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U.S. DEPARTMENT OF THE NAVY
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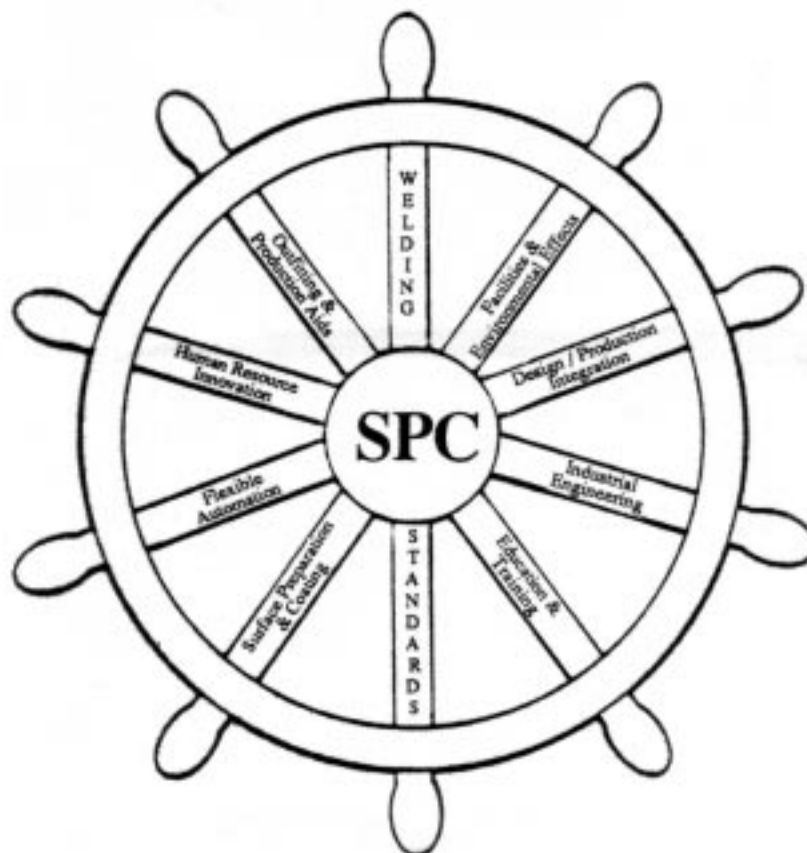
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THE NATIONAL SHIPBUILDING RESEARCH PROGRAM'S 1990 SHIP PRODUCTION SYMPOSIUM

**Preparing for the 21st Century:
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**August 22-24, 1990
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THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
601 Pavonia Avenue, Jersey City, NJ 07306

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CAD/CAM in Phased Maintenance

6B-2

Bruce A. Carr, Visitor, Thomas M. Houlihan, Visitor, Michael A. Polini, Member, Jonathan Corporation, Norfolk VA

ABSTRACT

The Jonathan Corporation is a medium sized engineering company specializing in Naval ship repair. The bulk of corporate work centers on the Phased Maintenance (PM) of three classes of ships. Typically, each PM contract covers three to five different ships per class scheduled for 90 day Availabilities at approximately one year intervals over a period of five years.

The type of work to be performed during each Phased Maintenance Availability (PMA) falls into one of two categories - ship alterations or ship repairs. The first group, ship alterations, are characterized by detailed, long lead engineering and planning efforts, typically beginning 540 days prior to the vessels's arrival. The second group, ship repairs, make up the other end of the spectrum with short lead times and compressed service details. The majority of repair items are identified 60 days prior to an Availability, while some are not determined until after the vessel has arrived in the shipyard.

The Engineering Department that services PMA work is composed of three disciplines - Structural, Mechanical and Electrical. The Mechanical Discipline is further sub-divided into the areas of Machinery and Piping/HVAC. While the nature of PMA work within each discipline is peculiar to the application, the process is similar in each. Reference information is gathered and verified, technical analysis is provided where necessary, and detailed drawings are prepared and submitted for Navy approval prior to shipyard production. All drawings are developed using two-dimensional (2D) drafting techniques at various sites by teams of Computer Aided Design (CAD) input operators utilizing color graphic workstations on a multi-shift basis as required by the workload. Completed drawings are transferred to the engineering site over a network link, where additional workstations are available for engineers to check and correct them as necessary.

PMA OPERATIONS

PMA Operations involve four distinct agencies - Engineering, Purchasing, Production and Management. Each is now considered in detail.

PMA Engineering

PMA Engineering encompasses both engineering design and production planning. As Ship Installation Drawings (SEX) near completion, the PMA planning process begins. For each PMA tasking, engineers experienced in the production trades and familiar with the company's resources prepare a work breakdown structure which features units called work elements. Typically, these elements encompass work that can be done by a single person in 16 hours or less. Detailed information specific to the element, such as primary work operations, secondary work operations, associated tradekills, material requirements, manhour estimates, specific references and a verbal description of each element tasking, is loaded into a database residing on the central corporate computer system. Once identified, the elements for the various trades are then grouped together into production work packages

(Figure 1) Which represent 200 - 400 manhours of work for a crew of 6 - 8 people.

PMA Purchasing

Upon completion of the work breakdown structure, PMA Purchasing commences. The database is searched for elements flagged by the engineers as requiring material. Sources are identified, cost estimates are prepared and tentative delivery schedules are set by seasoned procurement personnel. A material audit list is prepared linking the material purchased to a particular element the governing alteration and the applicable drawing for tracking purposes (Figure 2).

PMA Production

Ninety days prior to ship arrival, PMA production personnel review the work packages prepared for the ship alterations, the list of repairs and associated manpower requirements. Decisions are then reached on the exact scope of work to be performed and the operative production schedule is finalized. The job database is then updated and work is released in the form of work packages. The packages contain all the pertinent information concerning the work to be performed. Upon completion of each task, the expended time is recorded for each associated work element in a work package and the elements are then closed to further hourly charges being entered into the database. Various production efficiencies (Figure 3) are calculated from these expended and completed hour values to determine tasking progress.

PMA Management

While all this activity is taking place, PMA management personnel are working to control the job. Manpower loadings are developed and work schedules are continually adjusted to level out the production peaks and valleys (Figure 4). The process is facilitated by use of the Interactive Project Scheduling System (IPSS) developed to expedite the scheduling of PMAs and the setting of trade skill manloading levels. As work is completed, actual status from closed out work elements is entered into the database, enabling overall job progress to be monitored.

CAD/CAM SYSTEM DESIGN

Several considerations involving the work place, proposed and operative hardware as well as proposed and operative software were involved in the present Computer Aided Design / Computer Aided Manufacturing (CAD/CAM) System Design. Each is now considered in detail.

Working Environment

Before getting down to specifics, it is best to summarize the operating work environment. First is the fact that it is diverse. The parts associated with the Structural discipline range from rectangular steel panels measuring 10' x 40' to circular aluminum 3" diameter insert plates. Electrical discipline needs may be for a 1/8" steel plate dotted with 2" x 3" rectangular cutouts for mounting recessed gages.

Mar 7. 1986

J o n a t h a n C a r p (F r o n t S t . C)

time 14, 19

P A C K A G E W O R K S H E E T

Package 113.00 87K MODS 4TH AND 5TH DECK Ships 1315 USS SAGINAW (LST-1188) FY88

I	programs	signature	date	I	budget	.00

start date	completion date	planner:		rov e		
01/15/86	02/01/88	9643 Elbert P. Williams		1		6

leadcraft		primary operation				
shipfitter		modify				

line	no	Item	paragraph	100	prl	trade	100	operation	subject	bd	bd	location
1>	6496	529-90-087	3.3.1		4	110	02	layout/template	LOCATION FOR DPHM 11-E	4	0.00	5-192-0-E
2>	8499	529-90-067	3.3.1		4	110	63	install equip/str	BOLTED PLATE MANHOLES 11-E	12	0.00	5-192-0-E
3>	8600	529-90-067	3.3.1.1		4	605	69	control point	INSPECT FINAL WELDS	4	0.00	5-192-0-E
4>	8501	529-90-067	3.3.1.1		4	130	67	weld/burn	BOLTED PLATE MANHOLE 11-E	16	0.00	5-192-0-E
5>	8602	529-90-067	3.3.1		4	110	63	Install equip/str	KIT 761 DFT 11-C COLLARS	16	0.00	5-192-0-E
6>	8503	529-90-067	3.3.1		4	130	66	cut	ASSIST 110 W/DET 11-C COLLARS	16	0.00	5-192-0-E
7>	8504	529-90-067	3.3.1.1		4	605	69	control point	IHSP FINAL WELDS	4	0.00	5-192-0-E
8>	8603	529-90-067	3.3.1.1		4	130	67	weld/burn	DET 11-C COLLARS STOP	86	0.00	5-192-0-E
9>	8606	529-90-067	3.3.1.1		4	605	69	control point	INSP FINAL WELDS	4	0.00	5-192-0-E
10>	8507	529-90-067	3.3.1.1		4	130	67	weld/burn	DET 11-C COLLARS PORT	40	0.00	5-192-0-E
11>	8608	529-90-067	3.3.1		4	110	63	Install equip/str	SECT 14-A BLANKS	24	0.00	5-192-0-E
12>	6509	529-90-067	3.3.1		4	130	66	cut	CUT DRAIN HOLE BLANKS 14-A	4	0.00	5-192-0-E
13>	8510	529-90-067	3.3.1.1		4	805	69	control point	INSPECT FINAL WELDS	4	0.00	5-192-0-6
14>	8511	529-90-067	3.3.1.1		4	130	67	weld/burn	DRAIN HOLE BLANKS 14-A	40	0.00	5-192-0-E
15>	9512	529-90-067	3.3.1		4	110	63	Install equip/str	SECT 14-C ACCESS COAMINOS	1	0.00	5-192-0-E
16>	6513	529-90-067	3.3.1.1		4	605	69	control point	INSPECT FINAL WELDS	2	0.00	5-192-0-E
17>	6514	529-90-067	3.3.1.1		4	130	87	weld/burn	SECT 14-C ACCESS COAMING	6	0.00	5-192-0-E
18>	8515	529-90-067	3.3.1		4	110	63	install equip/str	SECT 14-D ACCESS COAMINGS	8	0.00	5-192-0-E
19>	8516	529-90-067	3.3.1.1		4	605	69	control point	INSPECT FINAL WELDS	2	0.00	5-92-0-E
20>	0517	529-90-067	3.3.1.1		4	130	67	Wold/burn	SECT 14-D ACCESS COAMING	6	0.00	5-192-0-E
21>	6653	529 90-067	3.3.2		4	110	55	remove equip/stru	3-TYPE"S" DINS/5 STOR DINS	36	0.00	4-203-2-A

Figure 1 Production Work Package Cover Sheet

6B-2-2

dec 14, 1987

J o n a t h a n c o r p (f r o n t S t , L)

P A C K A G E W O R K S H E E T

Package: 908.00 D-ALT KITS / PROGRAM / TSC Ship: 1315 USS SAGINAW (LST-1100) FV88

material requirements:		qty	UM	Description	requisition	Class	promised	received	whse loc
ws#	mic#								
7809	7234	2	SF	PLATE, CRES (304) 1/4 T 10.2 LB/SF 00-S-766	356653-003	CAM-T.STL.	1/05/88		
7871	7243	28	SF	PLATE,STEEL ORD STR 1/2-T 20.4 LB/SF	356217-032	CAM-T.STL.	12/22/87		
7871	7244	27	SF	WIL-S-22690 GR A CL U PLATE,STFEL ORD STA 3/4-T 15.3 LU/51	366217-033	CAM-T.STI	12/22/07		
7871	7245	2	SF	WIL-S-22698 GR A CL U PLATE,STEEL ORD STR 1/4-T 10.2 LB/SF	356217-034	CAM-T.STL.	12/22/67		
7871	7246	11	FT	WIL-S-22608 GR A CL U FLAT BAR,STELL ORD STA 1/4T X 4W WIL-S-22698 GR A CL U	356217-035	T. STL BUY			
7871	7552	1	EA	COC FOR WIC #7243	356217-036	FILE CLEANUP		12/14/67	173480
8100	7489	3	SF	PLATE,STEEL ORD STR 3/8'T 15.3 LB/SF	356652-003	CAM-T.STL.	12/22/67		
8300	7559	1	SF	WIL-S-22696 GR A CL U PLATE,STEEL ORD STR 1/4'T 10.2 LB/SF	358342-001	CAM-T.STL.	12/22/87		
8300	7560	1	SF	WIL-S-22698 GR A CL U CAM MATERIAL PLATE,STEEL ORD STA 1/2'T 20.4 LB/SF	358342-002	CAM-T.STL.	12/22/87		
8300	8170	1	EA	MIL-S-22698 GR A CL U CAM MATERIAL COC FOR MIC # 7560	358342-003	FILE CLEANUP		12/14/87	273480
8310	7563	40	SF	PLATE,STEEL ORD STR 3/4'T 30.6 LB/SF	356342-006	CAM-T.STL.	12/22/87		
8310	7564	40	SF	MIL-S-22698 GR A CL U CAM MATERIAL PLATE,STEEL ORD STR 1/2'T 20.4 LB/SF	358342-007	CAM-T.STL.	12/22/67		
8310	7565	6	SF	MIL-S-22698 GR A CL U CAM MATERIAL PLATE,STEEL ORD STR 1'T 40.6 LB/SF	356342-008	CAM-T.STL.	12/22/87		
8310	7566	4	SF	MIL-S-22698 GR A CL U CAM MATERIAL PLATE,STEEL ORD STR 3/8'T 15.3 LB/SF	356342-009	CAM-T.STL.	12/22/87		
8310	7567	5	SF	MIL-S-22698 GR A CL U CAM MATERIAL PLATE,STEEL ORD STR 5/6'T 25.5 LB/SF	356342-010	CAM-T.STL.	1/19/87		
				MIL-S-22698 GR A CL U CAM MATERIAL					

Figure 2 Work Package Material Listing

OCT 7, 1987 time: 17:09

J O N A T H A N C O R P O R A T I O N

PAGE 0001

W O R K P A C K A G E E F F I C I E N C I E S

- (VReport for JONATHAN internal use only) -

Pkg NO	Hours Budget	Hours Exp	Prod Eff	Hours Comp	Hours Budget	Prod Eff
210.00	114.00	104.00	109.615	114.00	114.00	100.000
211.000	106.000	63.00	168.253	106.00	106.00	100.000
212.00	110.00	153.25	71.776	110.00	110.00	100.000
213.00	73.00	18.00	405.555	73.00	73.00	100.000
214.00	376.00	362.50	103.724	376.00	376.00	100.000
215.00	302.00	333.50	90.554	300.00	302.00	99.337
216.00	259.00	154.50	167.637	86.00	259.00	33.204
217.00	468.00	16.00	3050.000	227.00	468.00	46.516
218.00	130.00	110.00	116.161	82.00	130.00	63.076
219.00	125.00	82.00	152.439	117.00	125.00	93.600
220.00	67.00	6.00	837.500	67.00	67.00	100.000
Final Totals	2150.00	1404.75	153.052	1658.00	2150.00	77.116

Figure 3 Work Package Efficiencies Report

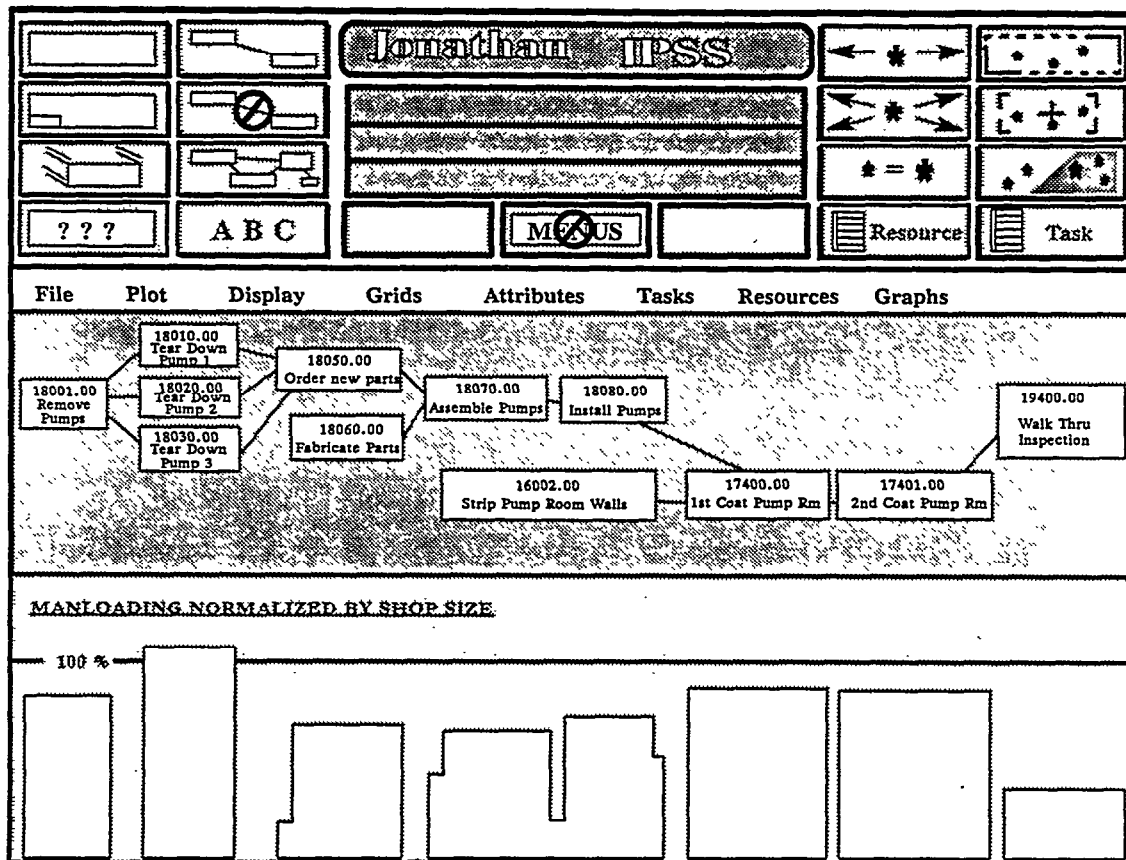


Figure 4 IPSS Manloading Display

Mechanical discipline requirements could demand a rough cut 3" thick gear tooth one day and an intricately shaped, 16 gauge, flattened piece of duct work the next.

Second, corporate facilities and resources are physically separated making communication difficult. If network links between the various nodes are subject to failure, vitally needed data becomes inaccessible.

Third, schedules are critical because of the restricted Availabilities. This translates into high reliability and accuracy requirements. Lost, uncut or incorrect parts can cause delays impacting not only the crew working the job, but also the crew scheduled to follow on the job. Nothing is more disastrous than burn files stuck on the engineering mainframe system because a data link is down.

Finally, the short lead times necessary to handle the repair items, the remaking of parts that were designed wrong or those ruined during fabrication require a system that is streamlined. The fewer manual interventions that are required and the more automated the process can be, the quicker the overall turnaround time can become.

Hardware Considerations

In considering CAD/CAM hardware, several points are important. Foremost is compatibility with existing or planned mainframes, microcomputers, terminals, work stations, plotters and printers. In our case, there existed multiple workstations capable of running CAD applications and one capable of running Computer Aided Manufacturing (CAM) programs. Rather than purchase additional workstations, the corporation opted to create the part geometry and to nest from within the CAD applications programs. These two steps represent the majority of time spent in generating numerical control (NC) data and

workstations dedicated to these functions can easily be adjusted to meet fluctuating production needs. While part geometry definition in the CAD application was easier than in the CAM application, some features were sacrificed by performing part nesting from a two-dimensional CAD environment. This was offset by limited plotting capabilities offered in the CAM program.

Another area offering considerable flexibility was that of interfacing the engineering mainframe and the NC Burning Machine. The simplest interface was a manual interface. Programs would then have been loaded into the burning machine form either the 8" floppy diskette or from the paper-tape reader. A major disadvantage to this mode of operation was the slow turnaround time. A second method considered was a direct interface, where modems or multiplexers would be placed at each end of the communication link and programs transferred over telephone lines with operators at each end coordinating the effort.

A third method, and the one utilized in the present system, is the indirect interface. An intermediate processor was inserted between the mainframe and the burning machine, in this case a Texas Instruments minicomputer. Programs are sent from the mainframe to the minicomputer, where they are stored on the disk. Transfer to the burning machine is over a direct line by a single operator. Whatever the chosen method of interfacing, one thing that is certain is that there must be some form of backup in the event of a mechanical or electronic failure of any component. To this end, the system must be configured with some redundancy in mind. A final consideration concerning hardware requirements is the need to design the system allowing room for growth. Added productivity will surely enhance demand.

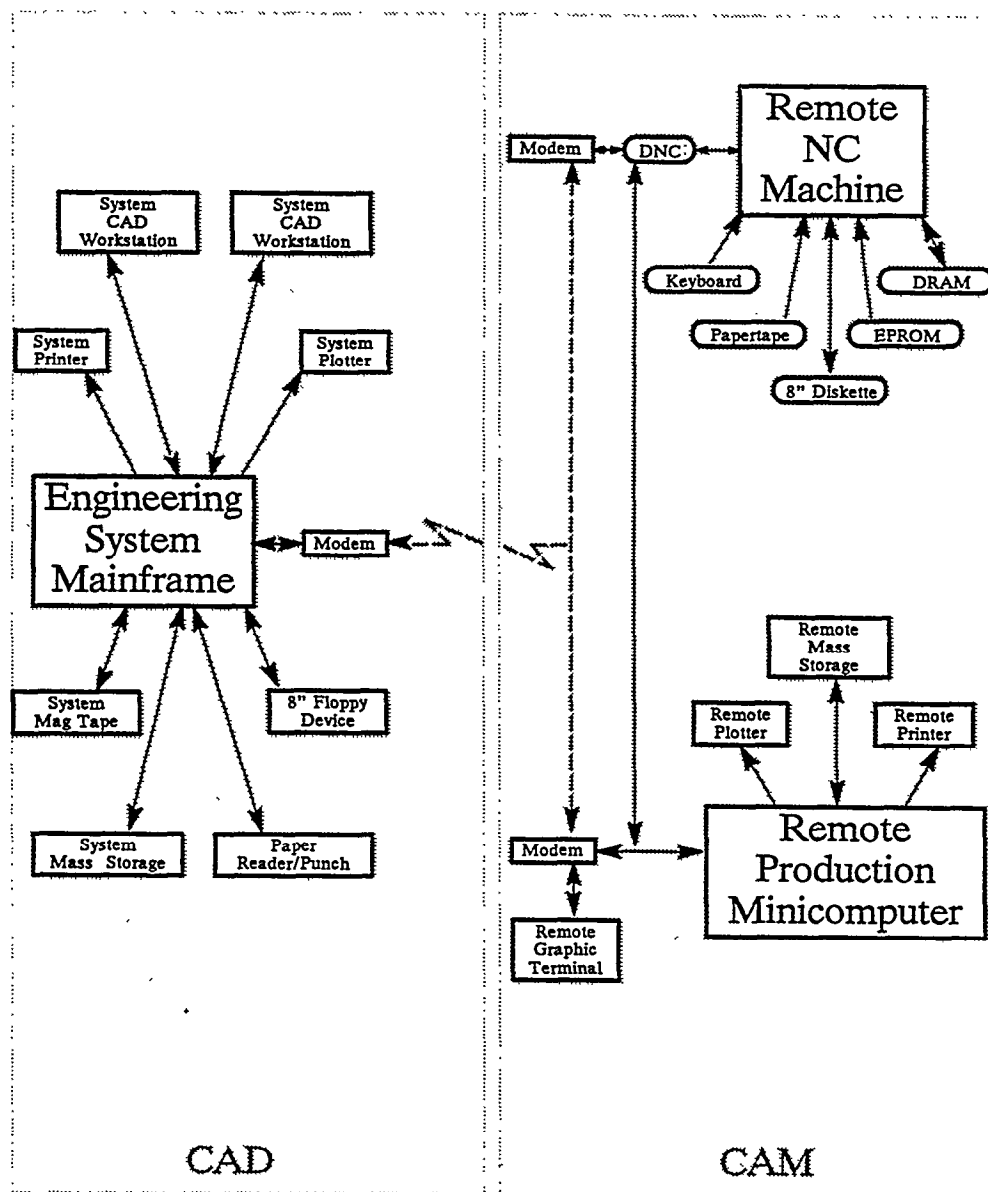


Figure 5 CAD/CAM Network

Software Considerations

In selecting the software and the utilities to be used on the system, training requirements were a foremost consideration. While the corporation had many users trained in CAD, there were no users trained in CAM. The existent workload of NC programming was handled by two people, one strictly defining geometry and nesting, the other tool pathing and coordinating the efforts of the various groups within the company. Development of macros within both the CAD and CAM applications helped to bring new users quickly up to speed. They further helped to guarantee the quality of the final product by streamlining the number of commands needed to be issued by the operator, hence, reducing the potential for error.

Cycle times were shortened by the use of system dependent "command" programs and file naming conventions. Because it was necessary to repeatedly switch from one program to the next, "command" streams that supplied the necessary startup prompts, built the input and output files, loaded the necessary macro files and programmed the terminals

special function keys had a tremendous impact on productivity.

The last software item to be considered was the post processor. Third party CAM packages were offered with two options pertaining to post processors. One was to have a custom program developed specifically for the output NC machine. The other alternative was to develop a more flexible program allowing the user to mold the output to match the machine. While the custom processor was cheaper, it offered no flexibility to the user, and any changes to its function had to be made through software revisions.

It is important to accurately specify the functionality of the post processor, paying close attention to the features and functions of the target machine tool. Failing to do this could result in the need for extensive file editing to rectify the problems. This interjects another possible source of error and increases the process turnaround time.

Part Database Fields . . .			Nested Plate Database Fields . . .		
ID CAM PART PHASE	Job Number	6	Job Number	6	
	Alt Number	6	Nest Number	4	
	Spec Item Number	8	Plate Length	3	
	Work Element Number	6	Plate Width	3	
	Drawing Number	3	Plate Thickness	3	
	Drawing Revision	1	Material Reference Flag	1	
	Detail Number	3	Material Type Spec		
	Kit Number	5	or Seagull Number	17	
	Born Number	3	Purchase Order Number	10	
	Part ID	3	Date Nested	8	
	Quantity	4	Estimated Bum Time	3	
	Material Reference Flag	1	Utilization Factor	5	
DEFINE GEOMETRY PHASE	Material Type/Spec		Work Element Number	6	
	or Seagull Number	17	Date Burned	8	
	Part Length	3	Actual Bum Time	3	
	Part Width	3			80
	Part Thickness	3			
	Half Flag	1			
	Modified Geometry Flag	1			
	Interior Cutout Flag	1			
	Marking Flag	1			
	Layout Time	3			
	Date Completed	8			
	POST NEST UPDATE PHASE	Date Nested	8		
Nest Number		4			
Process		1			
Description		2 5			
		128			
		Drop Plate Database Fields . . .			
		Job Number	6		
		Nest Number	4		
		Plate Length	3		
		Plate Width	3		
		Plate Thickness	3		
		Material Reference Flag	1		
		or Material Type/Spec			
		Seagull Number	17		
		Purchase Order Number	10		
					47

Database Considerations

The last topic for this part of the paper deals with the aspects of managing the information created, used, modified and referenced throughout the system. A simple job can generate hundreds of parts, a more complicated job, thousands. It is imperative that the user be able to determine the parts affected by a drawing revision, or a list of nests containing the parts to kit 804, or the status of nest 123. While manual tracking of this information is possible, it is not very practical. The flexibility built into the corporate Engineered Management System (EMS) allowed it to be adapted to the tracking of parts, nests and drop plates throughout the system and in generating reports summarizing the developed CAD/CAM work.

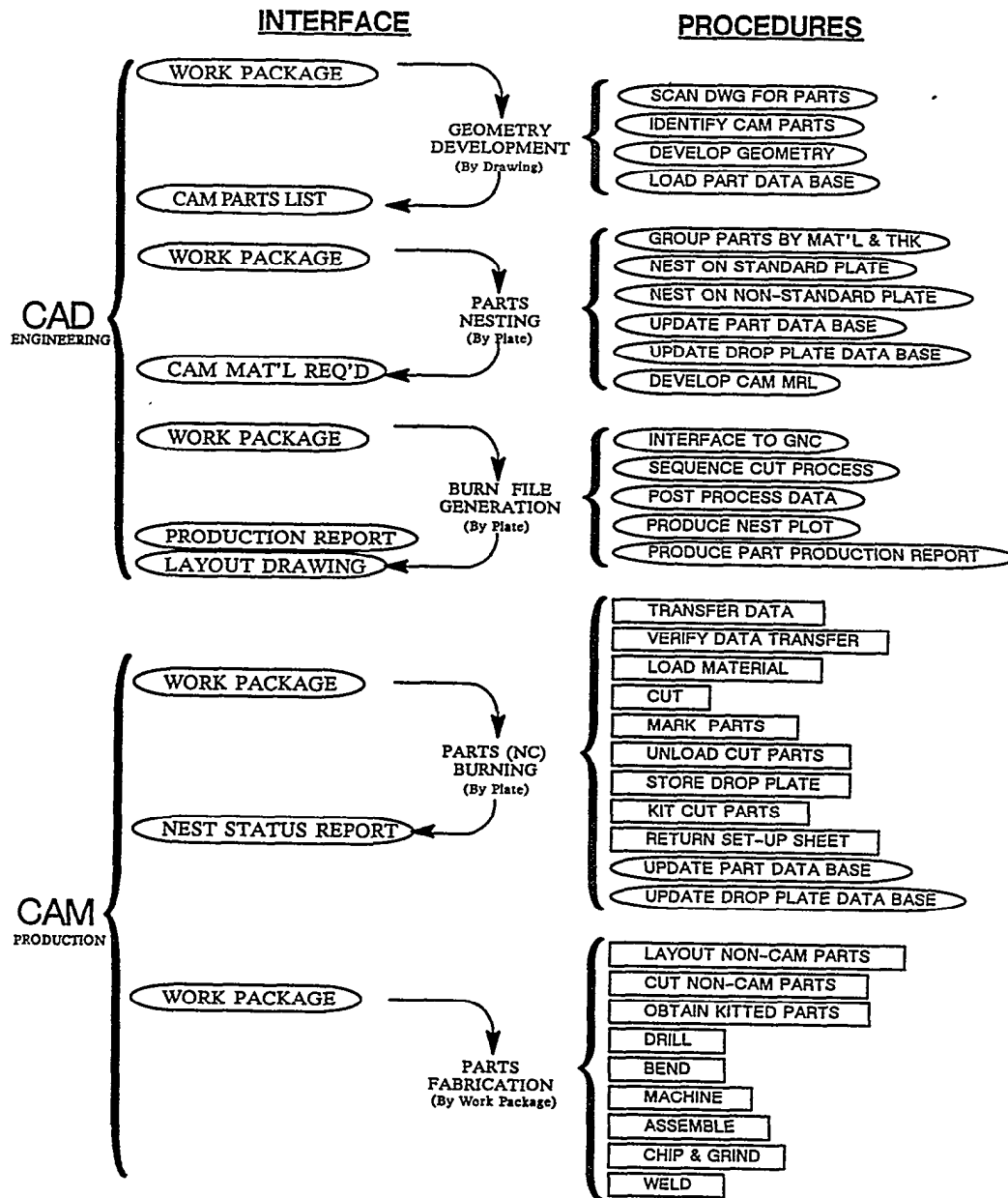


Figure 7 CAD/CAM Operations

files contain the application programs, operating systems and job data files. In addition, a nine-track magnetic tape unit is also attached and used for backups, archiving and cross-system data transfers.

Intermediate components in the form of Texas Instruments microcomputers add considerable system versatility. Equipped with 512K of RAM, color graphic monitors, serial and parallel communication ports, 10 megabyte fixed Winchester discs, 5-1/4" floppy disks, numerical co-processors and dot matrix graphic printers, they can operate as stand alone distributed systems enabling pre and post-processing of the data from the engineering system. They can also provide local word processing features or simply function as "intelligent" terminals with file uploading and downloading capabilities.

At the other end of the system is the LINDE CM-350 Burning Machine. Controlled by a UCNC-7/8 microprocessor and outfitted with an Anderson water table, it is capable of plasma or oxy/fuel cutting under control of programs conforming to the EIA Word Address format. Data

entry can be accomplished from a variety of sources i.e., the keyboard, an 8" floppy diskette, an ASII paper-tape, Direct Numerical Control (DNC), Dynamic Random Access Memory (DRAM) or Erasable, Programmable Read-Only Memory (EPROM). Once transmitted to the machine, programs can be locally stored on either the 8" diskette or in the DRAM by the operator. A built in line editor is available for previewing and/or modifying the data. With a DNC link, previously stored programs can be retrieved and transmitted back over the communication link to the host computer.

Operative Software

Tying the hardware together is the application software. Neglecting the various system editors, there are five major software programs required to keep the system functioning. The entire process starts with MEDUSA which is used extensively for geometry development, nesting, program reports and two-dimensional drawings. Other utilities such as the three-dimensional modeller, the viewer and the shrinker provide the

LINDE CM-350 BURNING MACHINE LIMITATIONS

<u>PLATE SIZE</u>	MAX	MIN
Width	10 ft	none
Length	40 ft	8 in
<u>PLATE THICKNESS</u>		
Aluminum	2 in	1/8 in
Stainless Steel	2 in	1/8 in
Steel (gas)	6 in	1/8 in
Steel (Plasma)	2 in	1/8 in
<u>SPECIAL CONSIDERATIONS</u>		
Bevel Cuts	not programmable at present time+	
Multiple Cuts	limited to gas only - 2 torches	
Surface Prep	plate must be free of multiple coats of paint plate must be free of built-up rust deposits the better the prep, the better the cut"	
Laminate Plates	not acceptable	
Expanded Metal	not programmable (manual jog, straight cuts only)	
Grating	not programmable (manual jog, straight cuts only)	
Structural Shapes	not programmable	
Pipe	not programmable	

NOTES

These limitations are flexible. For special applications contact the Engineering Department (Bruce Carr).

- Verification required.
- + Straight line bevels may be done manually.

Figure 8 Linde CM-350 Burning Machine Capacities

capability of generating meaningful visual representations of complex assemblies of parts when necessary.

The process continues with EMS. This application, developed in-house, provides for the creation and maintenance of relational databases to track labor and material associated with work elements. EMS was extended to include additional fields to properly track parts, nest and drop plate data (Figure 6). An associated variable reporting module allows EMS users to custom tailor outputs to suit their particular needs. Selection of entries can be made against user defined limits so that it is possible to select only parts with lengths less than 48 inches, parts completed after a certain date, parts associated with a particular detail on a specific drawing, etc.

Geometry definition, part nesting and cut sequencing are performed in GNC, the third major software component. In our implementation however, only cut sequencing (tool pathing) is done in this program. Part geometry and nest layouts are automatically loaded into GNC from entities present on MEDUSA drawing sheets via a direct transfer. The binary, "generic" data tile containing the "Cutter Location (CL) data" produced for sequenced nests requires messaging into a format suitable for the target NC machine. This messaging is done by CAMPOST the fourth software component. It is a custom developed post-processor that converts the CL data into the LINDE EIA Word Address format

The fifth software component in the chain is XTALK, which enables the Texas Instrument minicomputers to exchange data tiles with the mainframes and the LINDE CM-350 Burning Machine via a standard RS-232 interface.

CAD/CAM OPERATIONS

CAD/CAM fabrication at the corporation involves three. CAD operations and two CAM operations (Figure 7). Each of these operations involves several stages that are now considered in detail.

CAD Geometry Development

CAD/CAM operations begin with a consideration of overall material requirements. For a PMA, this entails both modernization and repair actions. Modernization material requirements by and large are specified on the applicable Ship Installation Drawings (SIDs) prepared for the proposed ship alterations. Material requirements for the repairs associated with a PMA are developed from Design Service Request (DSR) sketches or from technical manuals that accompany the repair or renewal of specific machinery and its surrounding structure. DSR sketches either define machinery foundations or the geometry of substitute parts. In either case, a drawing number of record identifies the DSR for both Navy review purposes as well as for reference entry into approved Navy specifications.

As each SID or DSR is completed and approved, the first CAD/CAM operation - CAD Geometry Development - begins. Production engineers review drawings from the viewpoint of CAM burning machine capacities and capabilities (Figure 8) in order to identify candidates for CAM fabrication. Plate size and thickness considerations are paramount for structural CAM entities. Likewise, minimum cut radius and machining speed considerations pertain to most repair part

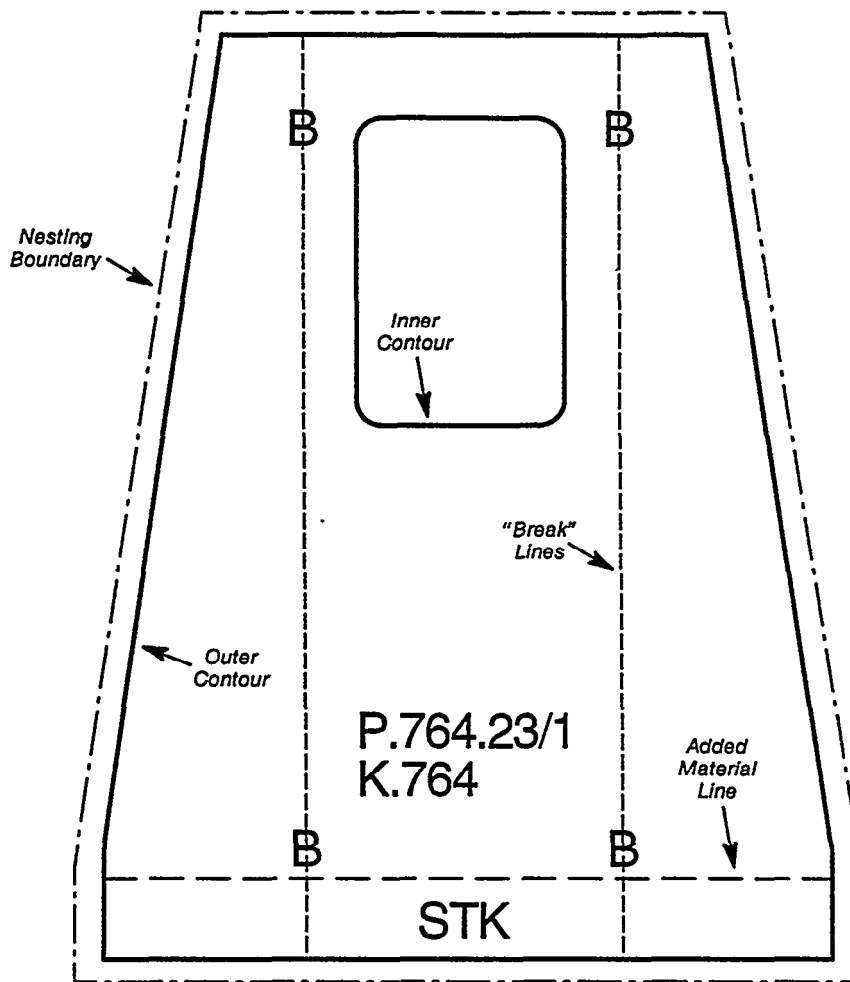


Figure 9 CAD Part Geometry

CAM identifications.

Once the possibility of CAM is indicated for a part, it is entered into the CAM Part Geometry database. The CAD application program is then used to create the individual part geometries. Numerical lofting techniques are employed to develop the planar outlines for each part. Special consideration must be given to such things as flanged parts, ductwork, rolled plates and added material for shipyard fit-ups. Each unique piece-part is then stored as a "symbol" (Figure 9), within a pre-defined file structure, for later use in the nesting phase. An added benefit of this file naming convention is the ability to reference "standard" parts. In this way, geometry can be re-used and lofting time reduced.

CAD Parts Nesting

The second operation in the CAD/CAM process is one peculiar to CAD/CAM - viz., Parts Nesting. Since parts having multiple thicknesses and material types are created in the CAD Geometry Development phase, the consolidation of these parts - enabling quantity buys of steel plate - requires two phases. The first is accomplished through the use of the selection and sorting features of the EMS part database. The second phase - Parts Nesting - is a graphical exercise within the CAD application program.

To aid in parts nesting, a variable report from EMS is produced (Figure 10). The first field in the output identifies the applicable drawing (SID or DSR) that pertains to the Job. The next field is the thickness of the part in sixteenths of an inch. The immediate aspect of this thickness listing is, of course, the possibility of combining like requirements into a composite, plate buy. The next fields in the output are the CAD Part Number - which is composed of the (last) three digits of the drawing number - and the piece/part number designation from the applicable drawing's Bill of Material. The next field is the drawing detail upon which the CAD part is specified. Quantity, material specification, length and width data (both in inches) comprise the next fields in the report. A calculation involving these entities produces the area (in square inches) of the plate (of particular thickness) needed to satisfy the material requirement. The field is a textual designation of the part that aids in subsequent identification for production purposes. As is evident from this listing, a total compilation of particular plate requirements from all drawings pertaining to a job can be readily determined.

Nesting is accomplished by placing CAD part geometries - available from CAD drawing detail files - upon various sheet patterns while maintaining considerations regarding minimization of excess material and attention to the peculiarities of CAM parts generation. The first consideration is automated by the computer which generates nesting

dwg	thickness	part no.	detail	quantity	length	width	area	description
002	5	P.002.01/08	5-A	175	9	9	98.437	9X9 BKTS (3X3 LEGS)
002	5	P.002.01/09	5-B	182	9	9	102.375	9X9 BKTS (3X1 LEGS)
002	5	P.002.01/04	6-A	24	24	7	28.000	INBD BTM CHKS FR 4-18
002	5	P.002.01/05	6-A	24	20	7	23.333	OTBD BTM CHKS FR 4-18
002	5	P.002.01/06	8-B	24	24	8	24.000	INBD DK CHKS FR 4-18
002	5	P.002.01/07	8-B	24	20	8	20.000	OTBD DK CHKS FR 4-18
002	5	P.002.01/10	6-D	30	25	9	48.875	TBHD BKTS @ SIDESHELL
002	5	P.002.01/11	8-C	34	29	9	81.825	TBHD BKTS @ LBHD
002	5	P.002.01/15	3-B	12	20	7	11.666	BTM CHK PLS @ FR 2
002	5	P.002.01/16	4-D	18	20	7	15.555	BTM CHK PLS @ FR 1
002	5	P.002.01/16	4-D	4	37	13	13.381	LBHD&SSWEBS@FR 1
002	5	P.002.01/03	4-A	24	79	19	250.188	LBHD TRANS WEBS FR 4-18
002	5	P.002.01/17	4-C	2	75	13	13.541	LBHD VERT WEBS @ FR 2
002	5	P.002.01/13	3-B	2	87	78	94.250	WT BHD PL @ FR 2-P/S
002	5	P.002.01/12	2-B	3	98	13	26.000	TBHD VERT TRUSS GDR-FR 3
002	5	P.002.01/14	3-B	2	98	78	104.000	WT BHD PL @ FR 18-P/S
				582**				933.184 **
002	8	P.002.09/06	2-C	21	15	1 0	21.875	BTM & TRN'SM LONG'L BKTS
002	8	P.002.09/07	2-C	21	14	9	18.375	BTM LONG'L BKTS @ KNUCKLE
002	8	P.002.09/01	7-C	16	24	22	58.888	SPUD SUP'T BKTS - ABV DK
002	6	P.002.09/04	4-C	18	28	1 5	43.333	OTBD DK STF'NRS - DK & BTM
002	8	P.002.09/08	4-C	18	28	8	17.333	INBD DK STF'NRS - DK & BTM
002	6	P.002.09/02	7-C	18	30	25	83.333	TRANS SPUD BKTS - BLW DK
002	8	P.002.09/03	4-C	16	31	30	103.333	LONGL SPUD BKTS - BLW DK
002	8	P.002.09/05	4-c	32	30	6	40.000	LONGL STF'NRS - DK & BTM
				154 **				366.246 **

Figure 10 CAD Part Geometry List

boundaries (Figure 10). As each part is nested by a CAD engineering technician, the status is updated in the parts database to reflect the operation. In this way, the completion of the nesting phase is readily verified when all of the piece parts in the CAM Parts File are associated with all of the nests in the CAM Nesting File. At this point, a consolidated Material Requirements List is generated (Figure 11) and a cost effective, integrated plate purchase is then made by procurement personnel.

The second consideration in CAM Part generation concerns the peculiarities associated with the operation of the burning machine. The plasma process only cuts cleanly when moving in one direction. Hence, machine operations for inside cuts must reflect the proper orientation of the arc - a situation that is specified in nesting by a skilled CAD engineering technician.

Associated with nesting is the concept of "kitting". As it stands, combinations of CAM parts are provided to production in kits to facilitate later fabrication. Of course, a kit can contain several CAM parts that are generated on several different nests! Again, skilled CAD engineering technicians determine the contents of each kit and reflect the necessary correlations between kit numbers, nest numbers and part numbers. A regular check of this database assures that the kit-nest-part number correlations are preserved correctly and that indeed kits required to accomplish a particular Navy work specification (Figure 12) are identified.

CAD Bum File Generation

Once nesting and kitting operations are complete, a "Bum File" is computer generated to provide the necessary machine instructions to cut out the required parts. The Bum File takes into account machine capabilities, plate thickness and material constituency and produces a record like that shown in Figure 13. Depending upon a combination of factors (plate thickness, material, burning machine torch selection), operating speeds (inches-per-minute @PM) and operational mode data are combined to produce a Machining Time profile record (Figure 14) that enables machine usage factors to be gathered for audit purposes. Although a "Paper Tape" output is mentioned here, its only significance is with respect to the buffer size of the target NC machine.

For every sequence of CAD/CAM operations on a plate size, a CAM Production Record (Figure 1.5) is computer generated to aid the CAM machine operator in producing and kitting the CAM parts associated with a particular plate.

CAM Parts (NC) Burning

As the production schedule dictates, the burn files are executed on the NC machine to produce physical parts. It is to be noted that the CAM Production Record (Figure 15) provides for feedback entry of tool path offset (kerf) and machine feed rate (feed). Both of these values are used to determine the accuracy and efficiency of the process. By

CAM MATERIAL REQUIREMENTS JOB 1588

- (VReport for JONATHAN internal use only) -

nest	material type	thickness	length	width	date nested
N.010	AL/QQ-A-2501/9	6	240	64	8/26/85
N.011	MATL PUR CHANGE				
N.012	SS/QQ-S-766	8	48	48	8/27/85
N.013	AL/QQ-A-2501/9	6	240	64	9/11/85
N.014	AL/QQ-A-2501/9	6	240	64	8/28/85
N.015	AL Q Q - A - 2 5 0 / 1 9	6	240	64	8/28/85
N.016	OS/MIL-S-66298	4	240	48	9/06/85
N.017	AL/ASTM-B-209	12	240	48	9/17/85
N.018	MATL PUR CHANGE				
N.019	OS/MIL-S-22698	4	46	48	9/06/85
N.020	OS/MIL-S-22698	6	240	96	
N.021	OS/MIL-S-22698	a	96	48	
N.022	MATL PUR CHANGE				
N.023	HS/MIL-S-24645	8	120	72	
N.024	HS/MIL-S-24645	a	120	72	
N.025	AL/QQ-A-250/19	10	120	96	9/16/85
N.026	ALQQ-A-250/19	5	120	96	9/16/85

Figure 11 CAM Material Requirements

monitoring these parameters, engineering personnel can retain control of the process and reduce the decisions that need to be made by production personnel.

CAM Parts Fabrication

The CAD/CAM process is finalized with the ultimate fabrication of shipboard parts. This fabrication is facilitated by the development of computer generated assembly sketches and production work packages. The assembly sketches illustrate the joining of kit parts while the work packages insure that all proper welding procedures and quality control (QC) actions are known and followed at the shipyard. Additionally, time estimates for the labor involved in each of the associated actions (drill, bend, weld, chip & grind, etc.) is recorded so that production labor costs can be related to a finished CAD/CAM entity. A review of the hours expended on the tasks versus those planned for the task provides a ready measure of the cost efficiency of the production.

BUSINESS IMPACTS OF CAD/CAM

The impact of an operative CAD/CAM system in the marine environment is significant. A review of this impact on several shipyard operations is now presented.

Engineering Impact

One of the most significant CAD/CAM changes impacted the engineering groups due to the added design responsibilities placed upon them. Whereas before the "final" product was a design drawing, now it is an actual cut part. The responsibility of assuring that the part produced indeed agrees with the design is lifted from the production work force and placed directly where it belongs - on Engineering. This "accountability" has had a positive affect on the quality of the design. Now information previously omitted or determined incorrectly is discovered by CAM production engineers working side by side with design engineers.

Proper scheduling of part generation can identify deficiencies early enough to allow modifications to the drawings - before release - thereby eliminating a time consuming revision process. Another point consider is the time savings and design simplification that is attained by standardization. Geometries can be re-used. Warehousing overhead can be reduced and product quality improved by establishing and

maintaining design- and drafting standards. Raving the ability to generate NC machine programs from within the engineering environment can also open up a whole new market for a company specializing in design services.

With proper training, guidance and experience., design engineers can learn to generate their own parts and be freed of the drudgery and inefficiency of detailing. Their time and effort can be better spent preparing sketches identifying the parts comprising and assembly. The sheets of drawings previously sent to the shop floor can be replaced with one or two assembly drawings that identify the parts needed and depict their orientation and relationship to one and other.

Planning Impact

Moving into the area of planning one immediately recognizes the existence of limitations. Not all parts are suitable for CAM - some are too small and others are too big. Production engineers must be aware of these limitations in order to properly estimate and direct the work flow. Major assemblies may have a mixture of CAM parts, piping, tubing, tees, angles and non-CAM parts and proper routing of individual components must be assured for smooth work flow. Production engineers must work closely with the design engineers and vice versa. Production planning is a step closer to actual fabrication and has the potential for exposing weaknesses in a design overlooked in the previous steps.

An important step in insuring that "cost savings" and schedule adherence are attributable to CAD/CAM is the push for pre-fabrication of structural assemblies. Just as pumps, motors and deck machinery are procured to be at pierside at the start of an availability, so too, must be the case of "structural" CAM parts and assemblies. With proper engineering and management involvement, this can be a realizable goal.

Finally, the concept of a "kit" is introduced in order to group parts after cutting. Whereas before a shipfitter received all the material for an assembly and personally laid out and cut the individual parts as needed. now an operator at a remote site will cut parts that may be used by four or five different shipfitters at four or five different periods in the availability.

spec	kit	part no.	nest number	description
57390001	K.595	P.595.6/1	N.000	PLATE
57390001	K.595	P.595.8/1	N.000	LOWER DOOR WT
57390001	K.622	P.622.1/13	N.000	FRAME
57390001	K.826	P.826.1/1	N.010	PLATFORM DK
57390001	K.826	P.826.1/3	N.013	CLOSED FR FULL
57390001	K.826	P.826.1/4	N.013	CLOSED FR HALF
57390001	K.826	P.826.1/5	N.014	PLATFORM BOTTOM
57390001	K.826	P.826.1/7	N.015	OPEN FR
57390001	K.826	P.826.2/1	N.025	SIDE
57390001	K.826	P.826.2/2	N.026	SIDE
57390001	K.826	P.826.2/3	N.026	CENTER FRAME ENDS
57390001	K.826	P.826.2/4	N.026	CENTER FRAME MIDDLE
57390001	K.826	P.826.2/5	N.026	STIFFENER
57390001	K.826	P.826.3/1	N.012	COLLAR
57390001	K.827	P.827.1/1	N.016	LOWER SLIDING DOOR
57390001	K.827	P.827.1/3	N.016	CHOCK
57390001	K.827	P.827.1/4	N.019	CHOCK
57390001	K.827	P.827.2/1	N.017	UPPER BI-FOLD DOOR
57390001	K.827	P.827.3/1	N.018	LOWER SLIDING DOOR
57390001	K.827	P.827.3/2	N.018	STIFFENER
57390001	K.827	P.827.3/4	N.018	BACK PLATE
57390001	K.827	P.827.7/1	N.000	SIDE PLATE
57390001	K.827	P.827.8/1	N.000	GUIDE RAIL

Figure 12 CAM Part Report

Purchasing Impact

Unlike the previous groups, the impact of CAB/CAM on the purchasing department tended to simplify their job. About the only detrimental effect was the loss in flexibility of filling purchase orders. Prior to NC burning, purchasing was given a relatively free hand. For example, if a plate 20' long was requested and two 10' long plates were all that could be found, the substitution was made and the shipfitter left to piece the two together at fabrication time. Since engineers worked on one assembly at a time, they identified material for assemblies one piece at a time. If assembly A required a piece of 1/2" plate 12" x 12", that was what was ordered. Later, while planning assembly B, if they found that another 12" x 12" piece of 1/2" plate was needed, it was ordered. Purchasing agents, not in a position to judge the proximity of shipfitter A to shipfitter B, had no recourse but to order 2 pieces of 12" x 12' plate. Meanwhile, purchasing agents were accumulating orders from many engineers, each identifying material requirements in a disjointed, piece-meal fashion.

To carry the scenario a step further, the purchasing agents, after contacting several sources for the material, discovered that most handled stock sizes and charged extra for cutting to non-standard sizes. For thinner plates, 2' x 4' is about the smallest stock size carried and the cost differential for the extra 7 sq. ft. per plate would amount to about \$35. The end result - 2 sq. ft. needed, 16 sq. ft. delivered. With the implementation of NC part generation and nesting, many of these inefficiencies are avoided. Nesting, which begins after all parts are defined, provides for consolidation and better overall material utilization. The user of standard sizes, readily stocked by either the warehouse or local vendors, eliminates the need for last minute scrambles to find odd sized plates. Lastly, the unused portions of the larger plates can be returned to inventory and re-used at some later time.

Production Impact

The net result of these changes on production is evident in the quality of the final product. The need for excessive grinding to clean up the ragged edges from manual burning is eliminated. Less time is spent re-cutting parts because a worker in the field guessed at a dimension obscured by a blob of grease or lost to a careless spark from a nearby cutting torch. Welding time is reduced due to closer and more uniform fitups. On the negative side, it imposes increases material handling requirements, as cut parts must be temporarily stored in the warehouse and then subsequently delivered to the job site.

In the long run, the level of skip needed in the trades is significantly reduced. The ability to understand and interpret blue prints is no longer a criteria for filling a shipfitter position. Anyone capable of simple assembly possesses most of the skips needed to understand the work to be performed.

Management Impact

What does all this mean to management? It increases the administrative duties that must be performed. People with highly specialized skills ranging from an in-depth knowledge of production methods and practices, to familiarity with computer hardware and software, to an understanding of cutting processes must be strategically placed within the corporation. A tremendous amount of inter-department communication is required to keep the job on track. Hence the need for a common operative database (like the one available from EMS) is evident. Most important of all, it is necessary to re-evaluate the way you do business to be sure that the system is as productive as possible. In the present case, an enviable PMA record of accomplishment (Figure 16) attests to the efficacy and cost savings of CAB/CAM parts generation.

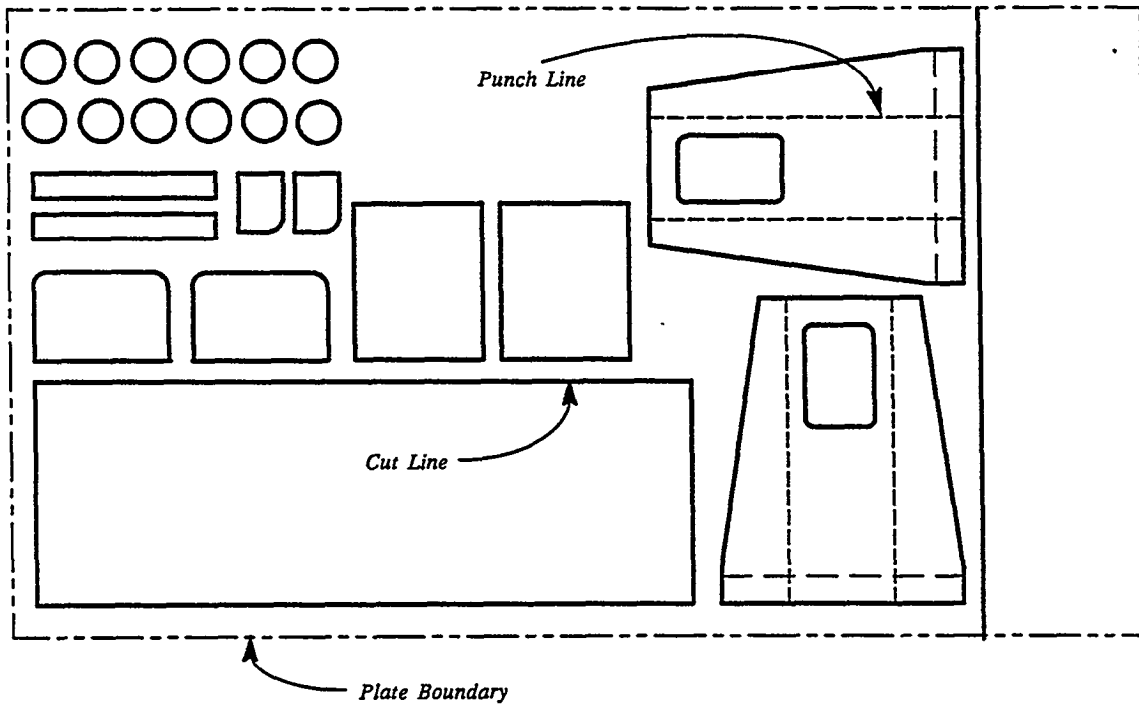


Figure 13 CAD Generated Burn File

CNC STATISTICS SHEET

INDEX NUMBER 223.0
SOFTWARE REVISION 1.0

ENTER OUTPUT MEDIA (DISC/TAPE) : DISC
ENTER CLDATA FILENAME : CLD.999
ENTER TAPE FILENAME : N1090999
ENTER PRINT FILENAME : P.999

POST-PROCESSING COMPLETED

TOTAL NUMBER OF TAPE BLOCKS OUTPUT. . 313
LENGTH OF PAPER TAPE OUTPUT.37.28 FEET (4,474 characters)

MODE	LENGTH(inches)	RATE(IPM)	TIME(minutes)
RAPID	1421.22	300.0	4.74
CUTTING	1920.07	130.0	14.77
MARKING	0.00	300.0	0.00
SUBTOTAL	3341.30		19.51

14 CYCLE STARTS AT 10.0 SECONDS

ESTIMATED MACHINING TIME 21.84 MINUTES

THE FOLLOWING FILES HAVE BEEN CREATED

TAPE FILE N1090999
PRINT FILE P.999

Figure 14 CNC Statistics Sheet

INSTRUCTIONS FOR USING LINDE BURN PROGRAM REPORTS

REV. 7/25/85 B. CARR

GENERAL NOTES

1. RETURN THIS SHEET WITH COMMENTS AND REQUIRED INFO TO ENGINEERING DEPARTMENT.
2. PART NUMBERS ARE WRITTEN :
P. / / - DWG PART NO
DWG NO
3. KIT NUMBERS ARE WRITTEN K. /
ALL CUT PARTS WILL BE GROUPED BY KIT AND STORED.
4. DROP PLATE NUMBERS ARE WRITTEN:
D. / - NEST NO
JOB NO
RECORD ACTUAL DROP SIZE AND STORE MATERIAL.
5. THE CAM PLATE NUMBER REPRESENTS THE BURN PROGRAM WHEN WRITTEN N1048015.

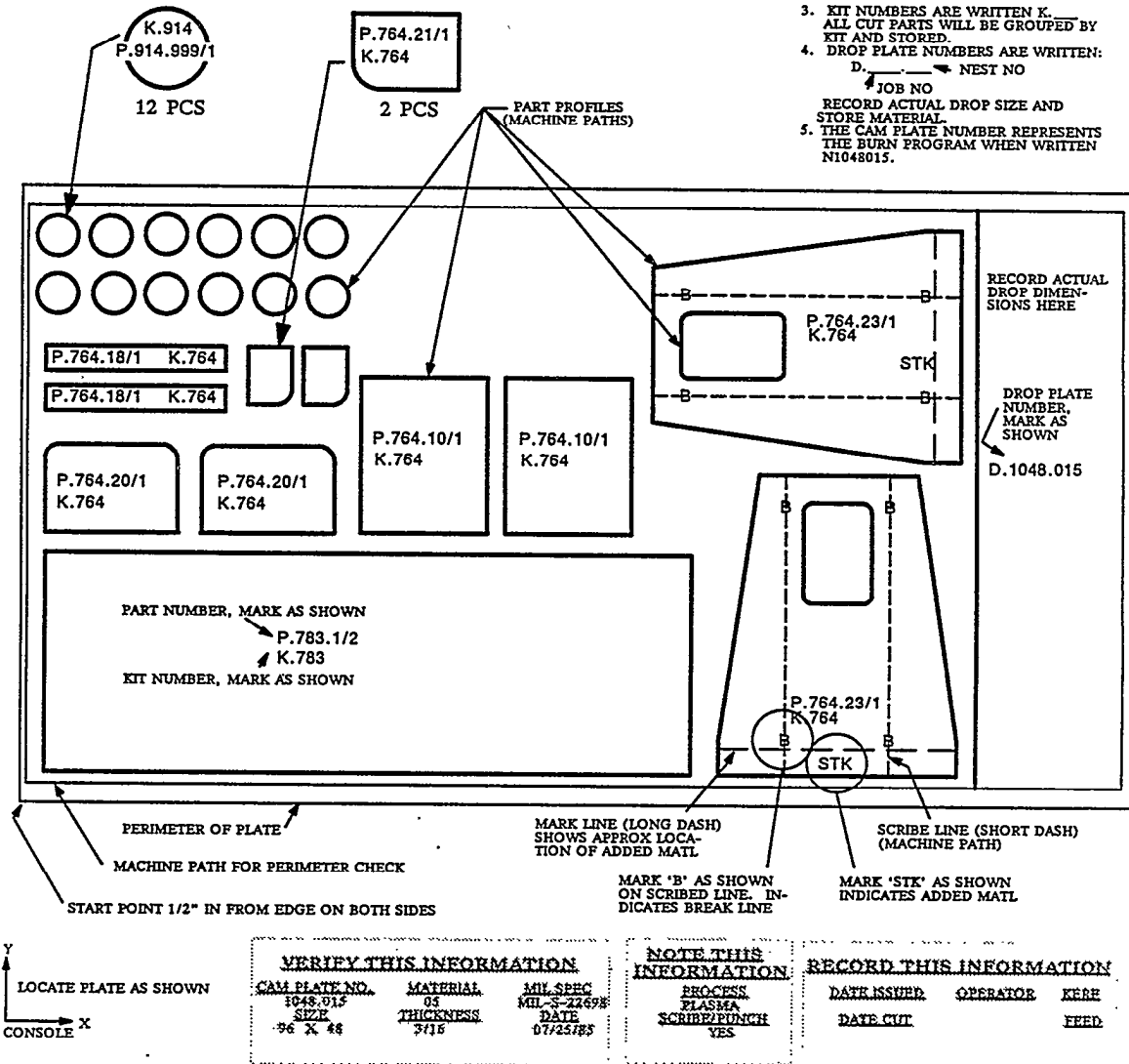


Figure 15 CAM Production Record

PHASED MAINTENANCE RECORD			
PMAS	<u>Class</u>	<u>Avg. Grade</u>	<u>Rating</u>
20	AFS	91.20	Outstanding
8	AOR	91.88	Excellent
10	LST	90.79	Excellent

Figure 16 PMA Record of Success

SUMMARY

As the foregoing presentation reveals, the introduction of CAD/CAM into a ship repair program produces profound and fundamental changes. First, business as usual cannot be practiced anymore. To offset the cost of CAD/CAM hardware, real cost savings attributable to better material utilization and more efficient production must be evident. Second, even a small-scale introduction of CAD/CAM into the related engineering and production phases of shipyard practice can indeed produce significant savings - in labor and material. Material products are much more accurate because CAD/CAM technology is able to produce parts with less requirements for subsequent finishing. Hence, labor costs are reduced. Likewise, the practices (not concepts - but practices) of nesting and Kitting insure that materials are optimally combined for both purchasing and production. The final lesson-to-be-learned from this CAD/CAM experience is the large and varied dedication of people resources necessary to effect installation. Job viewpoints as well as actual personnel may have to change to insure that a CAD/CAM operation is fully effective. Hence, the interest and involvement of management - at every level of manufacturing - is necessary to make CAD/CAM a real FABRICATION process.

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