ships is no different in that it represents the assembly of component parts. Unlike many of its industrial counterparts, however, a shipyard may be involved with hundreds of thousands of parts in the repair and assembly process. While literally thousands of individual processes are involved in ship repair, the vast majority are repeated over and over again, whether it be on different ships or different components. Circumstances can vary, but those processes remain basically constant. By careful examination of each step in those processes - how many people required, what material needed, how long the work will take - a reasonably accurate determination can be made of the work required to perform that process. When this information is captured in one data repository that will be used for all planning efforts associated with that process, the foundation has been laid for future improvement in that particular area. Herein lies the benefits of a computer-aided process system, for it is at this point that, the Deming principles of statistical quality control can

be brought to fruition. (Increasingly, industry is also learning that safety is intertwined with quality, for safety is dependent on understanding the processes being used. The Aluminum Company of America (ALCOA), for example, has determined that a major cause of accidents is the deviation from an approved process plan: i.e., a shortcut. But that accident is not necessarily indicative of negligence on the part of the worker, for analyses have concluded that, in far too many situations, that accident is merely identifying an inefficient process or inadequate tooling.)

In all process planning, the need for accurate information is basic to successful application, for the overall objective must be predictable performance if improvement is to be achieved. All work measurement standards stem from this premise. When the waterfront supervisor is spending a disproportionate amount of time off the worksite collecting information needed to do his job, subsequent variance analysis of planned versus actual expenditures are routinely misleading as to the underlying reasons for that performance. If nothing else, this lost motion can readily mask the root causes. Product-oriented work packages that stand on their own, however, allow meaningful analysis. But predictable performance is also not possible when the estimating base is either inconsistent or distorted by the application of a myriad of contingency factors. This mandates that those associated with a given work process share a common data file. When work is defined to the lowest practical level of detail, moreover, the entire

estimating process is greatly enhanced in that estimates are not mired in a web of competing factors so common with systems-oriented work packages. With the restructuring of work to a product-oriented format, the majority of existing engineered standards, in the main, may be found lacking without a major rewrite. Achieving the elusive objective of predictable performance requires the capturing of all relevant data germane to the work package under consideration. That should include relevant data from engineered or estimated standards, as well as data elements that may be available from existing methods and standards. The planning process seldom reaches a steady state, and only by a constant awareness of what the work entails, who is to do it, and how and when it is to be accomplished, can reasonable performance predictions be made. Predictable performance is central to realistic schedules. There are commercially-available automated time standards (ATS) that can be linked to the process-planning system. These cost calculation modules make it possible to predict the cost of finished parts at the shop floor level within a 5-8% accuracy range. By themselves, these cost modules can assist the planners (and others) in realizing the cost implications of their decisions. At the outset, that is until meaningful benchmark performance standards have been established, just the simple step of performing comparative analyses of like-processes at the macro level can produce tangible savings.

Computer-aided process planning (CAPP) capitalizes on the strength of computers to manipulate the literally thousands of data elements associated with production work. Just the step of eliminating the manual labor required to write or type each process plan can increase planning efficiencies by 20% or more. When applied to the Preparation of work packages, CAPP is the sorting tool that organizes, refines and electronically transmits production data in the format and sequence in which work is actually accomplished on the waterfront. By inputting all pertinent design and manufacturing data associated with the product into a common data repository, and making that data accessible via a mainframe hookup, all information and changes are given immediate visibility to the users. It is, then, a communication tool designed to meet realtime needs and which, depending on the degree of sophistication desired, can be linked to different computer-aided design and computer-aided manufacturing (CAD/CAM) systems. There are other applications as well. This incorporation of add-on features, however, illustrates the importance for shipyards to have a strategic plan for the use of computers, particularly when access to the mainframes is a prerequisite. Without a prioritizing of needs, both as to value added and their relationship to the predominate objective of supporting the productive effort, shipyards will routinely face the dilemma of system saturation and slow response. The constant demand for, and proliferation of, redundant or unnecessary status reports, by themselves, can quickly overwhelm a system's capacity to respond and relegate CAPP to a



secondary function. Many shipyards are already encountering lock-out periods in the futile effort to ration mainframe availability and still serve all customers.

A classification and coding system is obviously needed if data is to be retrieved and analyzed, and that includes relevant design, production and other features of the parts or products involved. But one system will not meet the needs of all departments, for each requires different types of information. Design, for example, may be interested in coding drawings into families (groups) of parts with similar manufacturing features that use common processes, but Production and Purchasing may not. successful classification and coding systems can be developed in-house but, in some instances, it may be more cost-effective to use commercial software.

Zone logic increases the productivity of design and production work by taking advantage of the underlying similarities in the products or subassemblies, those common characteristics classified by both design and production attributes. ZT is, in effect, the integration of many of the same common principles, tasks, and problems that find their way into job history files or are retained in the little "black books" maintained by lead planners. The goal is standardization, not only to eliminate unnecessary duplication, but to also determine the optimal utilization of material, time and personnel. Work packages, then, should reflect an accumulation of experience, and every available data base should be tapped for

inclusion in a data repository that can be routinely updated. The potential for applying new construction experience to repair work, particularly from those building yards utilizing modular or sectional construction drawings (SCDs), should be obvious.

Standardization of work content for common products or interim products is achieved by requiring planners and designers to share a common data base. The discipline associated with information retrieval, by itself, imparts a more structured approach to the development of work package content, and provides the means for the constant, iterative micro-improvement steps espoused by Dr. Deming. This classification and coding system should be based on characteristics that are product-independent, wherever possible. A centrifugal fire pump, for example, is a centrifugal fire pump. The manufacturers may vary, their capacities differ, and their parts be of different sizes, but the process by which they are overhauled remains essentially the same. (Analyses performed by one centrifugal pump manufacturer, for example, revealed that, of the 50,000 - 55,000 parts used in its various models, only some 1,000 of those parts, such as gears, spindles and other similar components, represented different shapes requiring different manufacturing processes.) If customized to specific products, the work packages are of limited value on different chip types. It is not recommended, however, that a menu of prestored sequences of operations for given processes be developed, for this approach can accommodate only a limited number of variables before it becomes

top-heavy. Regardless of differences in functional systems, comparable work packages for different ships of the same type can be readily modified if product independent characteristics are used.

New construction yards have recognized that the preponderance of their production costs are associated with joining things together; i.e, plate or piping joints. While the dollars associated with cutting plate are relatively small, the cost-savings associated with precise or "neat" cuts are high, particularly when weld preparation time can be minimized. Can sufficient dimensional accuracy be maintained to specify neat cuts? Castings are typically cheaper than forgings and weldments, particularly where small quantities and complex configurations are involved. Which way should the shipyard go? The features of joints, the materials used, their configuration and their ease of fabrication, are just some of the critical elements in the overall cost equation. Butt joints may be lighter and cheaper to buy, but socket joints are easier to produce. What are the cost trade-offs? If series 300 CRES is specified, is it cheaper to use 316 CRES rather than 304L? How does it impact the trades? By proper engineering at the outset, adhering closely to the tenets of form, fit, and function, and not over-engineering the product, significant cost-savings are being realized as the more cost-effective options with broad applications are identified. In somewhat loose terms, this upfront sorting function - looking for

commonalities at the product or interim product levels to lower manufacturing costs - is analogous to the process that any good new construction purchasing department exercises in the procurement of material. By sorting, grouping, and aggregating the material control numbers assigned to the parts lists on the hundreds of drawings involved, smart bulk-buy or make-buy decisions can be executed.

This same upfront design and engineering effort can be applied to repair work, but, at this point in time, it remains an opportunity waiting to be exploited. There have been some isolated exceptions, however. In one such example, Mare Island Naval Shipyard examined the drawings associated with 300 parts that had been recently manufactured in its machine shop [7]. More than 60% of the parts exhibited significant similarities to one another, permitting the grouping of specific manufacturing steps to improve tool utilization and reduce costs. Seven percent were either identical or close enough to share identical manufacturing processes. This action would have been greatly facilitated had a product-oriented classification and coding system been in place, with the requirement that Design routinely sort drawings to identify common products or interim products to like manufacturing processes. The elimination of the work effort for just a few duplicate parts, whether they are the final products or interim products, can result in significant savings. By minimizing design duplication, as well as the costs associated with the preparations

for manufacture (which includes the process plan itself and the set-up time for jigs and fixtures), a simple, flexible retrieval system can readily yield savings in the 5-10% range. And, in some cases, there is no need for shipyards to develop their own computer software. Off-the-shelf modules are readily available on the commercial market to address many numerically-controlled manufacturing processes. If necessary, they can be tailored to a company's practices and made more user-friendly.

When engineering and planning tasks are treated in isolation, as is so prevalent in a functional or systems-oriented structure, the across-the-board, quantum leap forward is not possible. If the Navy is searching for the means to interject this product-oriented approach into the design and engineering functions associated with ship repair, a logical jumping-off point is in the design of ship alterations. By routinely requiring planning yards, particularly those with Expanded Planning Yard (EPY) responsibilities, to engineer the ship alteration drawings in a zone logic format, the influence of those techniques will realize significant cost-savings. Not only is the SHIPALT process itself enhanced, but it allows the overhaul yard the capability to integrate the repair work package with the SHIPALT effort, thereby optimizing installation planning, execution and manning.

The level of detail required for the planning of product-oriented work directly influences the accuracy of material buys.

On older ships, configuration control is acknowledged as a serious problem impacting material procurement. Yet, it is not unusual to find re-buy rates in the 5-6% range or lower when effective horizontal integration of engineering and planning codes has been achieved in a product-oriented work structure. Philadelphia Naval Shipyard, in fact, has demonstrated the practicality of that step in its preparation of an LPH ship alteration package, one that was successfully executed by a private shipyard. And in those situations where a building yard, already using zone technology, also has EPY responsibilities, much of the informational grouping and analyses required would have already been accomplished.

There is a very subtle but powerful reason in having EPY's "prime the PWBS pump," and that is in the area of producibility - optimizing the manner in which work is done at the production level. The concept of designing for production is usually not an option that receives serious consideration in the development of an acquisition strategy. This is partly due to the perception that it might give the winning shipyard an unfair competitive advantage; but certainly the fear of losing control, or just not understanding the procedures by which work is or can be accomplished, enters into the decision process. The vast majority of Navy shipbuilding programs are rigidly controlled by the specifications invoked, with new production methods and processes developed within the constraints of those requirements. Production innovations that fall outside those boundaries are subjected to the tortuous rigors

of the contract change process. When designs are controlled by the shipyard, particularly at the preliminary design stage, that shipyard can directly influence the methods and processes by which the work is done. The development of ship alterations presents such an opportunity. There are standards that must be followed in the development of ship alterations, but sufficient specification latitude does exist to allow meaningful producibility changes. By specifically tasking Planning Yards to develop SHIPALTS using a product-oriented work structure, and making producibility an inherent part of that tasking, two noteworthy objectives could be met. There would be no fear of giving any shipyard a competitive edge, since SHIPALTS are but one part of a total work package that is competitively awarded. More importantly, it would start the slow transition to an across-the-board adoption of a repair methodology that would be product-oriented.

## THE PHILADELPHIA EXPERIMENT

In those instances where repair yards have started the transformation to a product-oriented work base, the central focus has been on the ship itself. None, for example, have matured to the extent that products or interim Products are routinely classified into groups (families) according to the production processes by which they are produced. As stated earlier, application within the shops has been limited. And this is understandable. Changing the attitudes and thinking of people who have been reared in a traditional functional organization is difficult. Despite the major strides Philadelphia Naval Shipyard has made in the application of zone logic to repair work, it was recognized at the outset that the change represented a cultural shock to many and that institutional barriers had to be overcome. Under these circumstances, it is not practical to eat the elephant at one sitting unless you are inviting chaos. It is far better to put in place the basic product-oriented work structure and fine-tune the operation once the initial barriers have been overcome.

Zone technology is relatively easy to understand, but fighting resistance to change is not an easy chore, and it certainly can't be viewed as a short term effort. Only a top-down management approach, with strong leadership involvement throughout, will nurture its development. The first step must be one of getting the workforce on board. Without that action, entrenched interests will



undermine its progress. That step must be close-coupled with the gradual, but steady, introduction of systems-oriented data into the product work breakdown (PWBS) structure that fuels zone technology. Absent that gradual transition, people will be overwhelmed by masses of data in different forms. It is a case of starting small, but keeping the ultimate objective constantly in sight, with the speed of development tied directly to the leadership capabilities of the individuals in charge. And it should not be implemented in the expectation of significant near term savings. Industry reviews, supported by Dr. Deming, suggest a 3-5 year timeframe before major payback is realized.

At Philadelphia Naval Shipyard, indoctrination into the principles of zone logic started with special briefing sessions for all senior managers, followed in sequence by the middle managers and design engineers. Zone technology experts from the Ishikawajima-Harima Heavy Industry Co., Ltd. (IHI) were brought in on a consultant-basis to accelerate the training and to facilitate the implementation steps required. In many instances, one-on-one discussions were held to ensure that there were no misunderstandings as to the course and speed the shipyard was embarking on, and that each recognized the importance of the initiative. First line supervisors and union leaders were similarly briefed. (As a point of record, production trade unions were not in direct opposition to the changes being advocated. Resistance to change should not be confused with a valid need to

know and understand the reasons behind management policies, particularly when they represent a radical shift in the way work is accomplished. Mr. Paul J. Burnsky, President of Metal Trades Department, AFL-CIO, properly expressed this point in his July 1988 statement before the Commission on Merchant Marine and Defense, when he stressed that "Shipyard labor has proven again and again our willingness to modify traditional work patterns to help achieve mutually advantageous production objectives". [8] A climate of openness, fostered by shipyard management, facilitated this cooperation.) Special training sessions were conducted for the 800 trade personnel who were assigned to the USS KITTY HAWK (CV-63) zone technology pilot project. These trade personnel were assigned to one of the nine product trades that were established, with each product trade representing a functional work group capable of multiple tasks. See Figure 2. To some, this smacked of cross-crafting, rather than the establishment of functional work groups. In reality, it was an extension of the same horizontal integration of work effort being applied to work planning. Assigned to one foreman, these multi-talented product trades not only improved trade coordination, but they reduced the time lost waiting on assist trades. A lo-person Zone Technology Office (C3201), with direct access to senior shipyard management, was established and charged with resolving all execution problems. The code number assigned clearly indicated that it was the bridge between the Production Department (C300) and Planning Department (C200) in the resolution of all interface issues.

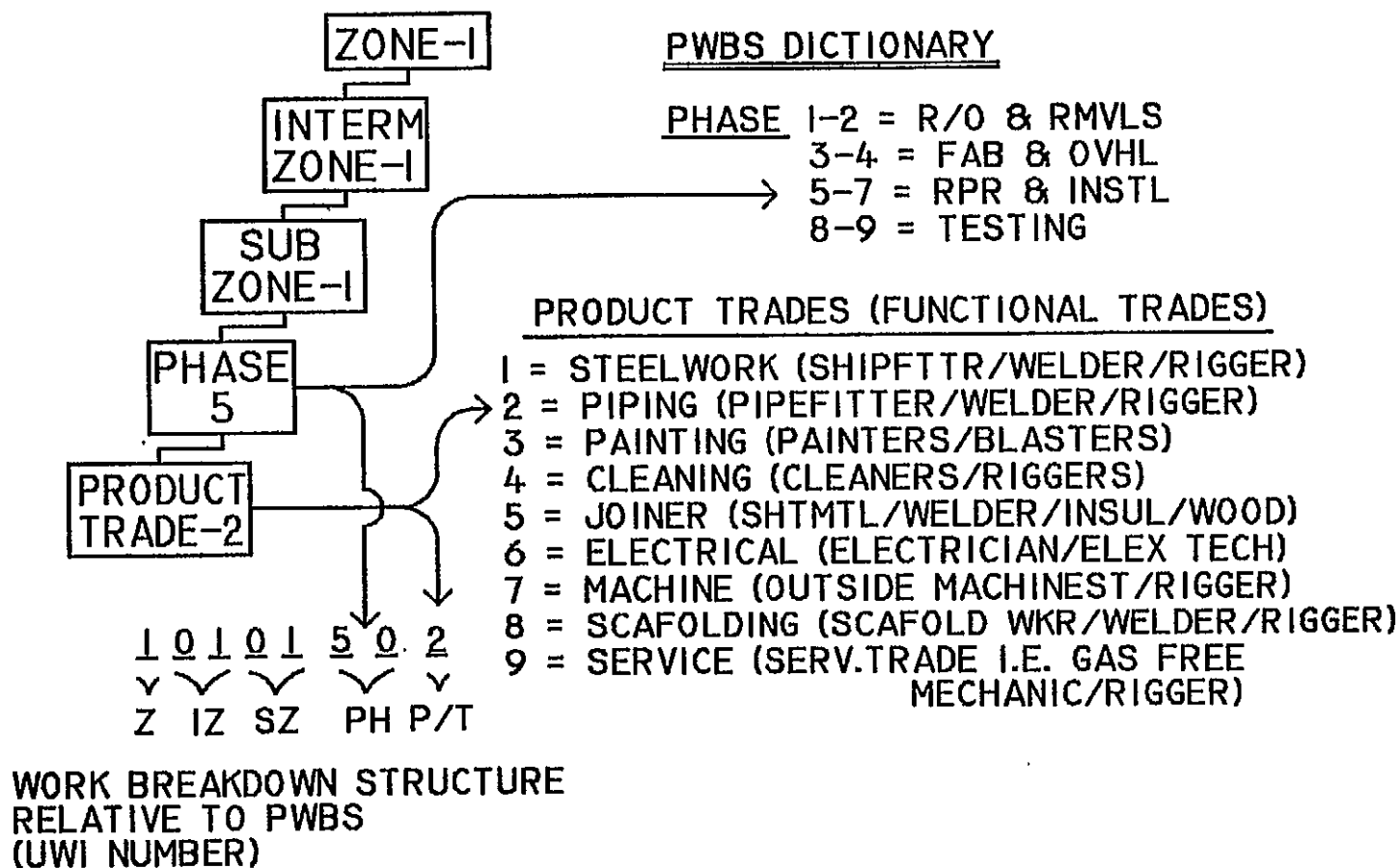


FIGURE 2.

PRODUCT WORK BREAKDOWN SYSTEM CLASSIFICATION AND CODING SYSTEM

Weekly progress meetings, chaired by senior management, were instituted to demonstrate that this was not a one-shot infusion of time and effort being devoted to an initiative that had a short half-life. Zone technology was, in fact, there to stay. To further foster an atmosphere of teamwork, copies of the Shipyard Corporate Plan, which included an overview of zone technology and the shipyard's competitive strategy, were sent to the homes of each employee. The shipyard has one major objective in sight: to apply zone technology to all ships in 1991.

What transpired at Philadelphia Naval Shipyard was the labor-intensive and arduous chore of manually realigning the way in which work would now be executed at the shipyard. The details of this effort have been fully described at the 24-26 August 1988 Ship Production Symposium in Seattle, Washington [9], and in subsequent publications. But the magnitude of the task warrants touching upon, if only to underscore the challenges that the shipyard overcame. For the initial plunge, yard management focused their attention on a 400,000 manday segment of work that represented one third of the total USS KITTY HAWK (CV-63) Service Life Extension Program (SLEP). It required that the traditional system-oriented job order system, which broke the work down by 14 production shops, as well as 147 work centers, be analyzed and transformed into a product-oriented format aligned to the geographical areas or zones where the work would be performed on the ship. In order to

accommodate the level of detail planned for each individual work package, KITTY KAWK was divided into four major zones - which were further divided into 117 intermediate and 338 subzones. WS-17 zone managers, with line authority over the product trades, were designated for each major zone.

For planning purposes and to establish work priorities, work was initially defined at the intermediate zone level. Detailed work packages would follow, and would be dependent on final work definition. As part of that detailed planning, each work item was reviewed against its applicable system drawing and those portions required for the accomplishment of the work extracted. Each work package was sequenced and issued on a product trade basic. As a basic objective, there would be no random work starts as is prevalent in a system by system approach to work accomplishment. Work would be scheduled with zero float and would be completed on a zone by zone basis, thereby allowing tighter management control. The underlying thrust of this total effort was to use the same people (product trade) to do the same type of work (work phase) in the same location (subzone). The glue that held this massive realignment effort together was the product work breakdown (PWBS) necessary for accountability and reporting of production work. The classification and coding system that evolved employed a 5-digit job order field to indicate location and a 3-digit Key Operation (KeyOp) field to specify the work phase and product trade. See Figure 2. While manhour allowances and other performance

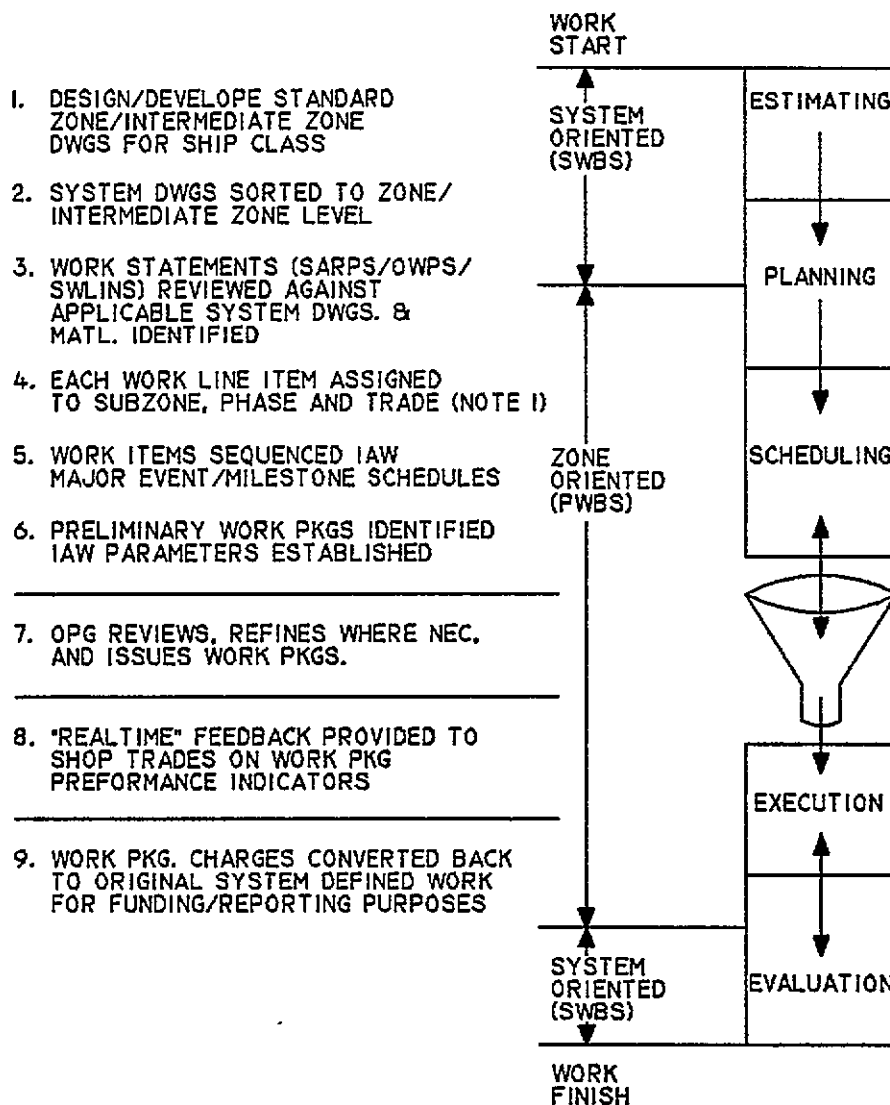
indicators were predicated primarily on historical KeyOp data extracted from existing systems-related files, that was appropriate. The important task was to set in place the basic structure, with refinement to come later. Comparable classification and coding systems can be developed to support design work, particularly when the emphasis is on the grouping of like manufacturing processes, with the production and design systems interactive at the first tier document level for common products.

And important to this entire project, a minor revolution of sorts was taking place: increasingly, the use of computers was being applied to labor-intensive efforts of sorting, arranging and refining of the mountains of data required to formulate the work packages required. A primary focus of the initial automation efforts was to provide direct correlation between the traditional 50-year old Navy Ship (Systems) Work Breakdown Structure (SWBS) and the new Product Work Breakdown Structure (PWBS) classification and coding system.

Experience has shown that an operational management structure that serves only the perceived needs of the financial community does not necessarily support the needs of production trades, and, when carried to extremes, is doomed to failure over the long term. What evolved in this case, however, was a work format that supports the way in which production does the work, yet provides the

financial community the tools to account for costs accrued. With the maturing of the shipyard's Zone Logic Data Base Management System, each line of work is now entered into the computer system, with the data sorted by zone number, phase number, trade number, job description, budget hours, parent job order number, supplement number and drawing number. Subsequent sorting by subzone, phase, and trade is dependent on sequencing in accordance with the master schedule. Figure 3 is a schematic of this information flow process. For Philadelphia Naval Shipyard, development of a cost accounting system to accommodate product-oriented work processes has been a case of playing with the cards it has been dealt. Improvisation has imposed an added administrative burden, but it is functional.

Now comes the more demanding challenge of sustaining those gains and putting in place the infrastructure that will ensure its future growth. More than 1500 additional personnel have since been trained, and the introduction of zone technology workshops lends credence to the belief that the Shipyard does not intend to rest on its laurels. By constantly sensing the pulse of day-to-day execution of ZT, including formal presentations to the Shipyard Commander and other senior managers, the cultural barriers are being rapidly demolished. No transition of this magnitude is without its problems, but by steady and consistent attention by senior management, each issue is amenable to solution. The issue of the zone manager having line authority over personnel from



NOTE 1: THE TOTAL SCOPE OF REPAIR WORK IS ROUTINELY NOT KNOWN AT THE START OF AN AVAILABILITY, WITH A LARGE PORTION OF THE UNKNOWNNS DEPENDENT ON INSPECTIONS. ACCORDINGLY, THE INITIAL ASSIGNMENT IS TO THE INTERMEDIATE ZONE, FOLLOWED BY ADJUSTMENT TO THE SUBZONE LEVEL AS WORK IS DEFINITIZED.

FIGURE 3.

INFORMATION FLOW IN A PRODUCT-ORIENTED WORK STRUCTURE



different shops, for example, was perceived by some as undermining the traditional authority of the shop head. Like so many issues that represent a cultural change, this problem could not be allowed to fester. In this case the solution came from the Group Superintendents. Traditional responsibilities for in-shop work would remain unchanged, but Group Superintendents have been given specific zone assignments, and that includes work that crosses all trade lines within the assigned zones.

The introduction of a product-oriented work structure is the management of change in the classic sense of the term. The USS CONSTELLATION (CV-64) SLEP, in its initial phases at this writing, is the part of this evolutionary process. While the basic techniques are similar, the breadth of the undertaking has increased dramatically. Engineering and production both drive the zone strategy. Design, P&E, Supply and Production - right down to the details of work packaging - are moving into an era of total integrated planning for production. Subsequent reviews will attest to its success.

## PRODUCT-ORIENTED WORK PACKAGES

Where shipyards have made the transition to a product-oriented work structure, there is general agreement that the format and specificity of the work instructions are critical elements in the successful application of group technology, or its derivative, zone technology. Philadelphia Naval Shipyard refers to this step as "outfit planning" while other shipyards appear to be more comfortable with the term "detailed planning". Regardless of terminology, they all share the common objective of avoiding the single greatest loss that plagues all industrial efforts: worker downtime, the lost motion that delays work execution and escalates the cost of doing business.

Computer-aided process planning, conducted within a product-oriented work structure, provides the tools and data repositories to eliminate the vast majority of these work instruction problems. Whether they are called Unit Work Procedures (UWPs), Unit Work Instructions (UWIs), C-Events (as at Philadelphia Naval Shipyard), Component-Oriented Technical Work Procedures (COTWPs) or just work packages (and there is a collage of other terms in use by the shipyard community), all share some very fundamental, yet common, characteristics when repair work is accomplished by zones:

1. The work instructions are self-sufficient, meaning that the work package is a stand-alone document with no supplemental

data needed to accomplish the work specified. The work package includes drawings of the component(s) to be worked, including amplifying sketches where necessary, detailed instructions for the accomplishment of the work, trade responsible for each line item, pertinent safety information, material listings, allocated hours, as well as required verification documentation. Wherever practical, only those portions of drawings depicting the actual component to be worked are incorporated, rather than burdening the trades with unwanted paper. That step forces the planner to review drawings for applicability. The conversion of systems-oriented data into a product-oriented format, extracting portions of drawings and material lists applicable to specific areas or intermediate zones on the ship, is admittedly labor-intensive upfront. Planners therefore cannot lose sight of the fact that standardization - repeatability - is the goal. If work packages are restricted in application, the opportunity for grouping common manufacturing steps has been lost. The objective of zone logic is to subdivide the ship into subsets of interim products or products that can be grouped according to similar manufacturing processes, with each grouping (family) identified to the trade or shop responsible.

2. The work can be accomplished in a reasonably short period, usually in three weeks or less. When the timespan for a work package is excessive, effective performance measurement is not possible and the risk of mischarging is real. This means that a

single job order to unship, open/inspect, shop repair, reinstall and test a high pressure air compressor - repair work that can cover as much as four or more months of elapsed time - has been replaced by separate, detailed work instructions for each phase. Zone logic, moreover, dictates that each of these phases, as a minimum, be treated as interim products. Each of these phases represents a discreet amount of value that has been added to the final end product and must be treated separately, thereby providing the opportunity for the statistical analysis so important for improvement. Wherever possible, the work packages must be structured for assignment to a single supervisor to permit clear accountability for costs incurred and schedule adherence. Broad KeyOp coverage, particularly those depicting work centers responsible for discrete line items of work independent of each other, must be minimized. It goes without saying that these individual line items must be scheduled upfront, rather than being left to the lead chop to coordinate. By defining the work in small, digestible chunks, the identification of problems impacting work execution can be brought into sharp focus. In this same vein, accurate progress reporting is greatly simplified and supervisory lines of responsibility and accountability are reinforced. Progressive improvement is keyed directly on the ability to isolate problems to their fundamental root cause. This requirement to plan work at the lowest practical level of detail applies to assist trade work as well. All too frequently, assist trade hours are allotted in eight hour or four hour increments. This practice may

facilitate the accounting system in place, but it does little to accurately determine the true cost of doing the work.

3. The work can be accomplished within a manhour allocation that allows efficient supervisory control of resources. It is not uncommon to find the average work package falling in the 160-200 manhour range, with some work packages containing only two to four KeyOps. (For the KITTY KAWK SLEP, on the order of 10,000 work packages were issued.) The upper limit is about 800 manhours, but that is restricted to special work scopes. The nature of the work, including its criticality and physical constraints, obviously influences work package sizing. (One illustration of the extremes would be the repair of in-line valves versus hull sandblasting.) The ultimate objective is to plan and schedule the work to the lowest practical level of detail. By that action, greater visibility is given to assist hours, "borrowed" hours among waterfront supervisors are minimized, and greater accuracy is achieved in tracking expenditures. For those shipyards accustomed to the ritual of planners handwriting job orders, clerks typing up the input, and then transmitting the work task by teletype, the workload suggested by this approach can be overwhelming. By utilizing the capability of the computer, coupled with a disciplined structure for accessing the existing data repository, the need for this archaic practice is negated.

4. When more than one component is defined in the work scope, none of the work items are mutually-exclusive in their execution. Properly planned, there is no need for competing trades to work in the same physical area. All work can either be accomplished in the assigned area at the same time or within the period of performance specified. Similarly, there is no interference with other on-going trade work. By going to this level of planning detail, parallel as well as series work can be achieved. Under a systems-oriented approach, the main and vital hydraulic work for a submarine overhaul can be scheduled for an overall duration of six to seven months in order to cover system pumpdown, component repairs, final assembly and testing. To expect such conflicts with other trade work to be resolved at the deckplate level, as routinely occurs with system-oriented job orders, is both costly and unrealistic.

5. Instructions for the work are released approximately two weeks before its scheduled start. Late release ignores the realities of the work place. The waterfront supervisor needs a reasonable amount of time to become familiar with the upcoming work and to assemble needed tooling and material. And there are frequently manning problems, equipment failures and ships force interface issues to be resolved before work starts. Conversely, premature issuance is an open invitation for labor charging in many shipyards, in order to account for personnel assigned to the work crew. New construction yards, especially those associated with

lead ship design efforts, have found that releasing the work instructions as little as two weeks before scheduled work start minimizes the disruption caused by design changes. But repair yards must also contend with changing work scopes and new work directed by the customer. By delaying the release of work packages to the last practical moment, work performance measurement is greatly strengthened. There is little need to add scheduling contingency factors (float) to account for disruption caused by late changes to work content or to account for the uncertain status of other work in the area, for the unknowns impacting work start are coming into rapid convergence at this point in time. Zero float, meaning firm start and completion dates, should be the objective. Work schedules issued in two-week snapshots, and updated on a weekly basis, provide both the flexibility and control required. Even though data is maintained in electronic format until the last practical moment, functional codes should have the capability to access data (Read Only access mode) contained in the mainframe repository, for work content can change based on evolving situations at the worksite.

Development of product-oriented work instructions usually entails a two or three-step tiered process, depending on the nuances of the shipyard's organizational structure, with each step iterative as to the degree of refinement. Some private shipyards prefer a three-step process that melds the efforts of three separate divisions, Advance Planning, Detail Planning and

Production Control. Working against the Master Construction Schedule or Strategic Plan, Advance Planning determines the most logical breakout of work, including long-lead time material ordering, work to be subcontracted ("make or buy" decisions) and workload allocations in-yard. The Detail Planning Division prepares the work packages based on this breakdown and initial planning and, using the master schedule for work sequencing, defines the specific work to be performed, including the hardware and software necessary to accomplish it. About two weeks prior to scheduled work start, Production Control calls out the work package and pre-kitted material is positioned by the Material Department. As work progresses, feedback from Production Control permits variance analysis as to hours expended and elapsed time, along with any refinement that may be necessary in the technical data repository. some shipyards have reached the stage where discrete action steps in the work package are bar-coded, thereby allowing real-time input as to work status and the timing of Support services such as Quality Control checkpoints. Staffed with personnel representing all required disciplines, particularly engineering and individuals with either current or, recent trade experience, personnel are shifted among the three divisions as workload dictates and to provide cross-training.

Under the Outfit Planning Group concept at Philadelphia Naval Shipyard, the iterative process leading to a detailed work package (called a C-Event) starts with inputs from Planning and Estimating



(P&E), Design and Scheduling. Working with the major event (A-Event) and milestone (B-Event) schedules, and the predetermined ship zones or area boundaries, P&E describes the work authorized and provides the required procedures and technical manual extracts to the Outfit Planning Group. Design furnishes selective portions of plans and drawings that pertain to the work in the prescribed areas. Based on P&E estimates of work scopes, Scheduling provides KeyOp scheduling information, as well as any supplemental data that may be germane to the task at hand. A typical flow diagram of this integrated planning process is shown in Figure 4. It could be rationalized that the Outfit Planning Group has merely assumed the role of the chop planning groups, but such is not the case. Planning and Estimating, Design and Scheduling, working from systems-oriented source documents, have provided the initial cut at providing product-oriented data and, in the process, have benefited the entire iterative planning process by their individual perspectives, expertise and experience. No functional code works in isolation, and by the cross-fertilization of data and ideas, each step is a refinement of data developed during earlier stages. And while everyone tends to view a job from a different perspective, the user reigns supreme throughout. The Outfit Planning Group (OPG), staffed with shopwise engineers and planners, as well as former senior shop planners and production foremen, proofs, collates and provides the necessary final refinement to ensure that each work package stands on its own and is, in fact, the most appropriate way in which to accomplish the work. If shop

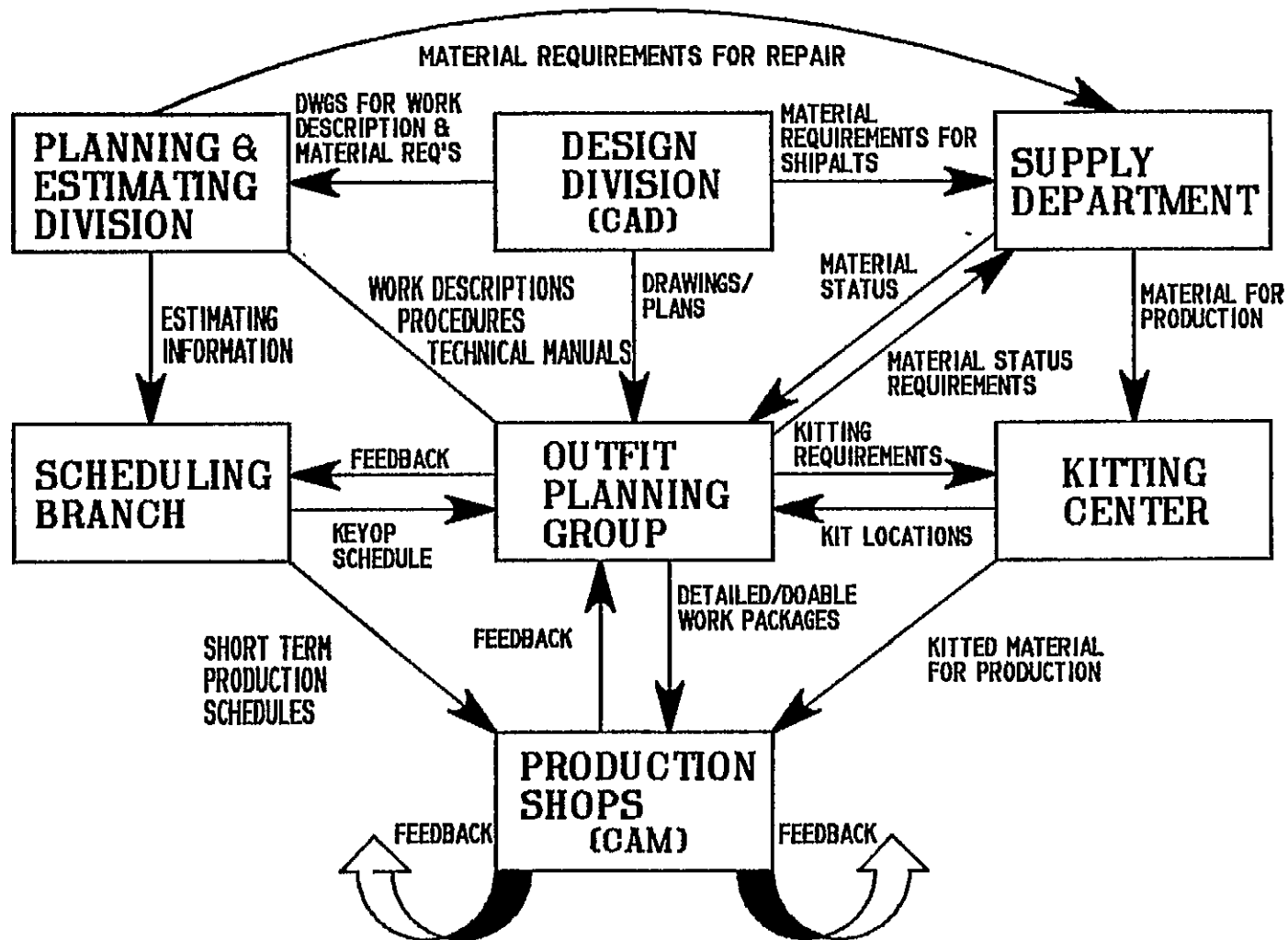


FIGURE 4.  
INTEGRATED PLANNING FOR PRODUCTION  
(COURTESY OF PHILADELPHIA NAVAL SHIPYARD)

repair, rather than in-place repair, for example, is deemed the most appropriate way to accomplish the work, that decision is made by the OPG. One priority function is the provision of quality drawings to support the task assigned, a common problem on older ships. By the use of a variable density, Versatec Acris II aperture card scanner and a high resolution laser printing system, sub-standard blueprints are reviewed, edited and image-enhanced where necessary. The use of six 19" viewing screens minimizes the need for excessive scrolling. To provide added assurance that the OPG is not isolated from the realities of the waterfront, and to allow prompt resolution of any emerging problems, a waterfront management team, staffed with combat systems, design and industrial engineers, provides prompt feed back to the OPG of any execution problems encountered.

The parallelism in the approaches used by Philadelphia Naval Shipyard and some private shipyards is striking. At the chokepoint of shipyard operations, a position comparable to functioning at the neck of a funnel, a multi-talented organization selectively integrates data elements from a myriad of sources and formulates doable work packages, as seen through the eyes of the trades that will do the work. Explicit in this integration effort is that everyone knows what has to be done, that the work is transmitted in a language understood by the individuals doing the work and it is scheduled in a sequence that is compatible with the way that the work is actually accomplished. The synergism that can result from

the horizontal integration of interdepartmental disciplines is remarkable. Probably one of the more important benefits derived from having one central clearing house for work package issuance is the realism that can be brought to bear on the scheduling of events. Based on the sharp exchanges that have been witnessed between schedulers and production supervisors at this juncture of the planning process, it certainly raises questions as to the actual need for a separate scheduling section at many shipyards.

Uncertain at this point is whether Philadelphia Naval Shipyard can afford to retain "one central clearinghouse" for work packages as it moves to apply zone technology to all assigned work. About 30 people are currently assigned to the Outfit Planning Group and, absent an augment in resources, some adjustments in responsibility will be required as the workload increases. Some OPG functions could be shifted to P&E, for example, but that decision is predicated on their full acceptance of the new work methodology. Job order structuring may be one such candidate. A quasi-cellular organizational structure, one that solidifies the horizontal integration of functional disciplines, is another option. Another factor concerns itself with the data repository, and the progress made towards standardization. If the stored data permits little repetitive action, the shipyard is faced with the task of building each work package essentially from scratch.

Regardless, when the "rules of engagement" are Precise and only that documentation necessary to do the assigned task provided, there is no need for the mechanic to sort through an endless listing of references and superfluous drawings before starting the job. Precise work identification means that broad, generalized drawing notes, such as "structure welding will be accomplished IAW MIL-STD 1689", are replaced by the specific portions directly applicable to the work at hand. Only the portions of drawings applicable to the job are provided, and they are shown in exploded view with amplifying details or sketches, if needed. (How many times has it been jokingly suggested that mechanics should be equipped with over-sized suitcases to carry the library of job order references and blueprints to the worksite?) The lead production trades must be involved throughout the planning process, rather than being required to sort out all the issues once the pieces are received on the waterfront.

In any shipyard, you win or lose on the waterfront. This forced integration of designers, engineers, planners and trade supervisors has been cited as the most significant benefit to be derived from product-oriented work execution [10]. But it really goes beyond that. It is a lesson in ownership: that problems do not end when the paper is passed into the outgoing basket. It is a synergistic effort, one where everyone involved in the process owns a piece of the action until the final product is satisfactorily completed. In sum, teamwork.

## THE NAVY'S ADVANCED INDUSTRIAL MANAGEMENT PROGRAM

The random application of zone logic by the shipyards, regardless of how successful, does not mean that it will shortly become standard policy for all repair work. Pockets of excellence do exist at the individual activity level, but the absence of a corporate repair strategy, one that endorses the concept of zone technology, and provides the focus and support needed, continues to be the major contributory factor to its excruciatingly slow incorporation into repair work. Current Navy maintenance philosophy, allied to a systems-oriented work methodology, is the singular most significant impediment to change. Only Navy action at the corporate level can rectify that.

There are initiatives underway by the Navy, however, that could both facilitate zone technology efforts already in progress, and accelerate the across-the-board adoption of a product-oriented work process. But they will require adjustments in thrust and purpose if that is to occur. The Naval Sea Systems Command Advanced Industrial Management (AIM) Program is one such example. This program would concentrate on accurate technical documentation to support the work authorized and the use of standalone work packages at the component level. As described at the March 1990 ASNE Logistics Symposium, the Advanced Industrial Management Program would consist of two basic elements: (1) Advanced Technical Information Support (ATIS) and (2) Advanced Planning and Packaging

Support (APPS). ATIS is a digitized and integrated technical information base, linking component technical documentation (such as technical manuals and drawings) with 3-D models via the Ship Configuration and Logistics Support Information System (SCLSIS). APPS would optimize job packaging methodology, and quoting from implementing directives, "... may be based on skills, physical ship zones (zone logic technology), schedule milestones, ship systems or other criteria" (sic).

With the exception of physical ship zones (zone technology), the practicality of "optimizing" job packaging methodology around the other polarizing factors is questionable at best. Job packaging by schedule milestones, for example, might answer the question as to when specific tasks are to be accomplished, but it ignores the realities of how the work is done. Unless there is an upfront analysis of related tasks, in the form of manageable productive units of work that balance the demands of multi-trade coordination, we're back to business as usual. Expecting the schedule to be the forcing function to pull events together after-the-fact, and that is what will happen, represents no change at all. It is possible to control by divisions in time, but the most effective way is to meld time with zone control.

Job packaging under the AIM program, however, would not be based on traditional, system-oriented key operations. Under this program, the central technical source document for repair

activities would be the Component-Oriented Technical Work Procedure ( COTWP ) . This procedure could be retrieved from either a local ATIS repository or a master digital database, and it would permit work tasks to be executed on a stand-alone basis. The ultimate objective of the AIM Program, then, would be to provide the shipyard users with accurate, real-time, digitally-based data and tool repositories, eliminating the onerous administrative burden inherent in today's paperwork process. In effect, it is envisioned as the industrial counterpart to the much espoused "paperless" ship of the year 2000. Nothing in that objective contradicts the purpose of computer-aided process planning.

Accurate technical documentation and improved work package methodology are worthy objectives, and both are essential to the successful application of computer-aided process planning. But process planning goes far beyond those two steps. It is the analyses of the processes by which work is accomplished that achieves lower assembly and manufacturing costs. Zone logic, using computer-aided process planning as its forcing function, derives its strength from its ability to subdivide the authorized work into subsets of interim products and products that can be grouped according to similar manufacturing/assembly processes. Improvement comes by constant refinement of those individual processes. It is this upfront sorting of common principles, tasks and problems, made possible by a product-oriented classification and coding system, that makes this possible. While AIM is silent on these factors, it



wouldn't take a major change in purpose to move the very promising COTWP initiative into the full realm of process planning possibilities.

AIM' S casual reference to zone technology, however, is disturbing, and would suggest that the lessons and experience of building yard group technology, specifically its linkage to repair yard zone logic, are either not understood or they are not appreciated. Component-Oriented Technical Work Procedures (COTWPS) should be viewed as a subset of zone logic techniques. To view zone logic as merely performing a sorting function for the execution of COTWPS is fallacious reasoning. The programmatic controls inherent in zone logic serve to strengthen the integration of work documents treated in isolation. Work execution is not the simple aggregation and sequencing of individual work tasks, it is the grouping of like processes that leads to efficient work execution. Therein lies a Key element in the success of the zone logic process that is lacking in the COTWP initiative as currently structured. With minor adjustments, COTWPS can form the basis for the grouping of like processes.

The procedure by which work packages are assembled and scheduled is central to realizing the savings that detailed planning offers under zone logic. Unless COTWPS are assembled into units of work that recognize the interrelationships of specific tasks within the area where the work is to be performed, as well

as the similarities of the processes by which work is done at the component or interim product level, that potential will not be fulfilled. Treated in isolation, COTWPS run the risk of becoming a refinement of Technical Repair Standards (TRS), but with a different veneer. Standardization of work requirements (specifications) does have merit, but when efforts are made to standardize the method by which work is accomplished, the flexibility needed to improve the process has been lost, in other words, producibility. Already the COTWP concept of standardized component work procedures, announced in March 1990, has seen re-direction. It was found that the method - the process - of work execution varies among shipyards, and that the COTWPS were not directly usable in each shipyard on a routine basis. Similarly, in the effort to also standardize the quality requirements for each COTWP, there was found to be a wide variation among shipyards as to what constitutes Objective Quality Evidence (OQE).

The preponderance of funding being committed to implement AIM in FY 90/91 is directed towards the submarine force. While the reasonably good configuration baseline afforded by these ships may appear to be a logical starting point, this concentration of funding to one segment of the Navy means that public and private shipyards doing repair work must continue to cope with two management structures, one product-oriented, the other the traditional systems approach to doing work. For shipyards with a mixed workload, the structure becomes particularly cumbersome.

More importantly, it does little to fuse a meaningful link between new construction and repair yards. With CALS (Computer-aided Acquisition and Logistics Support), along with the continuing emphasis on CAD, the new construction yards will be determining and defining the components that will populate the delivered ship. This build strategy forms the logical basis for a repair and modernization strategy.

As an integral part of the NAVSEA Corporate Operating Strategic Plan (COSP), AIM has the potential for fulfilling the need for total integration of all planning efforts in the execution of production work. When married to Computer Aided Process Planning (CAPP) within a zone logic structure, the significant cost savings of a product-oriented work environment can be realized. The technical information provided by ATIS is directly transferable to on-going CAPP efforts. But the APPS subset of AIM requires modifications if COTWP work packages are to be effectively blended into a zone logic work environment.

## CONCLUSIONS

The belief, shared by many, that ship repair is little more than a job-shop operation, offering few opportunities for the application of computer-aided process planning to the overhaul and modernization of ships, is a feckless opinion at best. It certainly runs counter to the productivity gains being realized by virtually every industry that has made the transformation to a product-oriented work base. Ship repair presents unique challenges, but each is amenable to solution by the corporate talent that resides in the shipyard community. Nurtured within a group technology (zone logic) framework, computer-aided process planning has the potential for revolutionizing a shipbuilding and ship repair industry that is mired in the archaic policies and practices of a systems-oriented work culture.

Shifting to a work structure oriented around computer-aided process planning, however, represents an attitudinal challenge, rather than achieving any scientific breakthrough. It requires adherence to a discipline that no single unit of work is the product of one individual, but that the work instructions represent the collective, albeit disparate, talents of many shipyard disciplines. Component design obviously impacts manufacturing costs, but production costs are directly determined by the process by which work is accomplished. It is here that the horizontal integration of tooling, skills levels and manufacturing methods

come into play - the "how" rather than the "what". But with experienced process planning in short supply, that experience will be lost unless captured. A CAPP-based data repository permits that.

Process planning is more than word processing. With a group technology based system, one utilizing classification and coding at the design and production levels, code numbers allow the retrieval of existing and preferred manufacturing information, with preferred being the optimal method based on experience and tools available. Standardized process plans permit preferred shop routings for component/part families, with this same GT breakout reducing the cost and time in the preparation of numerically-controlled tapes in both micro and macro format. Detailed knowledge of work requirements and work processes is required if the full benefits of computer-aided process planning are to be realized. But change will not be easy, nor will it be quickly achieved. At the outset, transformation of the U.S. ship repair industry to a product-oriented work base requires a strategic plan that is close-coupled to modern shipbuilding methods. The interconnectivity between ship construction and ship repair must form the central fabric of that overall plan. Just the step of exploiting that linkage and eliminating many of the duplicative and redundant planning efforts will result in significant cost-savings. But this integrated build and repair strategy transcend simple savings in repair yard engineering services, for the ultimate

objective should be to restore this country's maritime base to its former position of preeminence.

specific action steps that will start this transition process include:

1. For financial and progress reporting purposes, expand the current Ship Work Breakdown Structure (SWBS) to account for product-oriented work and management methods. Standardization of requirements, in conformance with DODINST. 7000.2, will preclude the need for individual activities to devise alternate systems, and it will ensure greater consistency of Defense Contract Audit Agency (DCAA) auditing actions.

2. Expanded Planning Yards (EPYs) should be tasked to prepare ship alteration drawings in zone format for assigned classes. In the initial phases, close liaison with repair activities is mandatory, for the zone strategy utilized must allow repair yards the flexibility to combine or further refine the zones to accommodate varying work packages and to allow repair and ship alteration integration. Depending on the size and complexity of the alterations, this approach by the EPYs would also permit the pre-sorting (grouping) of associated drawings to identify component parts amenable to similar manufacturing processes. It would, in effect, be the initial entry into a CAPP-oriented data repository.

3. New construction drawings showing **zone** and intermediate zone designations should be routinely provided, on a ship class basis, to all activities involved in repair package planning, including Planning Yards and PERAs. Using data already available from new construction yards employing group technology, this step would obviate the need for repair yards to duplicate some of the administrative steps associated with ship zoning. Admittedly, new construction zones may not be directly transferable to repair and modernization zone strategy on a "one for one" basis in all instances, but the mechanics of integrating build and repair strategies would be afforded the opportunity to start their gestation process.

4. The electronic distribution of technical documentation at the component level, and this includes that available in CALS, EDMICS and CAD data repositories, needs to be made readily available to repair activities. Work instructions, such as COTWPS, should also be part of this data package, but they need to be restricted to the applicable component requirements (the what), with the method of accomplishment (the how), determined by each individual repair activity. By making many of these elements part of the Contract Data Requirement List (CDRL) deliverables package, and providing them in digital-optical format, repair planning can be greatly streamlined (particularly when CAPP is utilized) and many of the startup costs associated with data verification and compilation could be eliminated.

5. Maintenance procedures need to be modified to accommodate product-oriented work, and that should include the identification of work location at the zone/intermediate zone level by activities involved in the planning efforts associated with Ship Alteration and Repair Packages (SARPS) and Overhaul Work Packages (OWPS). This upfront sorting would preclude the need for the same work effort by each activity involved. Preliminary review also indicates that the first four to five digits in a Product Work Breakdown Structure (PWBS) could be standardized on a class basis to identify the component and area (zone). This would permit a generic breakdown of the work item, with unique identification or "customizing" done at the repair activity level.

Both the time and opportunity for change is present. Practical, hands-on experience from the shipyards that have demonstrated the merits of zone technology, melded within a corporate framework that can provide course, rudder and speed changes as the entire integrated process unfolds, would inject a sense of National priority that, heretofore, has been seriously lacking.



#### SOURCES OF INFORMATION

- [1] "Third Report of the Commission on Merchant Marine and Defense: Appendices". U.S. Government Printing Office, Sept. 30, 1988. Pg. 214.
- [2] Washington Post, September 11, 1990, pg. A12; and September 13, 1990, pg. A1.
- [3] "Third Report of the Commission on Merchant Marine and Defense: Findings of Fact and Conclusions". Sept. 30, 1988, pg. 3.
- [4] "Report on the United States Shipbuilding Industry" promulgated by Naval Sea Systems Command, July 1990.
- [5] Coopers & Lybrand/American Management Systems Navy Industrial Fund Project, Shipyard Review Report, June 1986
- [6] Fortune Magazine, 26 March 1990.
- [7] D. Davison, "Applying GT to Increase Productivity in a Job-Shop Environment", Journal of Ship Production, Vol. 6, No. 1, Feb 1990.
- [8] "Public Hearings Before the Commission on Merchant Marine and Defense, May 1988 and July 1988", pg. 582.
- [9] "Initial Implementation of IHI Zone Logic Technology at Philadelphia Naval Shipyard", Journal of Ship Production, Vol. 5, No. 2, May 1989.
- [10] L.D. Chirillo, "product work Breakdown structure: An Essential Approach for Ship Overhauls", Journal of Ship Production, Vol. 5 Number 3, August 1989

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